**Hydrology and
Earth System
Sciences**

Open Access

Discussions

Interactive
Comment

Interactive comment on "Controls of macropore network characteristics on preferential solute transport" *by* M. Larsbo et al.

M. Larsbo et al.

mats.larsbo@slu.se

Received and published: 29 September 2014

Reply to anonymous Referee #3

-We would like to thank the reviewer for his/her comments and for constructive suggestions for clarifications and improvements. We have addressed all comments below and will make necessary corrections in the manuscript when all reviewers have posted their comments.

1. The interpretation of the data is based on the hydraulic parameters of the soils. The assumption on the shape of the parameter functions seems quite strong to me. In particular, the relation between pressure head and unsaturated hydraulic conductivity is important, as it is used to calculate hydraulic conductivities and saturation states that

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

are again related to transport properties. This assumption is also discussed in Section 3.2.2 (Page 9571, lines 12-14). A power law is assumed as functional form and the power coefficient is fitted from the data. The coefficient was estimated from two data points for a sample (at pressure head -1 cm and at -5 cm). The reasoning for the shape is that it has been found in previous work. However, there are other functional forms that are also used in practice and the estimates of hydraulic conductivity could be very different for different shapes. It would have been more convincing to use this shape if three data points would have been used (meaning that a third experiment for each probe would have had to be carried out). However, I guess that it is not possible to test this at this late stage and the comment is not so important that it would stand in the way of publication of the paper.

-We agree that measurements of hydraulic conductivity at a third tension would have provided information on the validity of the assumed power law relation between tension and near-saturated hydraulic conductivity for the columns used in this study. However, this would have further added to an already very heavy experimental workload. We are aware that other equations have been used to relate near-saturated hydraulic conductivity to tension but there is strong empirical evidence supporting the power law approach. The paper that we cite (Jarvis et al., 2013) show that a power law can be fitted with a coefficient of determination>0.9 for 90% of the data sets included in a global database containing 753 individual data sets.

-We will add a sentence clarifying that other forms for the relationship between tension and near-saturated hydraulic conductivity are possible.

2. Also, it would have been interesting to see the water content distribution during the transport experiments. One of the findings of the paper is that preferential transport is small if the macropore network is a well connected network of smaller channels. It would be interesting to know if this is also related to the variability of the water content distribution.

-It is the connectivity of the water-filled macropores rather than the connectivity of the total macropore network that should influence the transport. However, a direct quantification of the water-filled macropore space from X-ray images was well beyond the scope of this study as doing so would have required disproportionate additional efforts, i.e. imaging each soil column during the BTC experiments inside the X-ray machine at each irrigation rate. It would not be sufficient to do the imaging soon after the completion of the BTC experiment because the macropores would most likely drain far too fast. It is not at all clear that such an experimental approach is even possible. Instead we looked at the relation between the degree of preferential transport and the degree of saturation calculated using the near-saturated hydraulic conductivity function which implicitly accounts for connectivity of the water-filled pore space.

3. Line 17 on page 9554: It would here be useful to specify these measures or indicators. Some sentences would also be useful about the difference between the fitted parameters and the usual parameters for the CDE. Parameters for the CDE are also obtained from moments of the breakthrough curve (as outlined later, moments of the breakthrough curve are also used in this paper together with the 5

-We are not sure we understand what the reviewer means. There is a distinction between dispersivity as a parameter in the CDE and the apparent dispersivity used in our study which is not dependent on a pre-determined choice of model. Parameter values for the CDE are traditionally obtained by fitting the CDE-model to measured data. The dispersivity value obtained from fitting the CDE and the apparent dispersivity calculated from eq. 8 will be identical only for the case of a complete measured breakthrough curve and a perfect fit of the CDE to the measured data

-We do introduce and fully describe the model independent shape measures that we use in this study in the Materials and methods chapter (paragraph 2.3).

4. Equation (2): Are you sure that this is used as second central moment?

-The mistake in the equation will be corrected.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

5. Last sentence on page 9560: What does this imply? Is the expected error large or can it be neglected?

-Truncation of the breakthrough curves will have the same effect for all columns which means that even though 5% arrival times will be overestimated and the effective dispersivity will be underestimated the relations between these measures and measures of the macropore network will not be influenced. A more detailed discussion on how much relative 5%-arrival times are quantitatively influenced by truncation is not within the scope of this article. It is however investigated and discussed in Koestel et al. (2011).

6. Page 9563 around lines 14-16: I think it is not sufficient to give the commands of the names that are used in the specific software packages. The name of the method or algorithm that is behind this command should be given.

We will add that "The macropore clusters were determined using the "Analyse particles" ImageJ-plugin, which is an adaptation of the 3D object counter described in Bolte and Cordilières (2006)" to the text."

-The "Thickness" command is already described in the text.

7. Section 2.6.: It could be discussed a bit more that what is here measured is the effective hydraulic conductivity of the full system. I find it somewhat surprising that for a heterogeneous structure a power law is assumed for the effective hydraulic conductivity function. One would expect maybe something that is more bimodal.

A bi-modal hydraulic conductivity function would probably have been observed if we had measured the effective hydraulic conductivity of the full system (i.e. across a wide range of pressure potentials), but we did not. Hydraulic conductivity was only measured at two pressure potentials very close to saturation where the macropore network dominates flow. There is a large amount of data in the literature that show that uni-modal functions fit measured data in this near-saturated range very well, including the

paper we cited to support our choice (Jarvis et al 2013, see also our response to point 1). Note also that the measured macropore size distributions from the X-ray image data were not bimodal and hence a bi-modal near-saturated hydraulic conductivity function should not be expected from this point of view either.

8. Page 9565, line 22: How is 'mean aggregate width' defined?

-On P9563L18-19 it is written "Thicknesses were also calculated for the soil solid matrix as a proxy for aggregate size". To make it clearer we will change to ". . .aggregate width" which we later refer.

9. On page 9569 in lines 4-9 it is argued that in previous studies it has been shown that better connected flow pathways in flow direction result in preferential flow, while this is here not necessarily the case. I think that this comparison is misleading. To compare preferential flow in a heterogeneous medium, one would have to compare media with the same mean parameter values. In the studies on preferential flow in heterogeneous hydraulic conductivity fields, one would relate a heterogeneous medium to a homogeneous medium with the same effective hydraulic conductivity. In this case connected flow channels in general promote preferential flow. But also in these studies one would find stronger preferential flow if few highly conductive channels were connected than if a large volume of highly conductive channels would span the medium.

-We definitely agree with the reviewer's comment that stronger preferential flow would occur with fewer sample-spanning high conductivity pathways (both at pore- and Darcy-scales), We will rephrase the text so that it does not imply that previous studies have shown that increased connectivity of high conductivity zones at the sample scale always leads to a higher degree of preferential transport. The new text will read: "At first glance, these findings may seem to contradict the results of numerical studies carried out at the macroscopic Darcy-scale, where it has been shown that fields containing one or a few paths of high hydraulic conductivity connected in the flow direction exhibit stronger preferential flow than fields with poorly connected zones of high hydraulic

conductivity (e.g. Knudby and Carrera, 2005; Bianchi et al., 2011)."

10. Page 0570 line 15: I would disagree that in Figure 10 a strong relationship is supported. One could say that a trend can be supported. But the spread in the data is quite large. The same is true for the last sentence in Section 3.2.2: I agree that a trend could be postulated. But I do not really agree that there is a remarkably strong relation, in particular in the plots in Figure 8.

-We will change "strong" to "highly significant (p=4.1E-12)" on P 9570L15. We agree that the spread in the data is large but we stand by our statement that "Considering all these uncertainties and potential sources of error we consider that the relationships shown in Figs. 8 and 10 are remarkably strong".

11. Conclusions: From lines 25 on page 9571 to line 3 on page 9572 it is hypothesized that the dense macropore network prevents preferential transport as it increases diffusion into the matrix. This is one reason. But another reason is certainly that the heterogeneous structure is much more homogenized, so that a larger cross section of the medium participates in the fast transport.

-We believe that this point is already discussed, though perhaps in slightly different words (see lines 25-28, on page 9567). It is also repeated in the conclusions and in the abstract.

12. Conclusions: From line 3 to line 7 on page 9471 it is hypothesized that the near saturated hydraulic conductivity is a good measure for preferential transport. I do not understand why this should be so. The near-saturated hydraulic conductivity is one lumped parameter that includes many different effects. Different structures made of different materials could result in the same parameter. Also a homogeneous medium could have the same parameter value. I agree that it would be one useful parameter for preferential transport. However, I think that additional information on small scale structure would be required to estimate preferential transport.

-Our results showed that the largest water-filled pore exerts a significant control on preferential transport as does the degree of saturation in the macropores. Other studies have found the same (e.g. Seyfried and Rao 1987; Langner et al., 1999; Ghafoor et al., 2013; Koestel et al., 2013), so it seems to be quite a general result. This is explained in detail in the discussion at lines 15 P9570 to line 5 on P9571. There are of course other properties of the soil that may influence preferential transport, such as interactions between water-filled macropores and smaller matrix pores (discussed at P9586L12-17), but these do not seem to overshadow the dominant effects of the two hydraulic state variables in the macropore system noted above.

-From the above, it seems reasonable to suggest that the near-saturated hydraulic conductivity function could be a good predictor of preferential transport under field conditions if it was combined with some measure reflecting infiltration rates (i.e. the upper boundary condition), because together they will determine the largest water-filled pore. Rainfall statistics could be used to identify a proxy for this upper boundary condition.

-We will try to clarify this in the revised version, especially the fact that we are referring to the hydraulic conductivity function near saturation (i.e. conductivity as a function of pressure head or saturation).

References Bolte, S. and F.P. Cordelieres. 2006. A guided tour into subcellular colocalization analysis in light microscopy. Journal of Microscopy-Oxford 224: 213-232.

Ghafoor, A., Koestel, J., Larsbo, M., Moeys, J., and Jarvis, N.: Soil properties and susceptibility to preferential solute transport in tilled topsoil at the catchment scale, J. Hydrol., 492, 190–199, 2013.

Jarvis, N., Koestel, J., Messing, I., Moeys, J., and Lindahl, A.: Influence of soil, land use and climatic factors on the hydraulic conductivity of soil, Hydrol. Earth Syst. Sci., 17, 5185–5195, doi:10.5194/hess-17-5185-2013, 2013.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

Koestel, J.K., J. Moeys and N.J. Jarvis. 2011. Evaluation of nonparametric shape measures for solute breakthrough curves. Vadose Zone J. 10: 1261-1275.

Koestel, J. K., Norgaard, T., Luong, N. M., Vendelboe, A. L., Moldrup, P., Jarvis, N. J., Lamande, M., Iversen, B. V., and de Jonge, L. W.: Links between soil properties and steadystate solute transport through cultivated topsoil at the field scale, Water Resour. Res., 49, 790–807, 2013.

Langner, H. W., Gaber, H. M., Wraith, J. M., Huwe, B., and Inskeep, W. P.: Preferential flow through intact soil cores: Effects of matric head, Soil Sci. Soc. Am. J., 63, 1591–1598, 1999.

Seyfried, M. S. and Rao, P. S. C.: Solute transport in undisturbed columns of an aggregated tropical soil: preferential flow effects, Soil Sci. Soc. Am. J., 51, 1434–1444, 1987.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 9551, 2014.