



## Monitoring water stable isotope composition in soils using gas-permeable tubing and infrared laser absorption spectroscopy

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The water stable isotopologues  $^1\text{H}^2\text{H}^{16}\text{O}$  and  $^1\text{H}_2^{18}\text{O}$  are powerful tracers of processes occurring in nature. Their slightly different masses as compared to the most abundant water isotopologue ( $^1\text{H}_2^{16}\text{O}$ ) affect their thermodynamic (e.g. during chemical equilibrium reactions or physical phase transitions with equilibration) and kinetic (liquid and vapor phases transport processes and chemical reactions without equilibration) properties. This results in measurable differences of the isotopic composition of water within or between the different terrestrial ecosystem compartments (i.e. sub-soil, soil, surface waters, plant, and atmosphere). These differences can help addressing a number of issues, among them water balance closure and flux partitioning from the soil-plant-atmosphere continuum at the field to regional scales. In soils particularly, the isotopic composition of water ( $\delta^2\text{H}$  and  $\delta^{18}\text{O}$ ) provides qualitative information about whether water has only infiltrated or already been re-evaporated since the last rainfall event or about the location of the evaporation front. From water stable isotope composition profiles measured in soils, it is also possible, under certain hypotheses, to derive quantitative information such as soil evaporation flux and the identification of root water uptake depths. In addition, water stable isotopologues have been well implemented into physically based Soil–Vegetation–Atmosphere Transfer models (e.g. SiSPAT-Isotope; Soil–Litter iso; TOUGHREACT) and have demonstrated their potential. However, the main disadvantage of the isotope methodology is that, contrary to other soil state variables that can be monitored over long time periods,  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  are typically analyzed following destructive sampling.

Here, we present a non-destructive method for monitoring soil liquid water  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  over a wide range of water availability conditions and temperatures by sampling and measuring water vapor equilibrated with soil water using gas-permeable polypropylene tubing and a cavity ring-down laser absorption spectrometer. By analyzing water vapor  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  sampled with the tubing from a fine sand for temperatures ranging between 8–24°C, we demonstrate that (i) our new method is capable of monitoring  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  in soils online with high precision and, after calibration, also with high accuracy, (ii) our sampling protocol enabled detecting changes of  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  following non-fractionating addition and removal of liquid water and water vapor of different isotopic compositions, and (iii) the time needed for the tubing to monitor these changes is compatible with the observed variations of  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  in soils under natural conditions.