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Disentangling temporal and population variability in plant root water uptake from stable isotopic analysis: a labeling study

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Labeling techniques have been widely applied in the literature to infer profiles of plant relative root water uptake (RWU). By enhancing the rather flat water isotopic composition gradient in soil with labeled water, relative RWU values from a set of soil water "sources" can be determined from inversion of isotopic data with greater confidence. This is usually done in the isotopic community through Bayesian multi-source mixing models. These models are not demanding in terms of data (only isotopic data is required) but do not incorporate knowledge water transport processes. Combined observations of water status and flow (e.g., soil water matric potential and transpiration rate) and soil-root hydrodynamics models allow mining deeper into isotopic data, and provide novel insights into the spatiotemporal dynamics of water transport across plants.

A one-dimensional and isotope-enabled soil-root physically-based model was used to simulate both water and isotopic measurements recorded during a 34-hour long intensive labeling experiment where a population of tall-fescue (Festuca arundinacae) was grown in a macro-rhizotron (0.2 m^2 surface area, 1.6 m depth). Above-ground data included tiller and leaf water oxygen isotopic compositions (δ_{tiller} and δ_{leaf}) as well as leaf water potential (ψ_{leaf}) and transpiration rate. As for below-ground data, profiles of root length density (RLD), soil water content and isotopic composition were destructively sub-hourly sampled. A first analysis of the results showed a striking decorrelation in temporal dynamics of water status and isotopic information.

There was no scenario in which the soil-root model could simulate both ψ_{leaf} and δ_{tiller} time series well. While the model-to-data fit for ψ_{leaf} was satisfying (R^2=0.67), none of the tested root system groups of varying rooting depths could reproduce the measured temporal fluctuations of δ_{tiller} (R^2=0.00). The model however showed the great sensitivity of δ_{tiller} to the population average rooting depth at the labeling point, thereby suggested spatial heterogeneity as the explanation for the observed temporal dynamics.

For comparison, one Bayesian mixing model was used and could successfully reproduce the δ_{tiller} high temporal dynamics induced by the labeling of deep soil water. If it succeeded in simulating RWU profiles, it was obviously at the expense of physical consideration: the strong variations in δ_{tiller} were translated into strong changes of RWU profile, which appeared not to be driven by environmental factors such as ψ_{leaf} and transpiration rate.

This study highlights the need for a holistic view, i.e., complement isotopic measurements with data on water status and calls for the use of physically-based soil-root model, especially in the context of labeling experiments.