Simulating preferential flow in a two water worlds context

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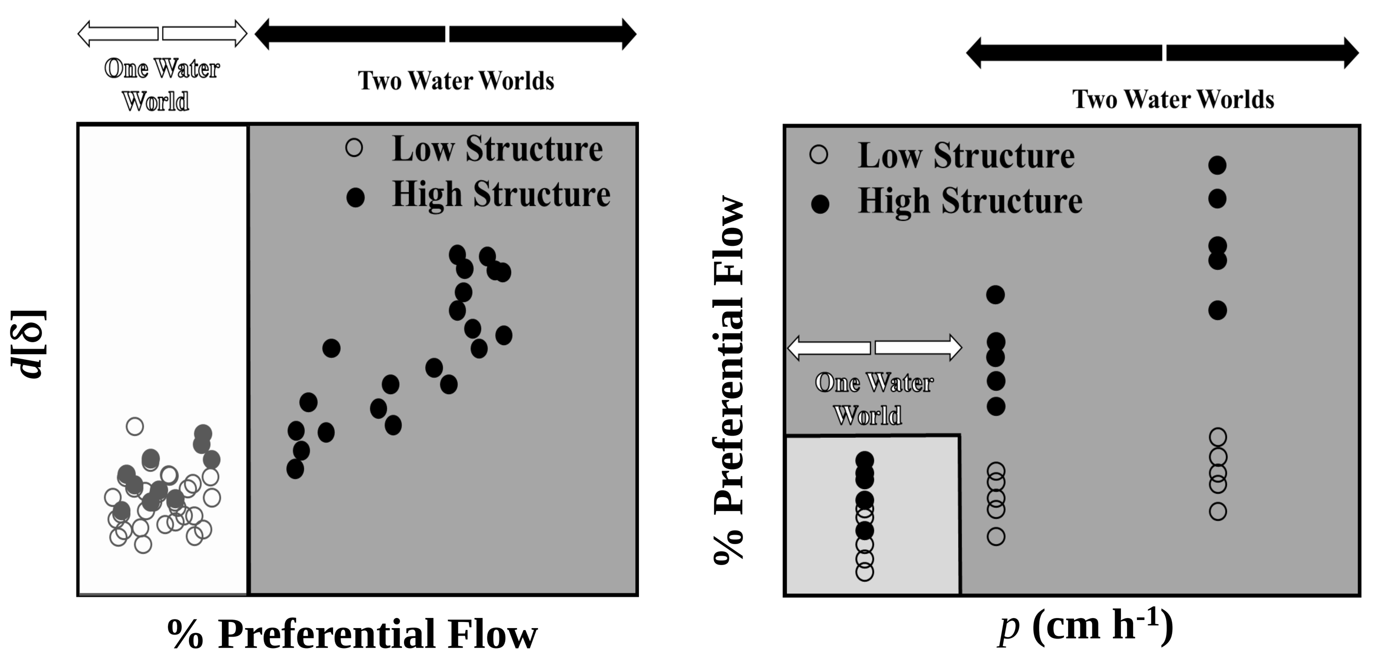
Introduction



Ecohydrological separation has been observed across climates and biomes, and at a fundamental level suggests that water in mobile versus immobile domains may resist mixing over varying periods of time; however little mechanistic evidence exists to explain this separation at a process scale. Non-equilibrium flow in the vadose zone may partially account for widespread perception of distinct hydrological domains yet no studies have weighed its contribution.

Objectives

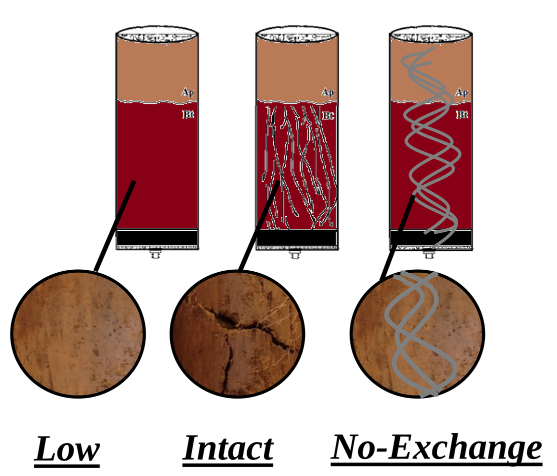
Determine the amount of preferential flow necessary to maintain a two water worlds scenario (i.e., physical separation between mobile and immobile water pools) using a simple isotope mixing technique.

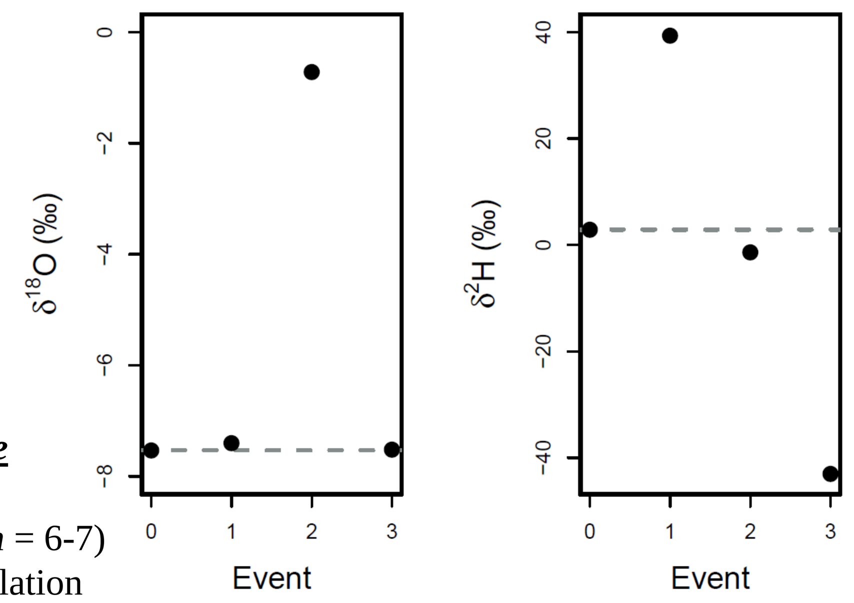
Methods

We constructed 60 cm soil columns (20 cm-ID PVC) containing either sieved soil material (***low*** soil structure), subsoil structure (***intact*** B horizon), or soil material with tubing-reinforced macropores to limit exchange with soil matrix water (***no-exchange***).

Columns were subjected to 3 rain storms of varying rainfall intensity (~2.5 cm h $^{-1}$, ~5 cm h $^{-1}$, and ~11 cm h $^{-1}$) whose stable isotope signatures oscillated around known baseline values.

Leachate and soil matrix water (via direct vapor equilibration) were measured periodically throughout the experiment and analyzed for their isotopic signatures using off-axis integrated cavity output spectroscopy (OA-ICOS).





Above) soil structure treatments (n = 6-7) and **below**) preferential flow calculation adopted from Stump et al. (2007).

Top right) Stable isotope signature of inputs and **bottom right**) rainfall intensity per event

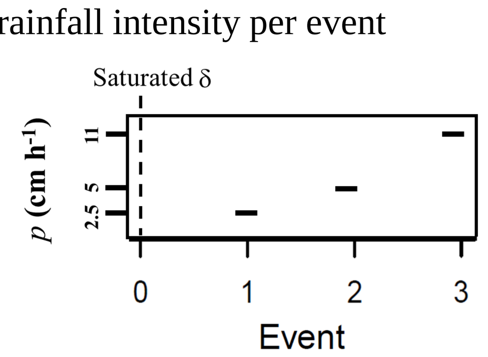
$$f_{PF}(t) = \frac{C_t(t) - C_{MF}(t)}{C_{PF}(t) - C_{MF}(t)}$$

$C_t(t)$ = Drainage water isotope signature [δ]

$C_{MF}(t)$ = soil matrix water isotope signature [δ]

$C_{PF}(t)$ = preferential flowpath isotope signature [δ] (≈ rain δ)

$f_{PF}(t)$ = fraction of preferential flow



Preliminary Results

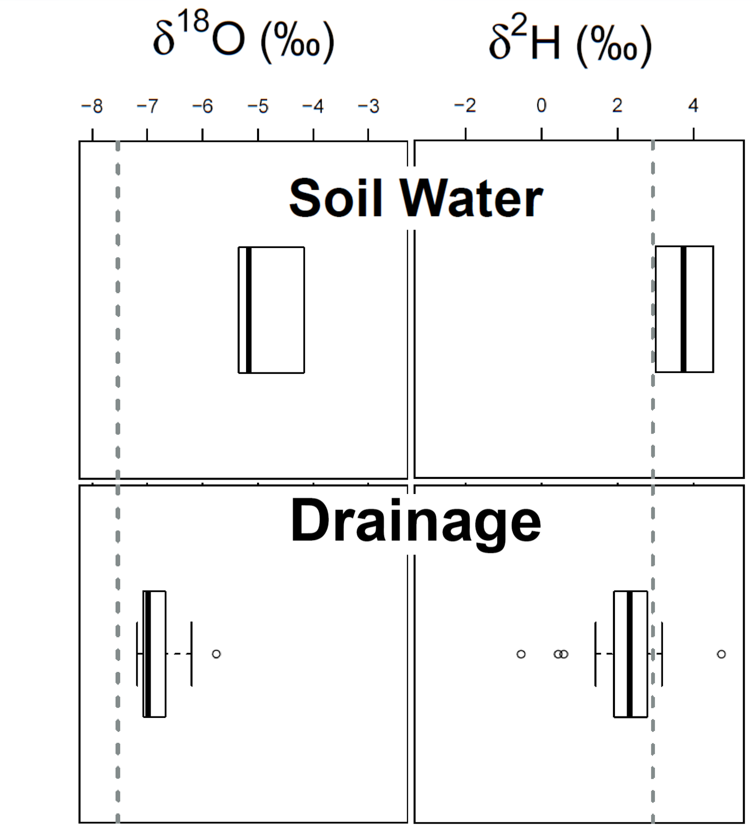
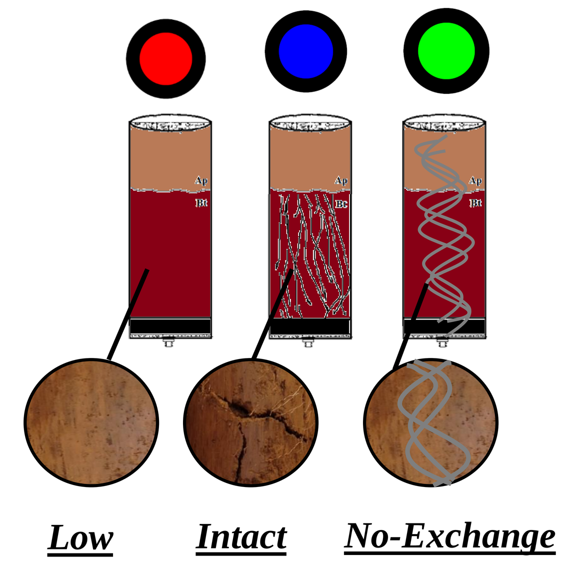
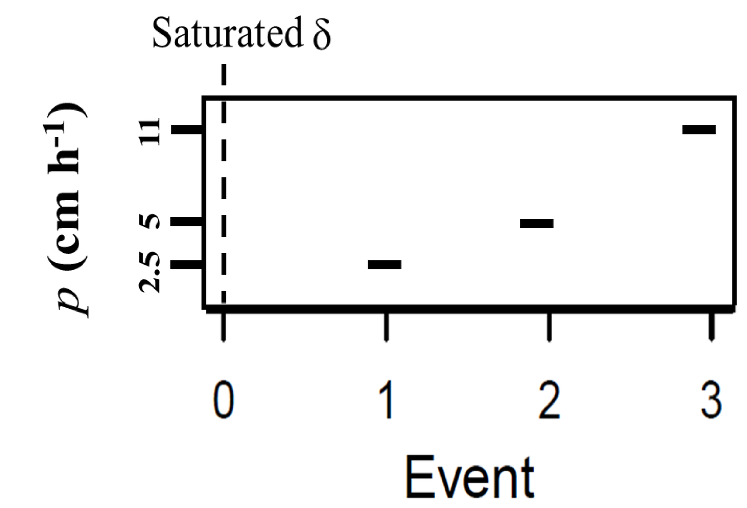


Figure 1. left) Isotopic signatures in soil (at field capacity) and drainage water (aggregated over 72 h of leaching) sampled from all columns following saturation. The gray dashed line indicates the labeled saturation signature.



Experimental Context:

Left) symbol color coordination of structure treatments and **right**) rainfall intensity corresponding to rain events



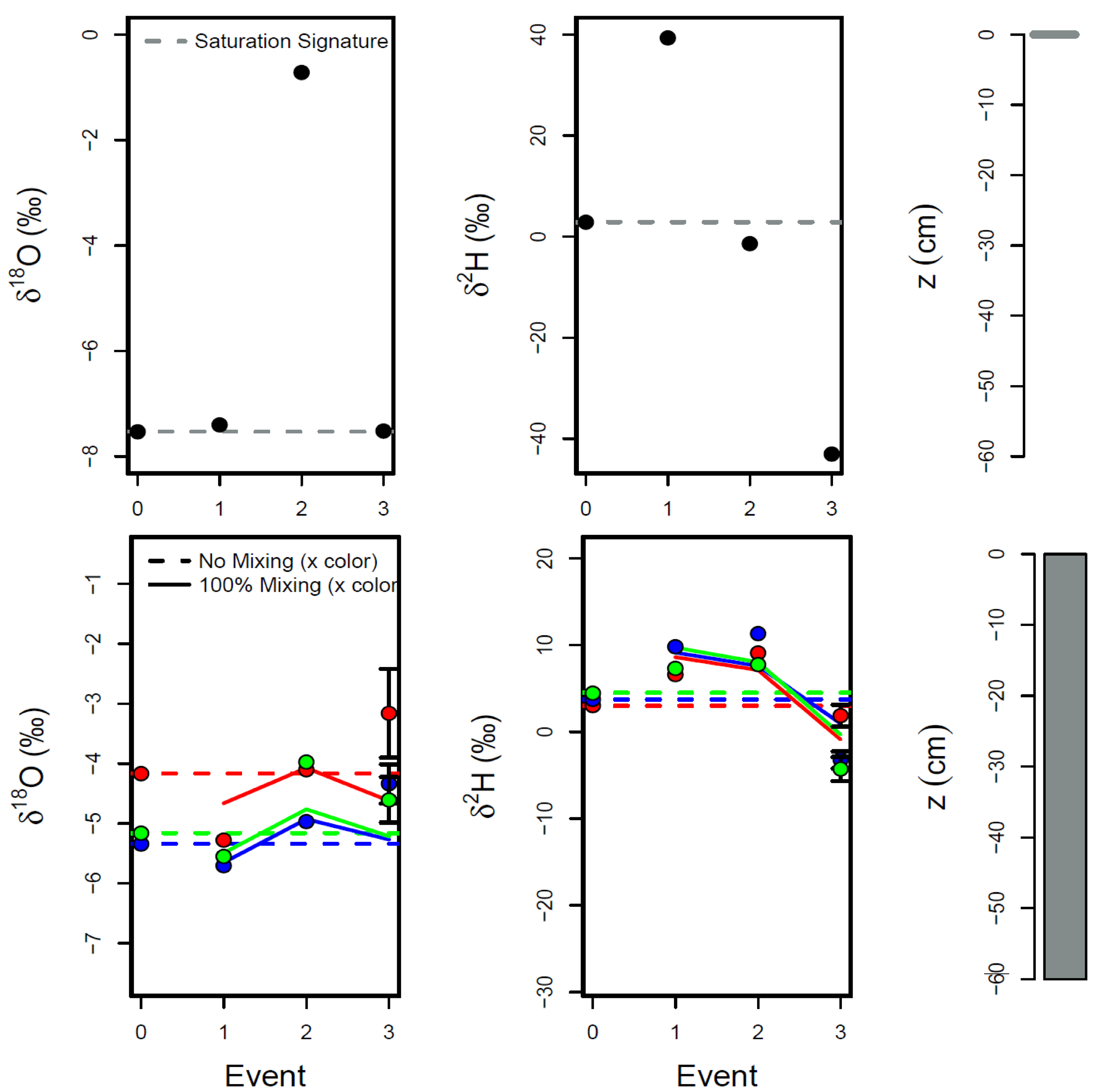


Figure 2. middle left) Rainfall input isotopic signatures, and **bottom left)** soil matrix water signatures with saturation values (gray dashed lines), and with 0 and 100% mixing scenrios expressed as dashed lines with colors corresponding to treatments.

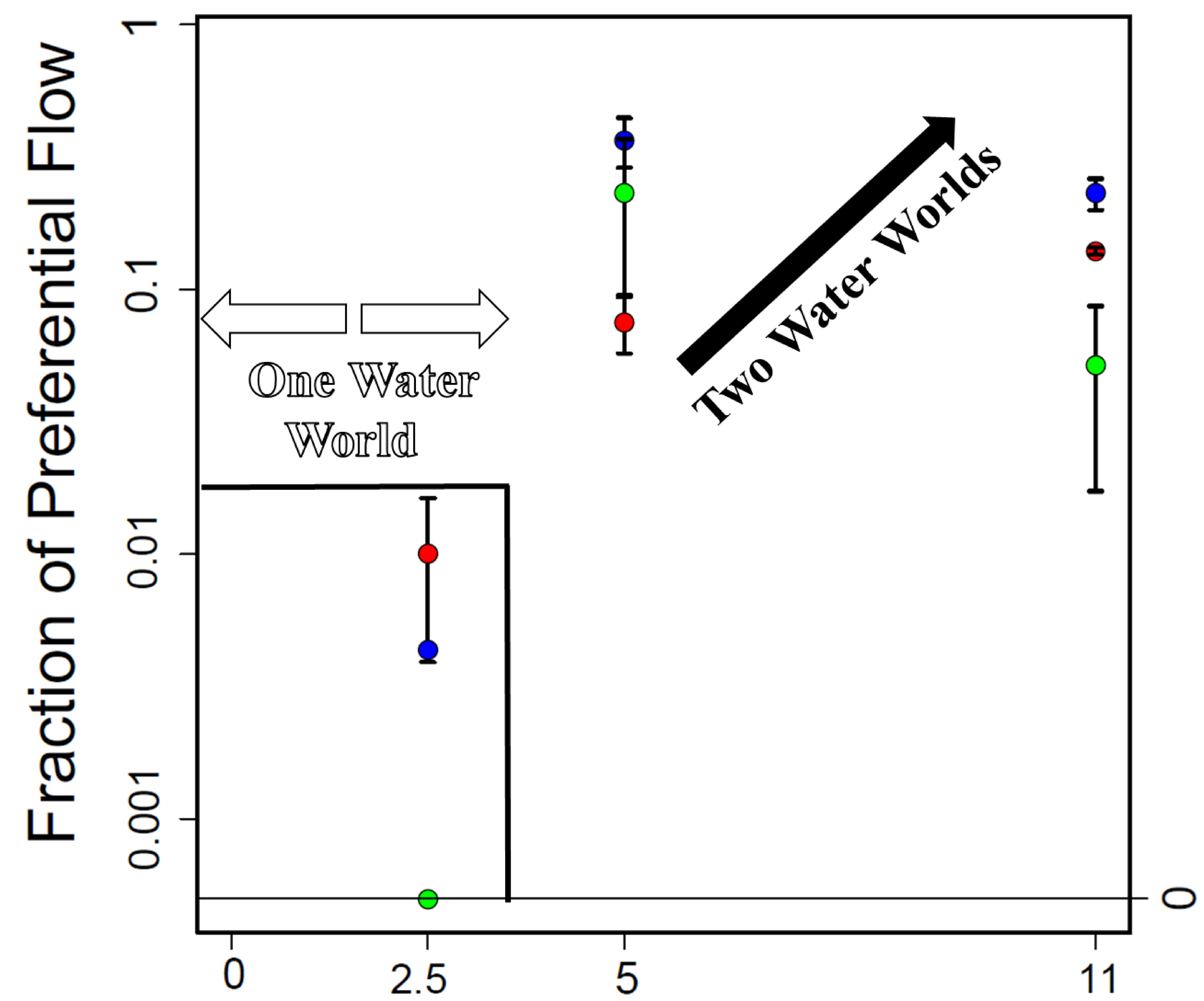


Figure 3. Average preferential flow estimates across the three simulated rain events. The separation of single domain (***low*** structure) with dual domain systems (***intact*** and ***no-exchange*** treatments) denotes a two water world scenario; however non-conservative behavior of oxygen isotopes limited our resolution under moderate rainfall intensities

Discussion

- We observed up to ~ 3 δ devation of soil matrix water ^{18}O signature from saturation values suggesting that soils may strongly fractionate ^{18}O relative to ^{2}H (**Figure 1**).
- Soils with varying degrees of structure showed up 100% mixing of rain water with soil matrix water under low to moderate rainfall intensities (~2.5 – 5 cm h^{-1}) yet high intensity (~11 cm cm h^{-1}) produced clear separation between columns with ***intact*** or artificial soil structure (***no-exchang***e) and those controlled for structure (***low*** structure treatment; **Figure 2** and **Figure 3**).

Acknowledgements

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References

Stumpp, C., P. Maloszewski, W. Stichler, and S. Maciejewski (2007), Quantification of the heterogeneity of the unsaturated zone based on environmental deuterium observed in lysimeter experiments, *Hydrological Sciences Journal*, *52*(4), 748-762.

Conclusions

- We present experimental evidence showing the degree of preferential flow required to produce hydrological domain separation (mobile vs. immobile flow) using stable isotopes of water. Contrary to the two water worlds hypothesis, mixing between preferential flow paths and soil matrix water appears to prevail under low-moderate rainfall intensity. Rather, limiting exchange between macropores (***no-exchange*** treatment, **Figure 3**) reduced preferential flow under intense rainfall. Additionally, non-conservative behavior of ^{18}O raises concerns that widespred observations of ecohydrological behavior (using dual isotope approaches) may have disprortionatley relied on soil water data that was fractionated by soils.