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Application of a single root-scale model to improve macroscopic modeling of root water uptake: focus on osmotic stress

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Root water uptake is a fundamental process in the hydrological cycle and it largely regulates the water balance in the soil vadose zone. Macroscopic stress functions are currently used to estimate the effect of salinity on root water uptake. These functions commonly assume stress to be a function of bulk salinity and of the plant sensitivity to osmotic stress expressed as the salinity at which transpiration is reduced by half or so called tolerance value. However, they fail to integrate additional relevant factors such as atmospheric conditions or root architectural traits.

We conducted a comprehensive simulation study on a single root using a 3-D physically-based model that resolves flow and transport to individual root segments and that couples flow in the soil and root system. The effect of salt concentrations on root water uptake was accounted for by including osmotic water potential gradients between the solution at the soil root interface and the root xylem sap in the hydraulic gradient between the soil and root. A large set of factors were studied, namely, potential transpiration rate and dynamics, root length density (RLD), irrigation water quality and irrigation frequency, and leaching fraction. Results were fitted to the macroscopic function developed by van Genuchten and Hoffman (1984) and the dependency of osmotic stress and the fitted macroscopic parameters on the studied factors was evaluated.

Osmotic stress was found to be highly dependent on RLD. Low RLDs result in a larger stress to the plant due to high evaporative demand per root length unit. In addition, osmotic stress was positively correlated to potential transpiration rate, and sinusoidal potential transpiration lead to larger stress than when imposed as a constant boundary condition.

Macroscopic parameters are usually computed as single values for each crop and used for the entire growing season. However, our study shows that both tolerance value and shape parameter p from the van Genuchten and Hoffman (1984) function were highly dependent on both potential transpiration and RLD. Plant salt tolerance was lower under high evaporative demand and lower RLD. In addition, the shape of the stress curve, which is defined by p, was found to be steeper under larger RLD and low transpiration rate. Time-variant macroscopic parameters based on knowledge of current potential transpiration rate per root unit length would be more convenient to accurately predict osmotic stress, and hence root water uptake, during a growing season. In a next step, simulations considering the whole root systems will be conducted to assess how macroscopic parameters are also related to root architectural characteristics.

van Genuchten, M.T., Hoffman, G., 1984. Analysis of crop production. Soil Salin. Irrig. Springer Berl. 258–271.