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Beyond the Gardner Model: Developing a Physical Understanding of Water Uptake by Single Roots.

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According to van den Honert's model, transpiration is a water flux along a potential gradient and through a series of pathways (soil, root cortex, xylem, stomata) with different resistances. The discussion about which of those resistances, namely plant or soil resistance to water flow, dominates the transpiration process at high atmospheric demand is still ongoing. It is often argued that the root resistance to water flow is much larger than the corresponding soil resistance, unless in very dry soils. Therefore the plant resistance is considered the main limitation to the transpirational flux under most conditions. Here we argue, based on the investigation of water flow towards a single root that the soil resistance might become dominating, even under conditions where bulk soil water content is elevated. However, plants might adapt so to minimize water shortages stemming from limiting soil hydraulic conductivity, for example by optimizing rooting density and interruption of water uptake during midday.

We investigated the root water uptake starting from water flow towards a single root and compare the results to the widely used model by Gardner. Gardner's solution for water flow towards a single root relates the root water uptake to plant available water based on the bulk soil water content and the bulk soil hydraulic conductivity. Experiments have indicated however, that the soil water content is not homogenous, but becomes depleted in vicinity of the root, which should lead at the same time to a local decrease in hydraulic conductivity. We investigate the implications of this heterogeneous soil moisture distribution for the actual soil resistance to water flow 'felt' by a single root and derive a new effective resistance for larger scale models. We find that Gardner's model may underestimate hydraulic resistance to water flow. Our results may become useful for investigation of the physical relationship between rooting density and available soil water, diurnal dynamics of water uptake as well as below ground competition for water.