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The plant water pump: why water flows uphill of water potential gradients in a root hydraulic anatomy model

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Guttation is the exudation of xylem sap from vascular plant leaves. This process is particularly interesting because in its configuration root water uptake occurs against the hydrostatic pressure driving force. Hence, it emphasizes the contribution of another driving force that lifts water in plants: the osmotic potential gradient.

The current paradigm of root water uptake explains that, due to the endodermal apoplastic barrier, water flows across root radius from the same principles as through selective membranes: driven by the total water potential gradient. This theory relies on the idea that during guttation, osmolites loaded in xylem vessels decrease xylem total water potential, making it more negative than the total soil water potential, and generating water inflow by osmosis as in an osmometer.

However, this theory fails at explaining experiments in which guttation occurs without sufficient solute loading in root xylem of maize (Enns et al., 1998; Enns et al., 2000) and arrowleaf saltbush (Bai et al., 2007) among others; studies concluding that experimental observations “could not be explained with the current theories in plant physiology”. Such flow rates towards combined increasing pressure potentials and increasing osmotic potentials between separate apoplastic compartments would necessitate an effective root radial conductivity that is negative; a mind bender.

What piece of hydraulic network would make it possible for water to flow against the total water potential driving force?

We implemented Steudle’s composite water transport model in the explicit root cross-section anatomical hydraulic network MECHA (Couvreur et al., 2018). All apoplastic, transmembrane and symplastic pathways are interconnected in the network. The results show that while root radial conductivity is particularly sensitive to cell membrane permeability, the combination of conductive plasmodesmata and increased dilution of protoplast osmotic potentials inwards is a key to explain root water flow towards increasing total potentials. A triple cell theory is suggested as new paradigm of root radial flow.

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