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Where Does Drought Begin? Linking Rhizosphere Processes and Forest Hydrology

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Soil water availability is a critical factor for plant transpiration and photosynthesis. As soils dry, their hydraulic conductivity declines, limiting water supply to the roots and ultimately constraining the whole water flow through the soil–plant-atmosphere continuum. To investigate where and when this limitation arises, we combined several experiments across scales and degrees of complexity.

Neutron radiography, a non-invasive technique that directly visualizes water distribution in soils, applied to young maize plants revealed sharp water potential gradients forming in the rhizosphere during drying, showing local depletion around roots. These rhizosphere-scale dynamics are tightly coupled to reductions in transpiration. The onset and severity of this hydraulic bottleneck depend strongly on soil texture: in sandy soils, weak capillary forces lead to early hydraulic breakdown at comparatively high water potentials (relatively wet conditions), whereas loamy soils sustain water supply over a wider drying range.

Plants can transiently buffer this process through the release of extracellular polymeric substances that enhance root–soil contact and displace depletion zones away from the root surface. However, this buffering delays rather than eliminates hydraulic disconnection. Analogous thresholds are observed in trees under field conditions, where individuals growing in sandy soils close stomata at higher soil and leaf water potentials than those in finer-textured soils.

Together, these converging observations point to universal, texture-dependent thresholds controlled by rhizosphere processes. By linking pore-scale hydraulics to whole-plant responses, this work positions the rhizosphere as a central regulator of plant water use and a key, yet often overlooked, determinant of ecosystem drought sensitivity.