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Estimating plant water uptake source depths with optimized stable water isotope labeling

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Depth profiles of pore water stable isotopes in soils in conjunction with measurements of stable water isotopes (SWI) in plant transpiration allow the estimation of the contributions of different soil depths to plant water uptake (PWU).
However, SWI depth profiles that result from the variations of SWI in natural precipitation may lead to highly ambiguous results, i.e. the same SWI signature in transpiration could result from different PWU patterns or SWI depth profiles. The aim of this study was to find an optimal stable water isotope depth profile to estimate plant water uptake patterns and to compare different PWU source depth estimation methods.

We used a new soil water transport model including fractionation effects of SWI and exchange between the vapor and liquid phase to simulate different irrigation scenarios. Different amounts of water with differing SWI signatures (glacier melt water, summer precipitation water, deuterated water) were applied in order to obtain a wide variety of SWI depth profiles. Based on these simulated SWI depth profiles and a set of hypothetical PWU patterns, the theoretical SWI signatures of the respective plant transpiration were computed. In the next step, two methods - Bayesian isotope mixing models (BIMs) and optimization of a parametric distribution function (beta function) - were used to estimate the PWU patterns from the different SWI depth profiles and their respective SWI signatures in the resulting transpiration. Eventually, the estimated and computed profiles were compared to find the best SWI depth profile and the best method.

The results showed, that compared to naturally occurring SWI depth profiles, the application of multiple, in terms of SWI, distinct labeling pulses greatly improves the possible spatial resolution and at the same time reduces the uncertainty of PWU estimates.
For the PWU patterns which were assumed for this study, PWU pattern estimates based on an optimized parametric distribution function were similar to estimates based on BIMs. The study demonstrates the need of virtual labeling experiments to optimize irrigation schemes for real world experiments aiming to estimate PWU patterns.