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Discussions

Interactive comment on "Water movement through plant roots: Exact solutions of the water flow equation in roots with varying hydraulic properties" *by* Félicien Meunier et al.

Félicien Meunier et al.

felicien.meunier@uclouvain.be

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General comment for both referees:

For most of criticisms and remarks, both reviewers had similar opinions and we understood their requests for clarification. In particular, we were asked to consider the following points in our revised version of the manuscript:

- To more clearly state the importance of analytical (vs numerical) solutions;
- To give more insights on biology and implications of our development;
- To present experimental data.

We have now revised our manuscript to include these points and we have the feeling that these additions have definitely enriched the manuscript and could meet referees' demands. In particular, we now present the results of an experiment that was designed in the meanwhile to illustrate the benefits of our developments. We built a point-by-point response for both referee comments to explicit the changes. Since some of the comments raised by reviewers are similar, we sometimes refer to the other response.

This paper proposes new solutions of water flow through plants roots by extending the solution with a constant root hydraulic conductance from Landberg and Fowkes (1978) to linear and exponential variations of hydraulic conductance (radial and /or axial) along the root. These solutions are further extended when hydraulic conductance variations along the root can be decomposed into piecewise linear/exponential variations. Examples of applications are given for hydraulic conductance variations estimated from experiments, which differ from a constant conductance or to illustrate effect of tissue maturation (on root conductance) or how root effective conductance could be maximized.

This paragraph summarizes well the manuscript. We would also like to stress out that the newly developed solutions are analytical and, in that sense, exact solutions of the water flow equation.

The paper is interesting in pointing to the differences between a uniform conductance along a root and a variable (exponential or piecewise linear) conductance variation, which is more biologically realistic and which rise, for the latter, to a more regular, less abrupt variation of xylem suction or radial flux along the root. This is not necessarily new, as general solutions to water flow equation with any conductance variation (including those shown in the paper) in roots have been solved numerically since at least 2 decades, but the authors clearly show here the difference and non-equivalence between constant and variable root.

It was indeed one of our main goals to demonstrate the dramatic impact of root hydraulic property distributions (including linear and exponential spatial variations) on root water uptake patterns, and their potential consequences on plant and soil water status distribution. While numerical schemes allowed for conductance spatial variations in the past, their solutions were not exact and not as didactic as the ones developed here.

The added value of getting analytical solutions could be better stressed, even if numerical solutions are available, in the sense that such analytical solutions can be used to verify the numerical resolution and to get a generalization of the hydric behavior (. . .)

This second aspect (analytical vs numerical solutions) was indeed not well stressed in the introduction and discussion of the current manuscript and will be in the revised version. As noted by the reviewer, another added value of our work is to provide the community with exact solutions that can be used to verify the accuracy of numerical solutions, or replace them, for example in eco-hydrological models. Furthermore, our solutions can be expressed in terms of hydraulic parameters κ and τ whose impact on water uptake distribution and overall conductance is easier to grasp.

(. . .) to get a generalization of the hydric behavior with the main influencing parameters of the solution, to a branched root system and/or with varying soil water potential. That's the way followed by Landsberg and Fowkes (1978) who broadened the reach of their solution of the single root flow. This also the case of Ariyaratna (1990) who developed afterwards a solution equivalent to the equation A2 (linearly varying kx; Ariyaratna R 1990, An extension to the Landsberg and Fowkes' model, Master of Science thesis, Texas Tech University). Unfortunately, the authors don't show that in this paper, restricting to the single root, uniform soil case. It would be worth to present how their results could be extended, more precisely than what it is stated in conclusion (P19 –L 28-30 or P 3 L8).

The suggestion of the reviewer to look at solution with varying soil water potential is very relevant. This will easily be done analytically by applying the methodology of Landsberg and Fowkes (1978), i.e. imposing a defined shape of potential at the root-

soil interface, to our new solutions. We now show how non-uniform hydraulic properties may improve the uptake as compared to homogeneous case by increasing the local water uptake in wet zones and the collar potential under identical flux boundary condition. This is now discussed in the new version of the MS. Finally, we were not aware of the publication of Ariyaratna (1990) and it is now referenced to.

From another point of view, my feeling is that the authors don't really come back to real life and the biology (in the examples), but rest on comparisons between calculations. That stems in part from the fact that only the single root case is addressed, and not a root system. However, for example trying to compare types of uptake pattern with root growth (as in section 3.3) with real behavior of plant would be interesting; Looking at the implication of the optimal radii as presented section 3.4 would make the calculation more interesting. Indeed, for example, an optimal radius of exponential root that would be 0.11 cm would lead to a root length of 1cm. Is it the kind of roots that is observed in reality?

We took this remark (also raised by the second reviewer) with serious consideration. We consequently decided to include in a future version of the MS experimental results obtained meanwhile, which were analyzed using the new analytical solutions. The new results consist in measurements of total root conductance for several root length (and for several roots considered as repetitions) of a maize as well as axial conductance using a root pressure probe. The results clearly show that:

- The axial conductance is not homogeneous along the root axis;
- Homogeneous radial and axial hydraulic properties allow fitting the measured total root conductance rather well, but do not use the measured non-uniform axial conductance profile;
- Coupling the measured non-uniform axial conductance with a uniform radial conductivity profile only yielded poor fits of the total root conductance;

- However, with more complex functions (such as piecewise functions) reasonably good fits can be obtained.

A new figure will then be included in the manuscript (see attached file).

With such an analysis, we believe that the biological implications of our new solutions will be clearer. Mohsen Zarebanadkouki who ran the experiments, treated the data and helped us in the analysis will also be included in the list of coauthors. In addition, we believe that more discussion about biological processes explaining root property distribution is necessary. We could dedicate a new section about it in a revised version of the manuscript.

Concerning the derivation of solution, some of them could be rechecked and possibly verified with numerical integration (see detailed comments).

It is of course worth doing it and will be done. Numerical errors could also be given in appendixes by comparing analytical and numerical solutions while decreasing progressively segment lengths.

As to the form of the document, the paper is rather well written but I would suggest reconsidering the use of some expressions. The use of "root branches" is misleading as we expect an investigation of a branched root system, which is not the case. I would rather suggest using "single root" or simply "a root" throughout the paper.

We agree and will replace the term root branch by single root or root.

I'd rather use also a "segment of root" homogeneously within the document. The axial conductance is denominated here "intrinsic axial conductance". Generally "intrinsic" refer to the transfer property of a porous medium independently of the flowing fluid. It's not the case here, as conductance is referred to water and "intrinsic" could be dropped in the text.

By intrinsic, we wanted to insist that is a root inherent property. It could be indeed

dropped out if we specify it when defining it for the first time.

Concerning the title I would be more explicit and suggest: "Exact solutions of the water flow equation in roots with linearly or exponentially varying hydraulic properties".

The title would then be more explicit but wouldn't we give up all the solutions obtained by assembling linear, constant and exponential functions? The title then could be "Exact solutions of the water flow equation in roots with piecewise linear or exponential hydraulic properties hydraulic properties". But wouldn't it be too long then?

Detailed comments: See the annotated manuscript in attached file P2 L13 ref. Martre et al. 2000 is for leaves, better cite works by McCully and coll. (for maize roots).

This is a valid point and we will cite the work of McCully for maize roots instead from now on.

Please also note the supplement to this comment: http://www.hydrol-earth-syst-sci-discuss.net/hess-2016-633/hess-2016-633-RC1-supplement.pdf

We particularly thank reviewer 1 for the detailed comments included in the supplement. They will improve the readability, accuracy and final quality of our work. They were all taken into account when preparing the revised version of the manuscript.