Dear reviewer,

Thank you again for your constructive comments. The manuscript has been adjusted accordingly by:

- 1. this reviewer is not clear or the authors did not show how the current approach can be applied elsewhere in the field. Particularly, the most important parameters (e.g., u2/u3) are determined via sensitivity analysis, which makes this reviewer wonder how to obtain these parameters in the field, and further at regional/global scale?

We included an extra paragraph in the discussion section about the application at field scale. The idea is to include the model in a land surface model and to calibrate the parameters against field scale data. (Ideally it would be possible to link the parameters from the field scale calibration to the ones obtained from the single plant systems).

2. This reviewer commented on "the top soil was covered with plastic to prevent evaporation from the soil" (section 2.1), and the author responded that they are using actual ET as the boundary condition.

Considering the top soil surface is covered with plastic, can we still define the boundary condition with actual ET?

We reconsidered this description of our boundary conditions and noticed that we made an mistake in mentioning the evapotranspiration. The evapotranspiration was actually only used as a validation method, not as model input (only the input irrigation flux is)

Also, in the current experiment, transpiration and actual ET are equal (and determined by the weight change of the system and the known irrigation volume), because evaporation from the soil is negligible due to the plastic. (if the plastic is not placed, the evaporation from the soil in the first phase could play a small role for the water balance/water input/boundary condition, especially around the drip lines where the top centimeters are moist, then evaporation will take place).

In field conditions where the soil is not covered, the boundary condition will have to be given by actual evapotranspiration. In the land surface/crop standard models, evaporation at the surface of the bare soil is also taken into account.

3. This reviewer commented "This reviewer is wondering why not using the soil sample in this experiment to determine the SWRC?" on line 118 or the original version.

The author responded "We agree that this would have been the more elegant option. We however assumed that the differences between the real SWRC and the standard values for loamy sand are small compared with other uncertainties (like in the tracking of the roots and the limited homogeneity of the soil moisture). Hence, with this experiment (with considerable error flags) we aim to focus on very clear dominant aspects and relationships (like soil moisture driven root growth). We however did play with the model and did some parameter sensitivity tests for these paramters. The qualitative/main results are not sensitive for variation in a wide range around these values."

This reviewer is not convinced by the above response. The lab experiment is there, this reviewer assumed the authors have access to the experiment column and can easily get the SWRC parameters. This step is important for proving the reproducibility of this work.

We included the water retention curve in the MS and an extra figure on the sensitivity to soil parameters.

Dear reviewer,

Thank you again for the constructive comments. Below you find our remarks and the way in which the manuscript was adjusted.

- Thank you for considering my previous comments and expanding on the missing explanations, which enabled me to understand the contents of the paper and results much better. I found a few more contradicting statements (see detailed comments below), which may suggest that I have still misunderstood something. However, based on my now more complete understanding, I cannot recommend publication of the paper in its current form in HESS, for the following reasons.

  The main conclusions of the paper are:
  C1) Soil moisture exerts a strong, dominant influence on root density growth and vertical root distribution. (L200, L212)
  C2) Root profiles can be predicted realistically from information on soil moisture profiles only. (L201)
  C3) The root system is "insensitive to above ground processes and overall biomass growth". (L204)
  C4) Implementation of the proposed root growth model in regional Land-Atmosphere models would result in "more correct representation of soil-plant water fluxes, and a more realistic representation of root biomass". (L216-219)

  These conclusions are based on a single experiment where water was applied to a soil profile at progressively deeper depths as the root system of a single maize plant developed over 50 days in a rhizobox. Since there was no control experiment with a different irrigation scheme, it is not possible to tell from the results presented here whether the root system development was indeed governed by soil moisture availability or whether the pattern found here is just a result of the seedling exploring an empty soil volume. The irrigation scheme was designed "in an attempt to follow the water demand of the plant" (L76) and to "control the vertical soil moisture gradients and stimulate vertical root growth" (L78), such that water was always applied towards the bottom of the expanding root system (compare Fig. 2C with Fig. 6A-D), resulting in a vertical soil moisture distribution that largely reflected the irrigation scheme (Fig. 2). Although C1) is plausible, due to the lack of a control experiment, I cannot confirm that the results support this conclusion.

We added a control experiment to the manuscript.

Consequently, C2) is not supported by the presented results, as it is not clear whether root growth responded to soil moisture at all in this experiment, or whether the implied correlation between root growth and soil moisture was due to selective irrigation in soil layers where root growth was expected to be highest (at the bottom of the advancing root system).

In the main experiment irrigation was generally not at the root tip. Note that the standard procedure in the main experiment was to wait until the maximum root length was relatively static, and only then switch to a lower drip line. Also, root density was generally not growing mostly at the root tip. But a strong correlation was found between soil moisture and root growth.

The conclusion that the root system "is insensitive to above-ground processes" (C3) is entirely unsupported, as above-ground processes were neither controlled nor monitored.

Our reasoning: if you are able to calculate something that could depend on factor A-Z by taking into account only 'factor A' without including 'factor B' in your calculation, this suggests that something is relatively independent of factor B. Actually, we of course monitored some above ground parameters, but certainly not everything that could be of influence (as also other below-ground parameters as (in)organic components/micro-organisms) . How should we include all these parameters, and why should we if we could also do without?

Similarly, there is little support for Conclusion C4) in the results presented here, as the dynamics of the root system development of a single seedling growing in an initially root-free soil is of limited relevance for the simulation of the root system of a plant community in a regional Land-Atmosphere model. There are other papers in the literature that point out the importance of representing root system dynamics in such models, some of which have been cited here, but it is really far fetched to conclude that the model presented here would improve land surface models based on the results presented in this study.

Other factors could be included in a similar fashion as the soil moisture. Our model just gives a very simple way of calculating where the roots should grow to access water. It is true however that this study does not show the relevance by itself. We express the expectation that by including the routine some fundamental dynamics can be captured in a fairly simple way. From a system point of few it is important to capture the dynamics so that the plant can react and adjust. This will have an impact on the whole system.

The different model versions presented here provide limited potential for new insights. The finding that the exponential root distribution led to very different simulations of the vertical water uptake profile than simulations based on measured or dynamically simulated root distributions is not surprising given that root water uptake was simulated as a linear function of root length density and soil moisture. In fact, the representation of root water uptake adopted here ignores the non-linearity of the water retention and hydraulic conductivity curves, so it is not clear what can be learned from these simulations.

Our intention has never been to improve the water uptake routine, since this is already captured in much greater details in the standard models. Our intention is to improve the root growth and to consider the interaction between the parameters (the feedback loops)

The water uptake routine is only build in here to be able to study the system behavior including some feedback loops. However, we also draw the conclusion that the use of a very simplistic water uptake model does not reduce or dilute the advantage of using a more realistic root distribution function. Which, from our view, points towards the dominance /importance of taking into account the soil moisture driven root growth

The main insights I drew from the paper are:
1) Maximum root growth was observed predominantly at the bottom of the advancing root system (Fig. 2c).

Figure 2c shows that peaks in the root density growth do not predominantly occur at the bottom, but at all depths with high soil moisture… For instance in the period between day 20 and 40 the root tip is somewhere between -20 and -40 cm depth. But the root density growth in the depth interval -10 to -20 cm is comparable with the density growth between -20 and -30.

At the same time, this is where the watering was predominantly taking place. Therefore, it is not clear if this growth pattern was due to the watering or a natural root system development of this variety of maize, whereas the watering followed the root development. I assume that the decision to design the irrigation scheme in a way to "stimulate vertical root growth" was based on prior experiments where vertical root growth did not occur to the same extent. It might help to include these experiments in the paper as controls or different treatments, so that the effect of the watering scheme becomes more obvious.

Thank you for the remark. We included an experiment with a different irrigation scheme.

2) Vertical root distribution deviated substantially from an exponential distribution, with an almost inverted exponential root density profile, having the highest root density at the bottom of the root system at the end of the experiment (Fig. 6D). Believing that root growth does respond positively to soil moisture, or at least that it is hampered when the soil dries out, the vertical root profiles found in this study are likely due to the specific irrigation scheme at the bottom of the root system while the top of the root system is left to dry out after 20 days. This does show that root systems can deviate from the exponential distribution under certain conditions, but it does not automatically mean that exponential root distributions are wrong representations in land surface models where water replenishment happens predominantly by infiltration at the soil surface.

Unless soil moisture is distributed differently.

My co-workers and I are in the process of preparing a manuscript ourselves where we documented the dynamic responses of maize root systems to water pulses, so I do believe that your Conclusion C1) is correct, but unfortunately, I cannot see clear support by the data presented here. Since the other conclusions are in my view even less supported by the results presented here, I cannot recommend publication of the paper in its current form. However, I hope that my detailed comments below help re-structure and expand the paper in a way that it can be published in a suitable journal in the future.

DETAILED COMMENTS:

Unfortunately, the manuscript structure is still confusing:
1 Introduction
2 Experiments
2.1 Experimental Set-up
2.2 Diagnostic model of root growth: root follows moisture
Time series and correlations
Model formulation
Model parameter evaluation and results
2.3 Soil moisture and water uptake model
Model formulation
Model parameter evaluation
Results and discussion
2.4 A prognostic model for coupled soil moisture and root growth
Model formulation
Model calibration
Results and discussion
3 Conclusions

As shown above, there are numbered and un-numbered sections, where the un-numbered section titles are repeated multiple times. This makes the reading confusing, so I would recommend numbering all sections, and ideally consolidate them into one methods section where all three model

versions are described, followed by one results and discussion section.
Thank you. We adjusted the order of the manuscript accordingly

L76: How was water demand in each layer measured? According to Fig. 2A, soil moisture was highest at the depths where water was added, which suggests that water was added beyond the amount of water taken up by roots.
We derived the total water demand from weight changes of the system, mentioned in line 94.

Eq. 1: As L is increasing over time (Eq. 4), local root growth would decline at constant theta_n over time. Is this realistic? This diagnostic model is only used to test the vertical distribution of and correlation between both parameters, soil moisture and root growth. In the prognostic model the time evolution is calculated more realistically.

Eqs. 1-4: Please clarify in the equations that it is r(t), not r, and L(t), not L. So r(t) is the observed overall rate of increase in root length, whereas Eq. 1 provides the rate of increase in root length in a given soil layer. So in essence, Eq. 1 is:

dR(z, t)/dt = integral(d(R(z,t)/dt) dz) * theta_n/integral(theta_n dz)
The hypothesis formulated in Eq. 1 is hence that the vertical root growth distribution follows the vertical soil moisture distribution in a linear way. It would be good to make this clearer.
We added a sentence to clarify (end of page 4)

L119: This is not actually root growth, but extension rate of rooting depth, see Eq. 4.
this has been adjusted in the MS.

L119: Based on what observations? Based on observed rate of extension of the rooting depth or calibrated to reproduce measured root distribution?
Calibrated to reproduce measured root distribution. This has now been clarified in the MS.
L124: Why is this an extra condition? According to Eq. 2, theta_n<0 if theta<0.075, and according to Eq. 1, root growth should be negative if theta_n<0, so this should be already satisfied.
Eq 1 only gives the root density, not the extension rate of rooting depth. The condition has been applied to control vertical extension.

L135: I would put the fraction in brackets to make very clear that the exponent applies to the whole fraction.
this has been adjusted in the MS
Eq. 9: This ignores the non-linearity of the water retention and hydraulic conductivity curve. A linear relation between normalised soil moisture and root water uptake rate seems very unrealistic.
It is a very simple model which works well for the purpose of this paper. Our intention is not to improve the routine for water uptake that is already realistically included in Land surface model. But to show the effect of soil moisture driven root growth.

L148: Driven by the measured root density data?
this has been adjusted in the MS
L161: Why "except for the first period"? I see 0.75 for the exponential profile, compared to 0.77 and 0.81 for the others.
This is right, thank you for the remark. The textline has been removed/ adjusted.

L162-169: This suggests that the fact that the vertical soil moisture distribution was relatively similar between the exponential and modelled root profile simulations was due to a negative feedback loop between water depletion by root water uptake and reduced root water uptake by reduced soil moisture. However, this argument is not supported by the experimental evidence, as the experiment was designed in a way to avoid depletion of soil moisture by root water uptake. In fact, root water uptake was over-compensated, leading to a soil moisture profile with the highest soil moisture where the root density was highest (Fig. 6, except for 40-50 days). An alternative explanation is that the vertical soil moisture distribution is determined by the location of water input to the system. Fig. 2C illustrates that the soil moisture was generally highest where the water inputs took place. Since the top soil was left to dry out after 20 days (same figure), it is not surprising that root growth subsided thereafter in this part, eventually leading to the inverted vertical root distribution shown in Fig. 6D.

"the local peaks in the soil moisture coincide with the depths of irrigation." (line 209 in MS) If root densities at these depths are small, less is locally absorbed by the roots leading to higher local soil moisture values. But higher soil moisture stimulates root growth! This is the negative feedback loop controlling the soil moisture and roots around the drip lines.

L175: I don't think normalization is the right term, as this would suggested that the maximal "local root growth tendency" would be 1.
normalization here means making the two terms on both sides of the equation equal, by multiplying with the proportionality constant

L176: So now Eq. 1 is replaced by Eq. 10, i.e. root growth rate is a linear function of normalized local water content rather than the local fraction of total water content? I understand that r(t) from Eq. 1 had to be removed for prognostic simulations, but why was the division by integrated water content removed, too?

The chosen relationship is more straightforward. Hereby we assume that it is not only the relative soil moisture (i.e. vertical distribution of the soil moisture) that determines local root growth, but that the absolute soil moisture in itself is also stimulating root growth.

L179: "with identical overall root length": If the exponential root profile is set to have the identical overall root length as the dynamically simulated root profile, how come there is up to 54% difference in total modelled root length between the two in Table 3?
After each time step the overall root length of the normal and exponential profile are identical. Table 3 is a result of the online model /prognostic equation, including the feedback between soil moisture and (bulk) root growth. In the coupled version, using an off-shape profile implies higher soil moisture values and therefore more root growth in the next time step.

L193-: I do not understand this explanation, as according to L179, the exponential profiles were set to have the same overall root length as the dynamic root profiles, so I expect the profile to be always exponential and never become "off-shape".
with `off-shape' we mean: not ideally shaped for ideal/maximum water uptake (so roots develop not at the locations with highest soil moisture)as for the exponential profiles.

L200-: This is not clear, as irrigation was applied locally where the largest root growth was expected, so it is not clear if root growth followed irrigation and soil moisture or if the dynamics would have been similar under homogeneous soil moisture.
root growth was often found over relatively wide range of depths, and be more related to the soil moisture than to the single location of the root tip.

L201: What do you mean by vertical rooting depth? Do you mean vertical root distributions?
The extension rate of the maximum rooting depth. This has been adjusted in the MS

L202: Not infiltration, but vertical water transfer model.
Thank you for the remark, this has been adjusted in the MS

L206-: Not necessarily, as all the results show is that differences in vertical root distributions did not have much effect on the simulated soil moisture profiles, which could be due to the strong irrigation signal in the soil moisture profile, overwhelming the more distributed root water uptake profiles. This is underligned by the fact that soil moisture was highest where root abundance was highest in most cases, so there was no obvious effect of root water uptake on the vertical soil moisture distribution.
the text was slightly adjusted. The described feedback loops do certainly play a role, because if soil moisture is higher, more roots will develop. So it is possible and likely that these play a role in the relative small differences in the soil moisture and water uptake profiles. We compared the results with exponential shaped profiles. For the exponential profiles highest soil moisture does not correspond with highest root abundance. Therefore you could expect a bigger difference in resulting soil moisture fields and water abundance.

L212: Not necessarily, see above.
“suggest” and “can result”
L215: Why would it prevent water demand?
the line has been adjusted
L216: I would strongly advice against implementation of an empirical root growth model in LSMs, which was based on an experiment with maize seedlings.
We suggest implementing the principle of soil moisture steered root growth in LSM. This can be done by using simple equations requiring a very limited amount of calibration parameters. Nowadays fixed root lengths and distributions are included that are not flexible at all and also need the same amount of parameters to be calibrated…

L217: There is no evidence for such a benefit in LSMs in this paper.
The statement about biomass has been removed. The statement of water fluxes are a straightforward result of improved soil moisture profiles.

Table 1: To avoid confusion, I would write in the top row: "measured RP", "modeled RP", and "exponential RP", and in the caption: "...root profiles (RP)."
thank you for the suggestion. MS has been adjusted accordingly.
Figure 2C: What do the units of root growth given in cm/cm mean? Should this be cm/cm2, or is it the root length added divided by the initial root length? The line colours in the legends and in the plots are not the same. Perhaps it would be enough to have only one legend, as it is always the same between the solid, dashed and dotted lines.
This has been adjusted
Figure 6: Why not use squares for soil moisture in the middle column to avoid confusion? What does "driver" and "results" mean?
drivers are the input parameters
Figure 8: The lines are wrong in the legend, as there are only solid and dashed lines in the plot.

Thank you this has been adjusted in the MS