Reply to the editor

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Dear Prof. Ursino,
Thank you again for the handling of our manuscript and the guidance of the review process. On behalf of all Co-Authors we hereby want to put up the revised version of our manuscript for discussion.
We carefully reviewed and edited the entire manuscript in order to treat all issues raised during the second review process. Our detailed answers to the reviewers are given below. We tried to emphasize all recent changes applied to the manuscript by color highlighting. Within the following, we want to give a brief overview over the major points that were clarified in the revised version of our manuscript.

> *"The scientific contents of your manuscript have been evaluated in a very different way by the reviewers. Nevertheless the revised version of your manuscript received in this second run also positive reviews, and all the reviewers acknowledged that it was much improved as compared to the previous version.*
> *I recommend a second thoughtful revision before resubmission. Please address all reviewers' comment, and make the presentation of the new results more concise and compact in a way that no more controversial arguments could be raised."*

New title We see that the word "parameterizing" in the title is often used in context of inverse modeling approaches, and it is true that this is not what we do in this paper. We changed the title to avoid this confusion as follows:
New title: "Effect of parameter choice in root water uptake models - the arrangement of root hydraulic properties within the root architecture affects dynamics and efficiency of root water uptake "

More concise presentation of our results
We revised the results section, shortened it and made sure to avoid repetition. We also streamlined the abstract, the introduction, the discussion and

the summary accordingly.

One-segment example within the background section
As the editor, anonymous referee #3 and anonymous referee #4 suggested, we carefully revised the entire manuscript to make it as compact as possible. In particular, we removed the one-segment example and all related equations from the background section (see also our reply to anonymous referee #1 , GC1 below).

Influence of gravity
Where necessary we enhanced and corrected parts of our manuscript, as ambiguities have given cause for confusion. In particular we added information about the influence of gravity (which was neglected in the simple model but was accounted for in the complex aRoot model) and revised the manuscript in order to state that all of our simulations are initially started with the respective total soil water potential being in hydrostatic equilibrium (see also our reply to anonymous referee #1 , GC3, RC3 and RC13b below).

Additional simulation on unbranched single roots
As anonymous referee #1 suggested, we performed additional analysis on single unbranched roots using both (a) constant segment length ($l_{segment} = 0.25cm$) with variable number of segments as well as (b) constant number of segments (n = 100) with variable segment length. The simulations confirm that our results are not influenced by an artefact. The optima presented in our manuscript using setup (b) are reproduced very well with setup (a) (see also our reply to anonymous referee #1 , GC2 and RC7 as well as Fig. 4 below).

Additional calculations on root hydraulic conductivity and effort
As suggested by anonymous referee #1 and anonymous referee #4 we calculated values for effort at the same time for all complex root hydraulic architectures, in order to confirm that our results are not an artefact of the evaluation time. When chosing time intervals longer than 2 days, the results are the same, only for shorter intervals there are small changes. As requested, we also compared water yield and effort with the respective root hydraulic conductivities of all root hydraulic architectures used in the complex "aRoot" model. There is a strong correlation between them, which is

linear at soil water potential being in equilibrium, but altered when soil water potential becomes heterogenous during the simulation (see our reply to anonymous referee #1 , GC4, anonymous referee #4 , GC4 as well as Table 2 and Fig. 5 below).

Reply to reviewer #1, referee report #2

We want to thank anonymous referee #1 for the in-depth review and his/her valuable comments.

> GC1: *"The improvements of the manuscript as compared to the previous version are significant, among which: (. . .)*
> *However, the theoretical background is definitely subject to the artefact mentioned in the first part of the reviewing process. I believe that it is misleading and should be removed from the manuscript.*

We removed the example from the background section after thoroughly thinking about the repeated suggestion, although we regret this. We still use a thought experiment to motivate efficient root lengths, based on the overall energy necessary for root water uptake. We deleted all equations related to the single segment example.

> GC2: *"The study on (un-) branched roots is seemingly still slightly affected by the artefact for young roots"*

This issue is detailed out in RC7 (see our comments there as well as Fig. 4 below). We performed the requested additional analysis with a variable number of segments with constant segment length of 0.25 cm for both young and mature roots. The results are in good agreement with the results previously presented in our manuscript. Although barely visible, some small differences for simulations of longer young roots pertain. The optima are perfectly reproduced and yield the same values of total root length.

> GC3: *"(. . .) the absence of vertical soil water flow coupled to the non-equilibrium initial soil water condition might be responsible for the increased effort for longer roots. If not, it should be clarified whether or not the increased effort actually results from an increased (absolute) xylem water potential."*

Thank you for this comment, which also refers to RC3 and RC13b: the information about gravitational potentials can be found in Table 1 of our

manuscript, but was not given anywhere else in the text. Gravitational potential was only considered in the complex but not in the simple model (see RC3 below). All simulations were initialised with the respective total soil water potential being in equilibrium. We added these very important facts to the methods section. To avoid any confusion, we also carefully revised the manuscript for the correct use of “soil matric potential”, “gravitational potential” and “total soil water potential”.
Please see the more detailed responses to RC3 and RC13b below in which we explain that our results are therefore not affected by this artefact.

> RC1 P4 L14: *“Lobet et al. [2011] and Lobet and Draye [2013] also did excellent work on the subject recently.”*

Thank you for these additional references. We included them.

> RC2 P4 L24: *“Doussan et al. [2003] does not appear in the bibliography. Isn’t it 2006?”*

Anonymous referee #1 is right, we changed this accordingly.

> RC3 P6 L2: *“Here it is mentioned that the soil water potential is initially homogeneous. However it is further explained that the initial water content is initially homogeneous. Was it first meant that the soil matric potential is initially homogeneous? Is the gravitational potential accounted for? This point is important for what follows (RC13).”*

This issue is related to GC3 above and RC13b below. Generally, all simulations were started with total soil water potential being in equilibrium. Within the simple model, gravitation was neglected. As soil hydraulic properties are homogeneous, homogeneous water content is in this case equivalent to homogeneous total soil water potential and to an hydrostatic equilibrium. Within the complex aRoot model, gravitation was explicitly accounted for, but again, simulations were initialized with total soil water potential being in equilibrium. We revised the manuscript accordingly. In particular we only refer to equilibrium conditions and total soil water potential when introducing initial conditions and added a corresponding indication to the caption in Fig. 2 of our manuscript.

> RC4 P6-7 L24-11: *"Equation (1) corresponds to the case of a root composed of a single segment. As demonstrated by Referee #1 (...) and by the authors (...), the estimation of total root resistance (Rtot) using a single long segment (...) leads to overestimated absolute values of collar water potential. About Eqs. (2-5), an aggregated radial resistance is valid if xylem potentials are uniform (assumed on short distances -> short segments), while an aggregated axial resistance makes sense if no radial conductances generate parallel pathways in the circuit. Equations (6-7) and the predicted minima are thus incorrect for hydraulic architectures with significant axial resistances and radial conductances."*

This issue relates to GC1 (and partly GC2). The example in our background section with its strong simplifications served as a thought experiment which allowed an arithmetic description of more complex processes. Since it has lead to confusion we removed it in the revision.

> RC5 P7 L23: *"The term nicely does not sound very scientific..."*

We agree with anonymous referee #1 , we changed our wording accordingly.

> RC6 P7 L25-27: *"Here is explained that the indices account for both root and soil hydraulics. The indexes are indeed sensitive to both root and soil hydraulic resistances (as long as both are present). However, only root hydraulic resistances are accounted for in most of this study (all of it except simulations with aRoot)."*

This section was removed together with the one-segment-example from the background section. A similar reference is in the methods section, which however does not refer to specific resistances in order to keep the explanation general. It reads as follows:

Old: "On the other hand effort relates to the time evolution of xylem water potential at the root collar and the work necessary for root water uptake. It depends among others on the total resistance to root water uptake a root

system has to overcome."
New: "On the other hand effort relates to the temporal evolution of xylem water potential at the root collar and the work necessary for root water uptake. It includes information on the total resistance to root water uptake a root system has to overcome and depends also on the soil water retention."

> RC7 P9, L4-6: *"The supplementary mentioned here demonstrates that for a mature root, a discretization of 100 segments is largely enough to avoid any significant artefact on the estimated total root resistance for a mature root. However, this was not demonstrated for young roots, which are more sensitive to the artefact due to their limited axial conductance. In the lower-left subplot of the attached figure, it is visible that an error of a few percents remains for long young roots. However this small error alone probably does not explain the significant change of effort visible in Fig. 3 of the manuscript (other possible reasons are discussed in RC13). Actually, a simple way to avoid the artefact of "increasing root resistance with root length" is to model growth by adding root segments of constant size instead of elongating existing segments (see low-right subplot of the attached figure)."*

This issue relates to GC2. We performed the suggested analysis (Fig. 4). We reproduced Fig. 3 top left of our manuscript using both (a) constant number of segments (n = 100) with variable length and (b) variable number of segments with constant segment length (0.25 cm each) for both young and mature roots. The two curves overlap really well. Although barely visible, some small differences for simulations of longer young roots pertain, the optimum is perfectly reproduced and yields the same value for both (a) and (b) simulations.
The supplementary Fig. 1 by anonymous referee #1 in the first review suggest that young roots of 1.5 cm length are almost not and of 2.5 cm little influenced by the artefact. Within the complex model, the longest segment length is 2.6 cm, 82 % are smaller than 1.5 cm and 95 % are shorter than 2 cm (see also our Fig. 1 below).

> RC8 P9 L18-20: *I agree with the authors, the simplifying assumptions chosen in this part of the manuscript are good as*

> *long as they do not lead to misleading conclusions. Their goal is to emphasize how simple root topologies and hydraulic properties affect the newly introduced indices, before testing these two indices on more complex hydraulic architectures.*

As our results are not affected by the above mentioned artefacts, we are convinced that the corresponding conclusions are also correct and not misleading.

> RC9a P13-15 L20-8: *“Here the authors provide clear definitions of water yield and effort (...) The following minor suggestions are rather a matter of taste:*
> *In the definition of water yield, the authors selectively exclude water transpired during water stress. This justifies the fact that water yield does not change once water stress was reached in the simulations with constant Tpot, and that it continues to evolve in simulations with day-night fluctuations of Tpot. I found it counter-intuitive that water transpired during stress events is not part of the yield; after all, the index including stressed transpiration would discriminate fully transpiring plants from plants under water stress anyway (even though not as much). It might actually be problematic for the application of the index on real plants, for which it is not always easy to delimit when stress begins and ends, while for a plant in pot the measure of total cumulative transpiration by weighing (not discounting stressed transpiration) is easy.”*

We agree with anonymous referee #1 that the applicability of water yield in its current form to real experiments would be problematic. However, it was not our aim to create an easy to measure index, but to fill the sparse information about likely and unlikely distributions of root hydraulic parameters with a novel approach. Making water yield constant at the onset of water stress simply allows us to speak of ”the“ water yield characterizing a root hydraulic architecture.

> RC9b P13-15 L20-8: *”Water yield and effort are said to represent the benefit and cost in the quantification of root water uptake efficiency. I easily see cumulative transpiration as a benefit (as it can be translated in terms of cumulative photosynthesis*

> *product) and leaf energy level and root length as costs (as a very low xylem water potential implies consequences that might be bad for the plant, while building roots involves a cost in terms of carbon and other elements). However the fact that water yield has root length (a cost) as denominator does not make the classification in terms of cost and benefit as straightforward. As is, water yield represents some kind of average benefit per root length, which does not make it as clear whether it is beneficial for the plant to build more roots. Actually increasing the root length might very well delay water stress (beneficial) but decrease water yield. Also, in effort, the energy cost is divided by the cumulated transpiration, the latter being a benefit. I believe that both indices are efficiency-related, but should not be categorized in terms of cost and benefit since they both represent the division of a cost by a benefit or vice-versa."*

We agree with anonymous referee #1 on the point that the interpretation of relative values is more difficult compared to absolute ones. However, it is not the absolute but the relative amount of energy (work per unit of root water uptake) that has physiological end hydrological meaning for a plant. The same holds for water yield: If plant has invested in any matter into its root system, it should be able to take up more water. Water yield reflects that within the simple model roots have different lengths; whereas overall unstressed transpiration does not. However, within the complex model, total root length is constant between all simulations and water yield is directly proportional to unstressed transpiration.
We are aware that more simulations with the complex model should be carried out, using root geometries of different lengths. However, this was not in the scope of this research.

> RC10 P14 L14: *"I think that the verb is "to take up", and the noun "the uptake"."*

We changed this accordingly.

> RC11 P14 L17: *"The symbol "V_{H2O}" is the same as in Eq. (15) while its definition differs, which might be confusing for the reader."*

We changed this by introducing the new variable $V_{H2O}^{unstressed}$.

> RC12 P15 L24-25: *"I searched for references to the index "water yield" in the articles of Javaux et al. [2008] and Schneider et al. [2010], but only noticed that both display transpiration rate versus time, or mean water content, from which the cumulated transpiration rate at the onset of water stress could be estimated. Dividing this value by the total root length would provide water yield. Mentioning that these authors used the index "water yield" thus does not seem really accurate, and I believe that, under its current form, this index should be recognized as newly introduced (unless other literature would refer to it)."*

We agree with anonymous referee #1 . We missed to state clearly, that in the case of the complex model, total root length was constant between all simulations and therefore water yield is directly related to transpiration (See also RC 9b). Transpiration in turn is the common index which occurs in different forms in the cited references. We changed this accordingly.

> RC13a: *"major comments about the interpretation of the index effort: Here I would like to discuss several points about the interpretation of the index effort.*
> *Firstly, in the definition of effort, it is said that the value of effort (w) is taken at the onset of water stress. Let's consider two root systems with constant Tpot, one reaching early water stress with its (absolute) leaf xylem water potential increasing in a concave way, the other reaches water stress later with its leaf water potential increasing in a convex way and always lower than the other plant's water potential. If effort is saved at the onset of water stress (a different time for the two plants), effort might very well be higher for the plant that permanently had the lower leaf water potential. With its current definition, and in the graphics displayed in the manuscript, low effort is thus not tantamount of low xylem water potential (in opposition to the statement at page 16, L7). I believe this is a big weakness in the definition of effort that might lead to misinterpretations in the results of this study. A simple way to dodge this weakness would be to save effort at the same time for all hydraulic architectures. Then a permanently lower (absolute) xylem water potential would always have for consequence a lower effort. This could also be*

> *applied to water yield by not excluding 'stressed' transpiration rate and estimating water yield at a uniform time."*

First we believe anonymous referee #1 mixed up convex and concave, because a convex evolution of collar potential which is at all times lower than a concave one spends most of its time in low values, thus resulting in lower effort. Clearly, the other case is more interesting. We agree with anonymous referee #1 , it is possible that a root system might have lower collar potential at all times, but higher effort and we depicted a hypothetic example in figure 3 below.

Although root system B has less negative collar potential than root system A at all times, its effort takes more negative values than that of root system A. This is no contradiction, as effort is by its definition a flow weighted (here also time average) work necessary for water uptake (see eqs. (10) and (11) of our manuscript). Thus, root system B has higher effort because it remains for a **relatively larger period of time** at more negative values. We revised the manuscript as follows:

Old: As lower effort is tantamount for lower xylem water potentials over the course of time, effort recommends itself as a tool for distinguishing efficient from less efficient parameterizations.

New: As lower effort is tantamount for lower average xylem water potentials, it recommends itself as a tool for distinguishing efficient from less efficient parameterizations.

> RC13b: *"Secondly, only the root hydraulic architecture is supposed to change when studying the impact of root length and topology on effort. However, if the gravitational potential was accounted for, and the soil matric potential initially uniform with depth, the initial total soil water potential must have been initially different in simulations having different root depths. Particularly, soil water potential around the extremity of long roots was up to 500 hPa lower than around the extremity of short roots. The initial plant-sensed water potential was thus initially more negative for long roots. Such situation may have participated to the increase of effort for longer roots. An initial hydrostatic equilibrium would probably result in significantly different results (particularly no increased effort for longer roots) and be in better agreement with the assumption of neglecting vertical soil water flow (soil water flow is null at hydrostatic equilibrium while drainage*

> *occurs for a uniform soil matric potential). Actually, even using an initially constant soil matric potential and accounting for vertical water flow would progressively tend to equilibrate soil water potential in the root zone and below, thus draining water away from shorter roots, and would probably also result in the absence of increase of effort for longer roots.“*

We answered this already in GC 2 above. All simulations were initialized with soil water being in an hydrostatic equilibrium. Gravitation was not accounted for in the simple model, and in this case soil matric potential equals total soil hydraulic potential. Within the complex model, gravity was accounted for, but the root geometry was kept constant between different simulations.

> GC4: *”These two points and RC7, make it possible that the chosen simplifications were responsible for the observation that effort increases with root length. In order to clarify the situation, I would advise the authors to repeat the simulations with (i) short and constant root segment lengths, (ii) an initial hydrostatic equilibrium, and (iii) to calculate effort at a uniform time for all hydraulic architectures, or to demonstrate that the increase of effort was a consequence of an increased (absolute) xylem water potential.“*

We thank anonymous referee #1 for this constructive suggestion. As stated above we showed that the respective simulations of unbranched single roots remain almost unaltered if they are performed with constant segment length ($l_{segment} = 0.25cm$). In particular, the optima with respect to effort were perfectly reproduced. We did not repeat our calculations on branched roots as they are computational expensive. We do however believe that the increased number of segments for branched single roots (n = 192) and the entire root system (n = 1412) are sufficient (see also Fig. 1 for a histogram of segment length in the complete root system).

We performed all of our simulations with total soil water potential being in equilibrium, just as anonymous referee #1 suggested. Gravity and soil water flow were only accounted for in the complex aRoot model. Root geometry and rooting depth were in this case kept the same in all simulations. The values of effort at fixed times are given in table 2 below. We additionally depicted the time dependent relation between total plant hydraulic resistance and effort in Fig. 5. Notably, the functional relationship between R_{Rs} and effort changes with time. Only at the initial stage of our simulations when soil water potential is in equilibrium, effort and root hydraulic resistance show a linear relationship. Subsequently, different effects influence values of effort which thus contains more information than root hydraulic resistance alone.

Reply to reviewer #3, referee report #1

We want to thank anonymous referee #3 for his/her critical examination of our manuscript. Within this note we want to reply in detail on his/her comments.

> RC1: *"Abstract is very confusing to read. Its just a bit clunky. I suggest the authors try and use as simple language as possible to bring across the main points of the paper."*

We revised the abstract accordingly.

> RC2: *"It is unclear to me why* $r_{soil} = 1.2cm.$ *Where does this value come from? Why is this value and not another one appropriate? Does this get propagated to the 3D root system scale model results also?"*

The value of r_{Soil} used within the simple model is derived from the half mean average root distance within the complex aRoot model. The corresponding distribution of virtual soil disc radii can be found in Fig. 2 below. Values range from 0.4 cm to 2 cm, with 95 % of total root length being attached to soil disc radii smaller than 1.2 cm. We decided in favour of larger soil disc radii to avoid limiting the available soil water reservoir too much.

> RC3a: *"Clearly, equation (13) that has in, out and radial components would in addition to collar potential also need "in" component at the root tip defined. I know they authors appear to implicitly assume that "in" at the root tip is zero, but they don't actually write this down anywhere."*

We changed this accordingly.

> RC3b: *"Simulations and modelling results are presented over the time course of 12-30 days. In this time the root system architecture changes significantly since roots grow roughly 2cm per day. Hence it is somewhat unclear to me why it is reasonable to assume on p 13-14 that the transpirational demand is constant Q. Clearly it would change as the root system/plant grows."*

We agree with anonymous referee #3 that neglecting plant and root growth is a strong simplification at the time scales used here. However, we perform this modelling study to fill already sparse information about the distribution of root hydraulic properties in entire root systems. Incorporating root growth would again increase the number of parameters that might be connected to our results: speed of root growth, transitions in root hydraulic properties and branching are likely to occur when its beneficial for plant's root water uptake - which is mainly the question of interest within our paper. Although it is principally possible to use growing root systems in aRoot, it would also complicate the numerics. Finally, the time constant transpiration rate greatly simplifies the presentation of our results. Following your comment we also compared the values of effort on shorter simulation periods. Shortly after the beginning of our simulations (approx. one day), the ranking remains constant (see Table 2 below). We included a corresponding comment in the discussion.

> RC4a: *"It is unclear to me if the root radius was different when comparing old and young roots. The root axial and radial conductivity mainly depends on their radius and as a sink term this radius significantly influences soil water flow. Could the authors please comment on this."*

The added the corresponding information to chapter 2.3 of our revised manuscript.

New: "For reasons of simplicity the root radius is set equal to 1 mm for both young and mature roots."

> RC4b: "Finally, it is unclear to me if the Darcy-Richards equation was solved in fully explicit 3D or if the cylinder approximation approach (as on p9) was used."

Within the simple model, soil water flow was not modelled. In the complex aRoot model, the water flow is calculated explicitly in fully 3D (see Schneider et al. (2010)).

Reply to reviewer #4, referee report #3

We want to thank anonymous referee #4 for his/her critical examination of our manuscript. Within this note we want to reply in detail on his/her comments.

> GC1: *“Recent attention is given to the impact of root architectural and hydraulic properties on root water uptake from soil in different contexts, e.g. breeding for drought resistant crops (Vadez 2014), improved representation of root water uptake and transpiration in hydrological and climate models (Li et al. 2012) but data for parameterization of models are scarce. This manuscript raises some interesting questions within this topic.*
> *(...) I found the representation of the approach and results lengthy and in parts repetitive, and I had to struggle somewhat to filter out the really new issues. I suggest that the whole presentation of the paper should be more concise and compact. Repetitive parts should be removed; e.g. P5 L24-25 and P8 L21-23 / P15 L20 and P15 L22-23 and P21 L25-27 and P23 L7-8 / P8 L11 and P23 L25”*

We carefully revised the manuscript in order to explain ourselves clearly and unambiguously, while avoiding repetitions. Corresponding changes are highlighted within the manuscript. Specifically, we took care to remove the repetitions pointed out above.

> GC2: *"I find the title misleading: When I read the title I expected to learn about new ways to find parameters for root water uptake models, perhaps by an inverse modelling approach. Instead, I found that this paper evaluated different hypothetical distributions of root architectural and hydraulic parameters on the efficiency of root water uptake by a root and root system, respectively. The authors might consider a new title "Optimal root lengths in dependence of root architectural and hydraulic properties - Implications for root water uptake from soil" "*

We see that the word "parameterizing" in the title is often used in context of inverse modeling approaches, and it is true that this is not what we do in this paper. We changed the title to avoid this confusion.

Old title: "Parameterizing complex root water uptake models - the arrangement of root hydraulic properties within the root architecture affects dynamics and efficiency of root water uptake"
New title: "Effect of parameter choice in root water uptake models - the arrangement of root hydraulic properties within the root architecture affects dynamics and efficiency of root water uptake "

> GC3: *"I agree with anonymous referee #1 that the explanation of "efficiency" as it is used here could be improved. In particular, I also find the use of two indices that give similar results more confusing than helpful. When looking up the two given references for water yield (Javaux et al. 2008 and Zwieniecki et al. 2003) I could not find a definition of this term there. Of course both papers discuss water uptake over time but I don't find this sufficient to state that water yield is a common index (while effort is a new one). In this context, I would also like to pick up on a comment of referee #1, namely the mentioning of water productivity (or water use efficiency). This is a well-known efficiency criterion, meaning efficiency of water uptake in terms of yield, and you could discuss the difference of your new (hydraulic?) efficiency criterion."*

We believe the reviewer means the references Javaux et al. (2008) and Schneider et al. (2010), which are given in context of yield? A similar issue was raised by anonymous referee #1 in his RC12. As stated above, we changed the wording accordingly. Also it is true, that we missed to state clearly that within the complex model total root length was constant between all simulations and therefore water yield is directly related to transpiration (See also our reply to anonymous referee #1 RC9b). Transpiration - and not water yield - is the common index which occurs in different forms in the cited references.

Water use efficiency (the amount of water transpired per amount of assimilated carbon) or water productivity (biomass per water use) are both of great interest from an ecological point of view. With our model, we can unfortunately only go an intermediate step. Because we do not have a carbon model included, and we can therefore not calculate water use efficiency or biomass production. However, the fact that water yield is normalized by root length does somehow account for investment in biomass - admittedly in a very simple way. We tried to bring this out more in the new version and add a discussion of next steps. Also we have tried to improve our argumentation why xylem potential is also an important property from an ecological perspective, which has received little attention in root modeling so far.

> GC4: *“I think it would also be interesting to compare this index ”effort“ with the ”equivalent conductance of the root system“ Krs as defined in Couvreur et al. (2012) as it directly depends on the root architectural and hydraulic properties. What would be the Krs value for the different parameter distributions that are found optimal with respect to effort?”*

Following this comment, we have calculated the $K_{RS} = 1/R_{RS}$, which can be found in Table 1 below. They were calculated as follows

$$R_{Rs} = \frac{\psi_{Soil}^{homo} - \psi_{C}^{homo}}{Q} \tag{1}$$

in which ψ_C^{homo} denotes the initial xylem water potential at the root collar, and $\psi_{Soil}^{homo} \approx -3.7m$ the initial homogeneous total soil water potential at equlibrium (please see RC3 and RC13b to anonymous referee #1 on the influence of gravity). We included this information also in table 3 of the revised manuscript. All indices, including K_{RS} give similar information: Both homogenous root hydraulic parameterizations have the lowest efficiency / lowest K_{RS}, followed by all heterogeneous ones. However, the most conductive root system (# 2) is not the one with highest water yield and lowest effort (# 3). We believe this is due to the fact that K_{RS} reflects conditions at homogenous water distribution, while the other two indices account for change of water distribution over the course of the simulation.

> RC 5: *"I did not understand why you would arbitrarily set root segments to be young or mature if you have the information about root segment age. You could still define two age classes such that you reach a desired length percentage in one and the other class, but the position of those would be realistic with respect to root segment age. Thus, the statement on P20 L10 that young roots are located anywhere within the root system should also be revised accordingly."*

The root hydraulic properties of roots are assumed to alter with root segment age and / or distance to branching points, both of these options were for example combined in Doussan et al. (2006) for tap roots and lateral roots. However, the actual distribution remains unknown and we wanted to find out if model output is influenced by the above mentioned assumptions. We did this by neglecting information about root geometry and root age, but we did not distribute root hydraulic properties arbitrarily. We only restricted ourselves to topological information in order to ensure that mature roots constitute the basal region of a root and that they are never preceded by young roots. We revised Sect. 2.4 to work out more clearly that root hydraulic properties were distributed with different approaches within the two models. We also changed the following sentence in Sect. 3.5 as it might suggest that hydraulic properties were distributed arbitrarily:

Old: "Maximum uptake rates occur in the young roots, which are located anywhere within the root system."
New: "Maximum uptake rates occur in the young roots, irrespective from their actual position within the root system (see Sect. 2.4 for the distribution of root hydraulic properties)."

> RC 6: *I find the term "root strand" rather uncommon. I found only one other plant root system model-related publication that used this term, and I could not find it in the plant ontology database http://www.plantontology.org/. Do you mean "single unbranched root"?"*

We revised the manuscript accordingly, in particular we changed the title of section 3.1 to "3.1 Effort and water yield in un-branched single roots". We use the phrase "root strand" only for the central part in a heterogeneous single branched root.

> RC 7: *"Another question regarding the use of terms: "redistribution of root water uptake" and "activation of mature roots" sound as if the plant would actively decide which parts of the root systems to choose for water uptake, as if it could be switched on or off. But is it not the case that the position where root water uptake occurs is a (passive) consequence of root architectural and hydraulic properties as well as the given scenario?"*

We agree with anonymous referee #4 that redistribution of root water uptake is a passive process that involves feedback between soil and root hydraulic properties. The term "activation" relates to "hydraulically active".

We always use the passive form "get activated" to reflect that the root does not decide actively when this happens.

> RC 8: *"The link between simple and complex model is not very clear. It is not the case that the results of the simple model are subsequently used in the more complex model, as I had expected after reading the section headings. Rather, the two examples are developed in parallel and it is not quite clear how and if to compare them. Would it not be possible to use the aRoot model with a single branched or unbranched root in order to have the same soil scenario for simple and complex branching structures?"*

It is possible to run the aRoot model with simple root topologies. However, aRoot is designed to capture relevant processes that are likely to occur at larger scales (e.g. local root length density in entire root systems, soil water flow and gravity for deeper and larger root systems, potential gradients in the vicinity of roots esp. in dry soils due to unsaturated soil hydraulic conductivity and the radial flow towards the root). These processes however would complicate the recognition and interpretation of the combined effects of branching structure and heterogeneous root hydraulic properties. We chose the simple model for single roots to gain these basic insights, and are thereby able both to recognize them and to distinguish them from other processes at the single plant scale at a full level of complexity.

> RC9: *"P21 L22-31 is more a summary than a discussion."*

We moved the above mentioned paragraph to the Conclusions.

> RC10 P23 L23: *"By "metric", you don't mean a metric in the mathematical sense but an "index"?"*

Anonymous referee #4 is right. We changed this accordingly.

> RC11 P18 L16: *"I believe that the definition of moving uptake front (MUF) as in Levin et al. 2007 is defined in terms of the soil zone where RWU occurs. This is different than in your definition that defined it in terms of the position along the root where RWU occurs."*

Anonymous referee #4 is right, we removed the corresponding citation.

> RC12 P27 L8: *"Q is a flow and not a flux as correctly stated on P 26 L21."*

We changed the manuscript accordingly.

> RC13 P28 L5: *"Is there a subindex 'C' missing in the definition of EU?"*

We changed this accordingly.

References

Doussan, C., Pierret, A., Garrigues, E., and Pages, L.: Water uptake by plant roots: II - Modelling of water transfer in the soil root-system with explicit account of flow within the root system - Comparison with experiments, Plant and Soil, 283, 99-117, 2006.

Javaux, M., Schroeder, T., Vanderborght, J., and Vereecken, H.: Use of a Three-Dimensional Detailed Modeling Approach for Predicting Root Water Uptake, Vadose Zone Journal, 7, 1079-1088, 2008.

Schneider, C., Attinger, S., Delfs, J.-O., and Hildebrandt, A.: Implementing small scale processes at the soil-plant interface - the role of root architectures for calculating root water uptake profiles, Hydrology And Earth System Science, 14, 279-289, 2010.

Tables and Figures

#	$p_{mature}[\%]$	ψ_C^{homo} [m]	$K_{RS}\left[\frac{cm^3}{hPa\cdot d}\right]$	$\tilde{w}$ [m]	$\tilde{v}$ [ml/m]
1	0	-67.0	0.04	-105.2	162.1
2	20	-15.7	0.22	-44.1	205.4
3	40	-16.8	0.20	-42.7	207.5
4	60	-19.1	0.17	-46.4	203.4
5	80	-23.6	0.13	-54.2	196.4
6	100	-34.7	0.09	-77.8	174.2

Table 1: Initial collar potential ψ_C^{homo}, root hydraulic conductivity K_{RS}, effort at the onset of water stress $\tilde{w}$ and water yield at the onset of water stress $\tilde{v}$ for one fixed root geometry with different amounts of young and mature roots. $K_{Rs} = 1/R_{Rs}$ was derived from the initial collar potential using eq. (1) above. The root hydraulic architecture with highest root hydraulic conductivity was not identical with the one with lowest effort and highest water yield.

#	p_{mature}	K_{RS}	$w(0d)$	$w(1d)$	$w(2d)$	$w(3d)$	$w(4d)$	$w(5d)$	$w(\tilde{t})$
		$\left[\frac{cm^3}{hPa \cdot d}\right]$	[m]	[m]	[m]	[m]	[m]	[m]	[m]
1	0%	0.04	-67.0	-79.8	-85.3	-89.7	-93.9	-98.4	-105.2
2	20%	0.22	-15.7	-20.1	-22.7	-25.0	-27.4	-30.0	-44.1
3	40%	0.20	-16.8	-20.4	-22.6	-24.6	-26.7	-28.9	-42.7
4	60%	0.17	-19.1	-22.8	-25.1	-27.3	-29.6	-32.1	-46.4
5	80%	0.13	-23.6	-27.9	-30.8	-33.5	-36.3	-39.4	-54.2
6	100%	0.09	-34.7	-42.8	-48.6	-53.9	-59.2	-54.9	-77.8

Table 2: Temporal evolution of effort w. At t = 0 d, total soil water potential is in hydrostatic equilibrium and effort is equal to the initial xylem water potential at the root collar ψ_C^{homo}, which is dominated by root hydraulic resistance here. $\tilde{w} = w(\tilde{t})$ is evaluated at the respective occurrence times of water stress. These are different between the different simulations. In the course of soil drying, collar potential and effort decrease along with the soil water potential. After one day, the ranking of simulations number 2 and 3 have interchanged with respect to effort. Afterwards the ranking remains unaltered not only at fixed times, but also at the respective onset of water stress. Notably, the functional relationship between $R_{Rs} = K_{Rs}^{-1}$ and effort changes with time (see also Fig. 5) and effort contains more information than root hydraulic resistance alone.

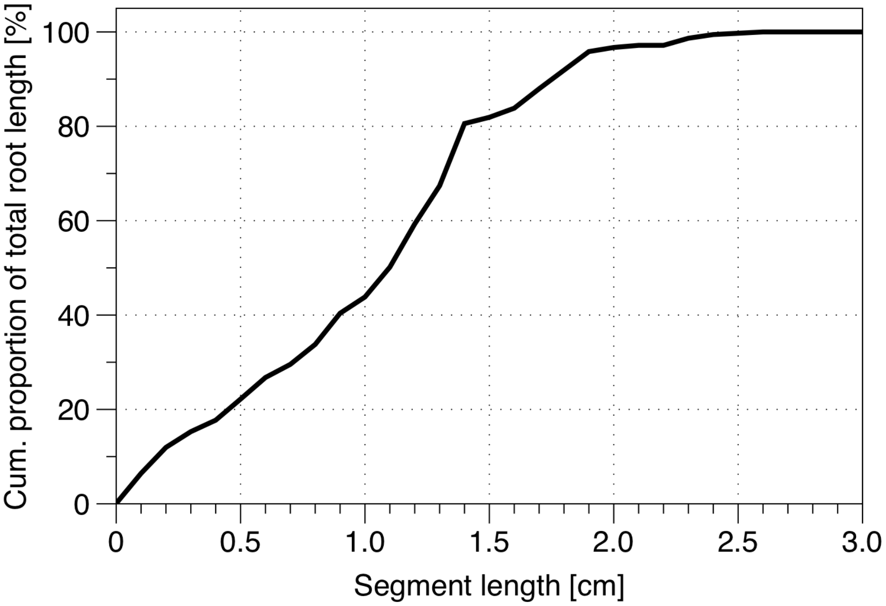

Figure 1: Histogram for root segment lengths present in the root geometry used within the complex aRoot model. Root geometry and segmentation was the the same between all simulations. Longest root segments are 2.6 cm, more than 95 % of total root length is constituted by segments which are shorter than 2 cm, more than 80 % of total root length is constituted by segments shorter than 1.5 cm.

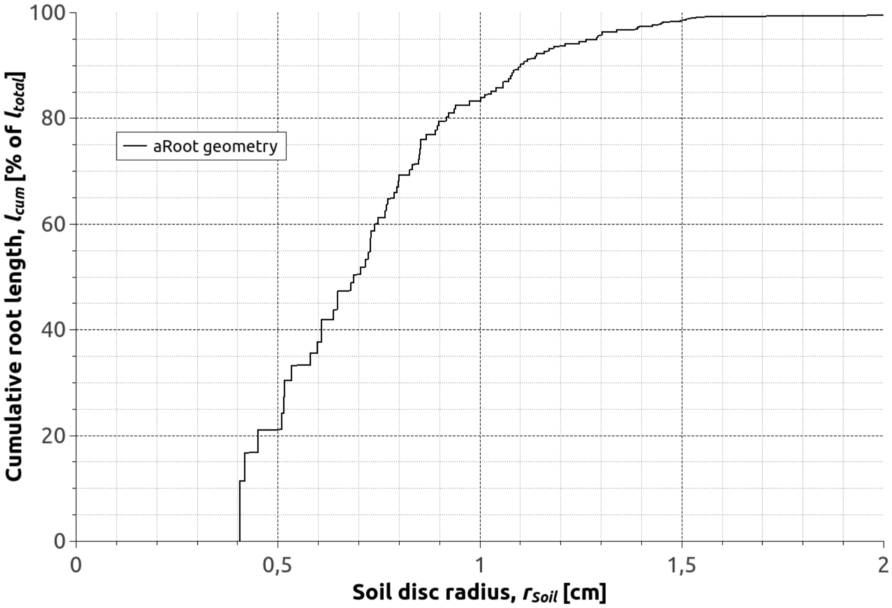

Figure 2: Histogram for soil disc radii around the root segments of the root geometry used within the aRoot model. Soil disc radii are derived by the aRoot model from local root length densities in different regions of the soil. They can therefore be interpreted as half average root distances. Root geometry and segmentation was the same for all simulations conducted with the complex aRoot model. More than than 90 % of total root length is virtually attached to soil cylinders with radii smaller than 1.2 cm. In contrast to the simple model, water flows along gradients in total soil water potential from wetter (sparsely rooted) into drier (densely rooted) regions.

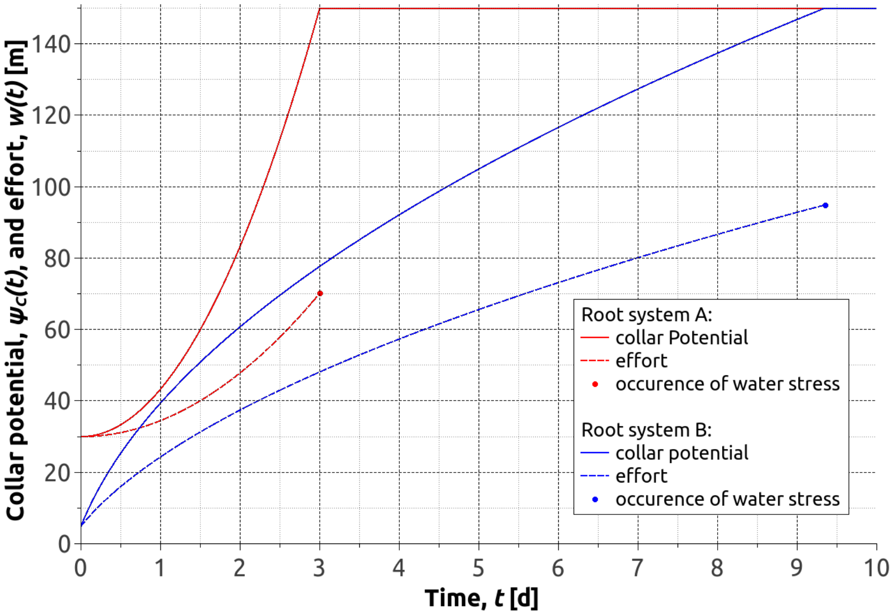

Figure 3: Temporal evolution of collar potential (solid line) and effort (dashed line) for two exemplarily chosen, hypothetical root systems. Transpiration rate is assumed to be constant over time and between the two root systems. Root system A has more negative collar potential at all times which additionally increases in a convex way and thus reaches water stress early. Root system B has at all times less negative collar potential which increases in a concave way and thus leads to later occurrence of water stress. The assumed constant rate of transpiration allows to calculate the temporal evolution of effort until the onset of water stress as a time average. At the onset of water stress, effort equals the average collar potential over the course of unstressed transpiration (see eq. (11) of the revised manuscript). It can not be calculated beyond water stress as no information is given about the evolution of limited transpiration. Although root system B has less negative collar potential than root system A at all times, its effort takes more negative values than that of root system A. This is no contradiction, as effort is by its definition a flow weighted (here also time average) collar potential necessary for water uptake (see eqs. (10) and (11) of our manuscript). Thus, root system B has higher effort because it remains for a relatively larger period of time at more negative values.

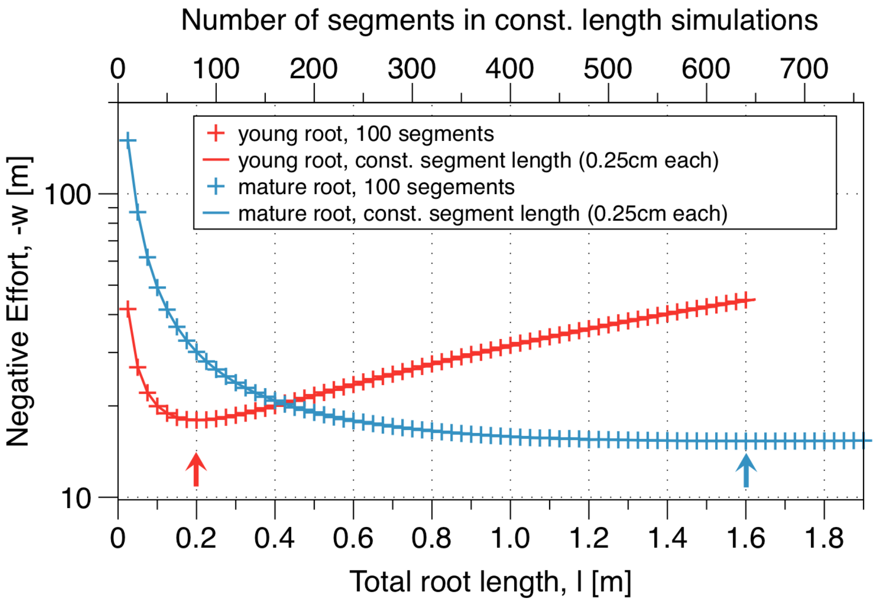

Figure 4: Effort for young (red) and mature (blue) single unbranched roots depending on their total length l_{total}. We reproduced Fig. 3 top left of our manuscript with (a) constant number ($n = 100$) of segments and variable segment length, and (b) variable number of segments constant segment length ($l_{segment} = 0.25cm$). The two curves overlap really well. Although barely visible, some small differences for simulations of longer young roots pertain, the optimum is perfectly reproduced and yields the same length for both (a) and (b) simulations.

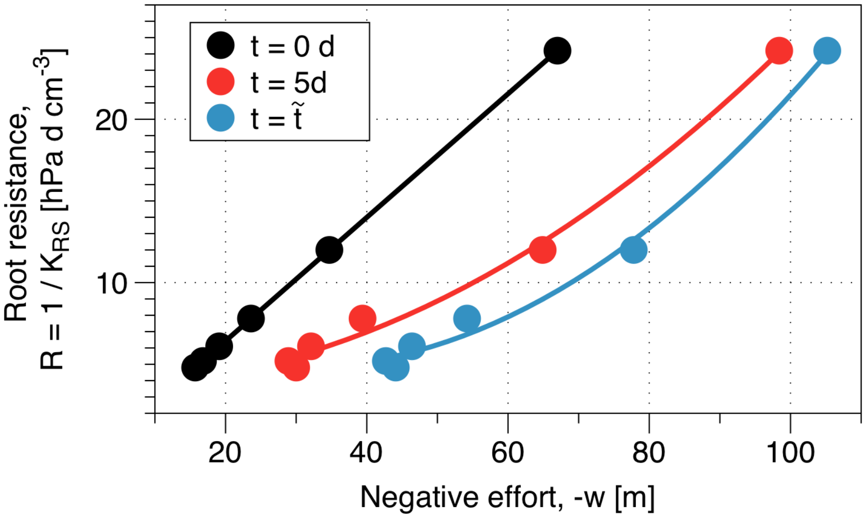

Figure 5: Time dependent relation between K_{RS}^{-1} and effort for the six hydraulic architectures presented in our manuscript. At t = 0 d, total soil water potential is in hydrostatic equilibrium and effort is equal to the initial xylem water potential at the root collar ψ_C^{homo}, which is dominated by total root hydraulic resistance R_{RS} here. An almost perfect linear relationship is observed. In the course of soil drying, collar potential and effort decrease along with the soil water potential in all simulations. After some days, the shape of the curve changes and gets more convex. Furthermore, the ranking of the root systems with lowest plant hydraulic resistance changes with respect to effort. $\tilde{w} = w(\tilde{t})$ is evaluated at the respective occurrence times of water stress. These are different between the different simulations. Notably, the functional relationship between R_{Rs} and effort changes with time and effort contains more information than root hydraulic resistance alone.