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Water uptake by rangeland plants: a modeling analysis

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Summary

We used a "macroscopic" root uptake model to quantify water use of rangeland plants based on field data of soil water contents, soil hydraulic properties, and leaf area index. The model considers a dynamic root distribution, the effect of water stress on plant water uptake and the compensation effect of root water uptake. The simulation was conducted for 111 days from May to September of 2009 on a moderately grazed pasture. The maximum rooting depth was estimated as $1.3 \sim 1.6\ m$*. Pattern of simulated seasonal water depletion was verified by observed data. Our work illustrates the importance of soil water retention parameters, and especially the root uptake compensation mechanism, in correctly simulating soil water flow on rangeland. The method and analysis of this work may be useful in a wider context of soil plant relationships.*

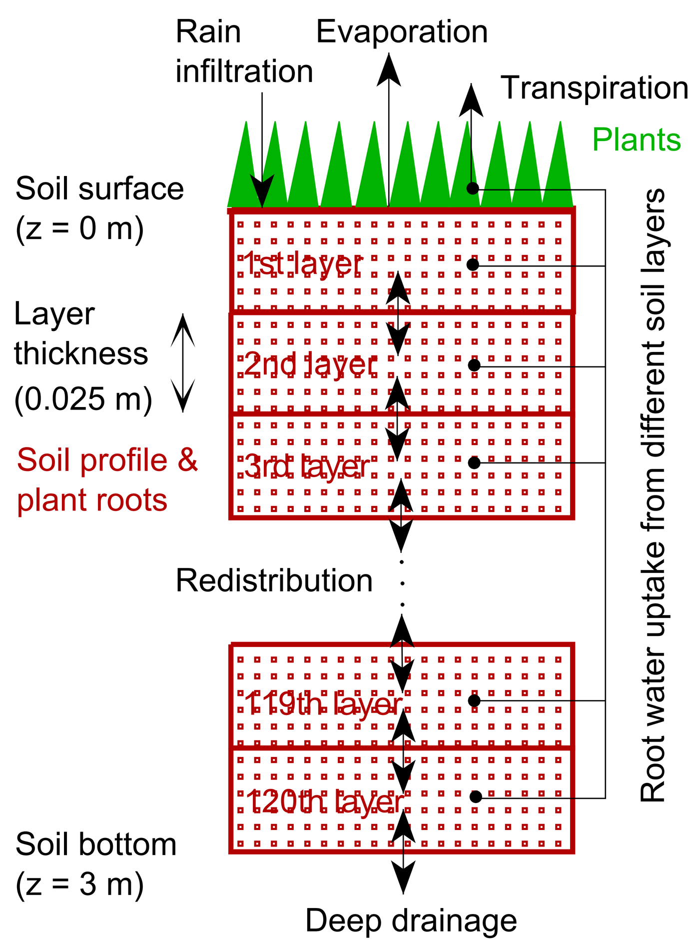
Introduction

Quantifying plant water use is essential for sound management policies with regard to both the plant production and environmental impacts of the soil-plant system. In recent years, the "macroscopic" root uptake modeling approach—roots of the plant community are considered as a whole regardless of the geometry and physiology of individual roots—has been frequently used to describe water flow in several annual crops. Successful application of this method to native rangelands, however, is not seen to us. One major difficulty is the uncertainly in accurate knowledge of rooting depth and root distribution of rangeland plants. In our work, this was overcome by the combined use of field measurements (soil water contents, plant leaf area index, and soil hydraulic characteristics) and iterated computing (Dong *et al*., 2010). In particular, we

- used a simulation-based search method to identify the optimal rooting depth and distribution parameters, which was accomplished by minimizing the difference between measured and modeled soil moisture content; then, we
- identified parameters that have significant impact on the model performance according to their influence on the magnitude of the root mean square error (RMSE).

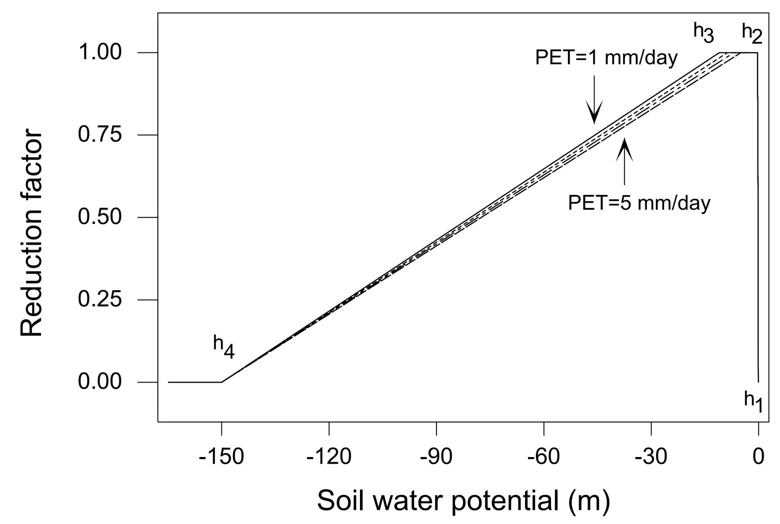
"Macroscopic" root uptake model

The soil water infiltration and redistribution model "Austere-layered" by Warrick (2003) was modified and extended to include the following new components: (a) dynamic root growth, (b) non-uniform root water uptake, (c) effect of water stress on plant water uptake, and (d) soil evaporation. The model considers one-dimensional, unsaturated liquid water flow in layered soils of rangelands, or similar ecosystems.



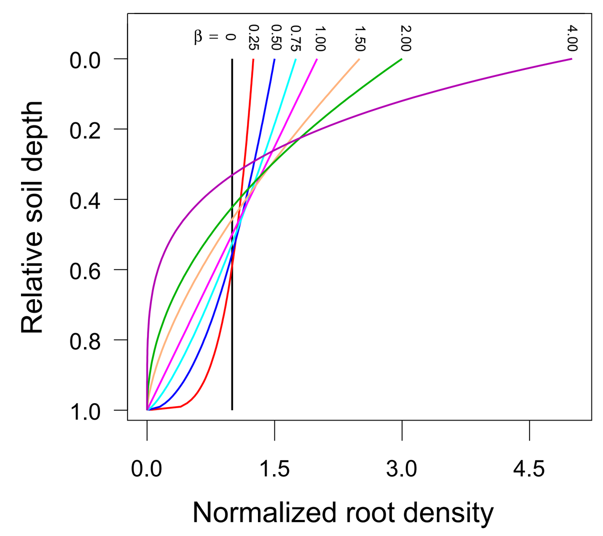
Water uptake according to soil water potential

We adopted a model by Feddes *et al*. (1978) so that root water uptake is attenuated with the reduction of soil water potential. Water potentials less than h_4 and greater than h_1 indicate the limitation due to oxygen deficiency and wilting point, respectively; water potential between h_3 and h_2 are for maximum uptake. The dashed lines depict the shift of the point of reduction to a lower water potential under lower evaporative demand as indicated by a lower potential evapotranspiration (PET).



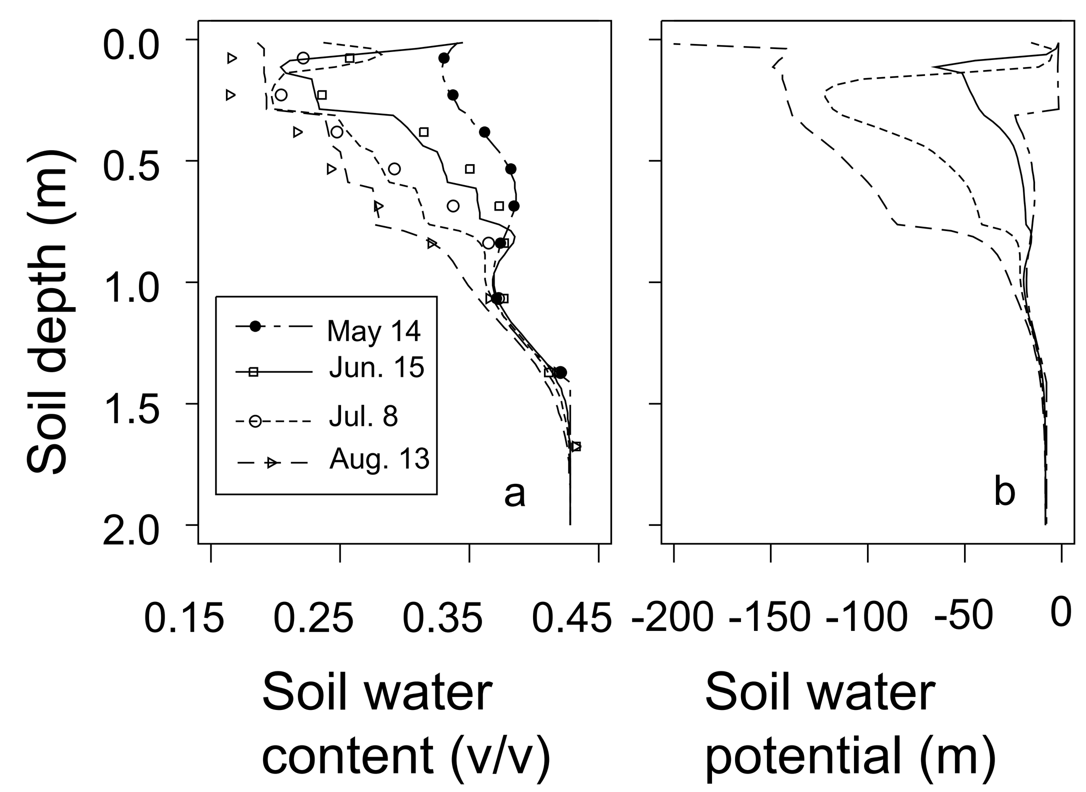
Water uptake according to root distribution

We adopted a nonlinear root distribution function of Ojha and Rai (1996) so that relative abundance of roots at different soil depths is determined by the root distribution parameter β.



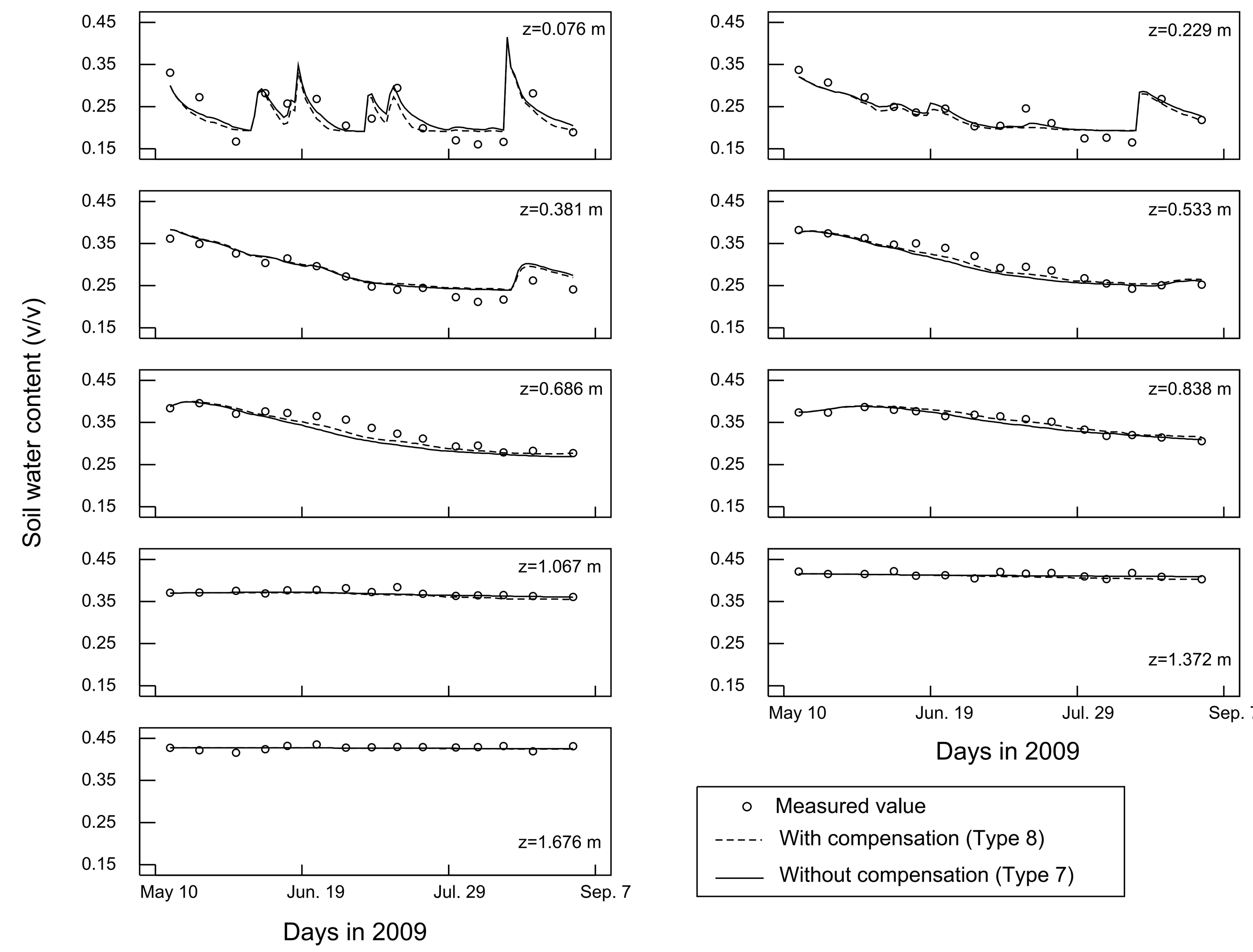
Soil water profile: simulated vs. measured

Shown below are model simulated water content profiles (Panel *a*: lines) compared against the field measurements (Panel *a*: symbols) on selected four days during the 2009 growing season. Note the development of seasonal drought from mid-May to mid-August. Also shown are simulated profiles of soil matric potentials (Panel *b*).



Soil water dynamics at different depths

The root uptake compensation hypothesis of Li *et al*. (2001) says that the reduced root water uptake at one location due to water stress may be "compensated for" by improved water uptake at other locations (or depths) where water is available. Although the use of this mechanism only caused slight improvements in simulated soil water contents, it had a significant impact on the accumulated water uptake by rangeland plants (see Table 1 below; also see Dong *et al*. 2010).



Optimal plant water use by uptake compensation

Table 1: Accumulated water uptake from the root zone of $0 \sim 1.6\ m$ during Aug. 1-13 (dry period) and Aug. 13-31 (wet period due to a heavy rainfall of 41.9 *mm* received in Aug. 14-16, 2009). Note the contrast in water use pattern before and after the rain event. During the dry period, the uptake compensation mechanism "allowed" water to be extracted from deeper locations, while during the wet period, it "facilitated" a uptake from shallower and wetter depths.

Period	Depth quarter	With compensation		Without compensation	
		Water use (mm)	% of total	Water use (mm)	% of total
Aug. 1-13	1st	4.48	39.2	3.93	48.2
	2nd	3.26	28.5	2.59	31.8
	3rd	2.97	26.0	1.61	19.7
	4th	0.71	6.2	0.02	0.3
	Total	11.42	100.0	8.15	100.0
Aug. 13-31	1st	24.30	86.7	18.52	74.2
	2nd	2.18	7.8	4.27	17.1
	3rd	1.25	4.5	2.13	8.6
	4th	0.30	1.1	0.03	0.1
	Total	28.03	100.0	24.95	100.0

Conclusions

1. The macroscopic root uptake approach is a useful tool for accurately predicting rangeland soil water dynamics through combined use of field measured data and computer-based search for the optimal parameter values.
2. Using the water stress compensation mechanism not only improves the accuracy of soil water prediction, but also enables a more sensitive response of roots to water availability in the whole root zone, and thus facilitates an optimal water use by plants.
3. Rigorous test of the model is needed using measured data of root distribution and transpiration.

- **References**: (1) A. W. Warrick, 2003, Soil Water Dynamics, Oxford Univ. Press, N. Y. (2) R. A. Feddes *et al*., 1978, Simulation of field water use and growth, Ctr. Agr. Publ. Document., Wageningen. (3) C. S. P. Ojha and A. K. Rai, 1996, J. Irrig. Drain. Eng. 122:198-201. (4) K. Y. Li *et al*., 2001, J. Hydrol. 252:189-204.
- Data (in table/figures) of this poster are from X. Dong *et al*., 2010, Plant Soil 335: 181-198.