Evapotranspiration partitioning based on d-excess and its in situ application in tallgrass prairie

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Abstract

The use of stable isotopic tracer methods is becoming a popular approach for in situ evapotranspiration (ET) partitioning studies at the ecosystem scale. Ecosystem evapotranspiration is usually partitioned based on different isotopic composition among the aggregated ET flux (δET) and its two components: physical evaporation process (δE) and biological transpiration process (δT). Uncertainties in calculating these three isotopic compositions, especially δET, are usually not negligible and could propagated to large uncertainty in the ET partitioning outcomes. In this study, we present a new ET partitioning approach utilizing dual isotope-based evapotranspiration partitioning based on d-excess (d-excess = δ2H - 8 × δ18O) . A field deployable laser absorption spectrometer was used for in situ measurements of isotopic composition (δ2H and δ18O) of atmospheric water vapor at different heights within the turbulently mixing ecosystem boundary layer for tallgrass prairie. This study incorporated a new refinement to the Craig-Gordon model to describe δE. During non-growing season, estimates of δET—based on Keeling plot and flux-gradient approaches—were compared against δE values derived by the Craig-Gordon model, under the assumption of no transpiration and thus the equality between δET and δE. During the growing season, coupled with isotopic sampling in plant and soils, we partitioned ET into transpiration and evaporation. This refined dual isotope-based approach of ET partitioning shows promise in reducing the uncertainties of the fractional contributions of evaporation and transpiration, thus enhance our understanding on the mechanisms underlying plant water use efficiency and the role of vegetation ecophysiological processes in eco-hydrologic processes under the changing environment.

Partitioning of Evapotranspiration Based on Deuterium Excess

— A case study in tallgrass prairie

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Introduction

Stable water isotopes (^2H and ^{18}O) are important environmental tracers for revealing mechanisms of ecohydrologic processes, atmospheric water cycle, and climate system. Evapotranspiration (ET) is a significant water-loss flux in many terrestrial ecosystems. Isotopic compositions of water (δ^2H or $\delta^{18}O$) have been widely used for many *in situ* ET partitioning studies. Rather than using a single water isotope, either ^2H or ^{18}O, we used a secondary parameter approach based on dual stable isotopes (deuterium excess or $d = \delta^2H - 8\,\delta^{18}O$) to partition ET flux into soil evaporation (E) and plant transpiration T) over a paired treated-control sites configuration in tallgrass prairie.

Main Objectives

1. Develop an isotopic ET partitioning approach based on d-excess
2. Incorporate soil water potential (ψ) or water activity into Craig-Gordon model (Eq. 7) for δ_E
3. Examine isotopic dynamics of atmospheric water vapor at high-temporal resolution
4. Comparison of ET partitioning Results among different approaches

Materials and Methods

This study was carried out over two neighboring grassland sites with different vegetation treatment in tallgrass prairie in Oklahoma, USA (Fig. 1). With similar edaphic and meteorological conditions, one site was treated with herbicide application and vegetation removal (Site T), while vegetation was undisturbed and kept as a control in another site (Site C). Sampling of atmospheric water vapor (Fig. 2) and waters in plant and soil was rotated between two sites between Jun.6–12,2016.

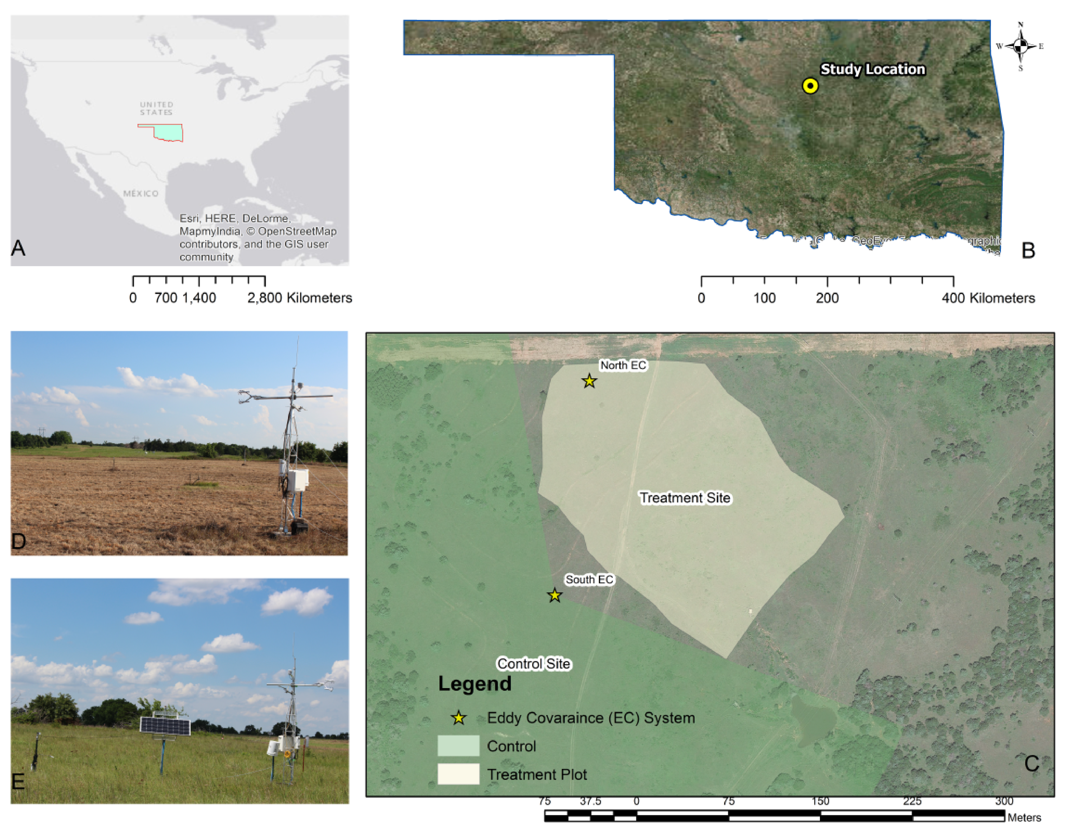

Figure 1: Study location and sites configurations

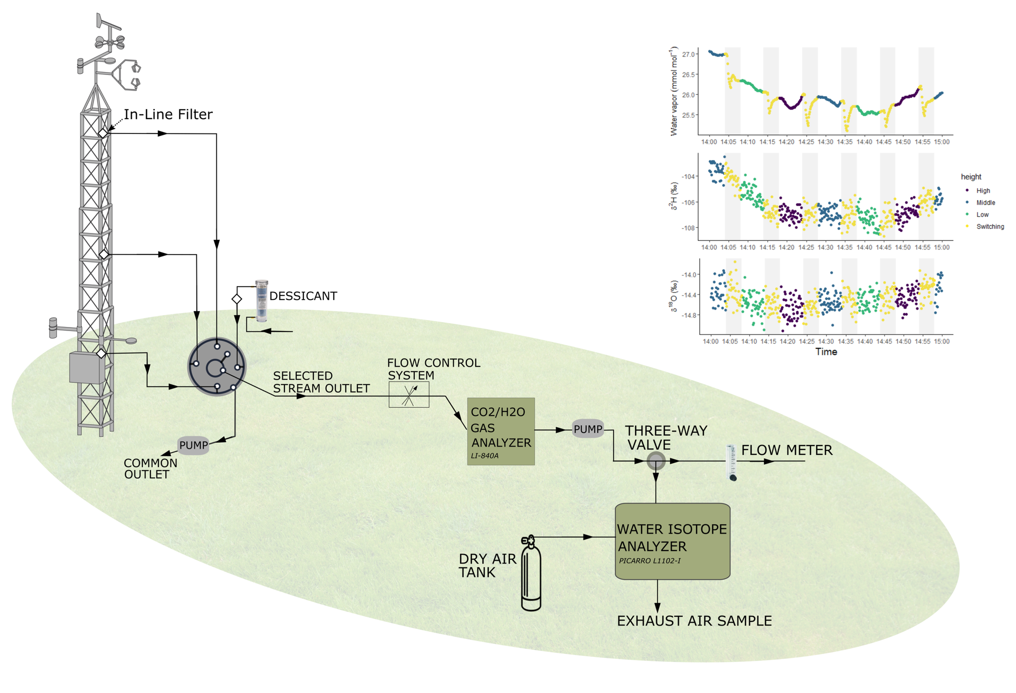

Figure 2: Sampling atmospheric water vapor with laser spectroscopy

Mathematical Section

Mass balance for vapor flux and water isotopes

$$ET = E + T \quad (1)$$

$$\delta_{ET_{2H}} ET = \delta_{E_{2H}} E + \delta_{T_{2H}} T \quad (2)$$

$$\delta_{ET_{18O}} ET = \delta_{E_{18O}} E + \delta_{T_{18O}} T \quad (3)$$

Eq. 2 $-8\times$ Eq. 3 gives

$$\left(\delta_{ET_{2H}} - 8\,\delta_{ET_{18O}}\right) ET = \left(\delta_{E_{2H}} - 8\,\delta_{E_{18O}}\right) E - \left(\delta_{T_{2H}} - 8\,\delta_{T_{18O}}\right) T$$

which can be integrated with Eq. 1 to generate:

$$f_T = \frac{T}{ET} = \frac{d_{ET} - d_E}{d_T - d_E} \quad (4)$$

Keeling-plot approach for δ_{ET}

$$\delta_v = \chi_{bg}(\delta_{bg} - \delta_{ET})(\frac{1}{\chi_v}) + \delta_{ET} \quad (5)$$

Craig-Gordon Model for δ_E

$$\delta_E = \frac{\frac{\delta_{Sc}}{\alpha_{eq}} - h\delta_a - \varepsilon_k - \frac{\varepsilon_{eq}}{\alpha_{eq}}}{1 - h + \varepsilon_k} \quad (6)$$

where h in Eq. 6 is normalized by water activity (α_w) at the evaporating front, which is calculated based on soil water potential (ψ) and saturation pressure of water vapor (e_s) by: [1, 2, 3]

$$h = \frac{h_{air} e_{s_{air}}}{\alpha_w e_{s_{soil}}} \quad (7)$$

Isotopic steady state assumption for δ_T

At daily scale, we assume isotopic composition of plant xylem water (δ_X, in root) reflects the isotopic value of plant-available soil water and δ_T, thus:

$$\delta_T = \delta_X \quad (8)$$

Results

Our results showed depletion in the meteoric part of water cycle and enrichment in evaporative systems, especially in grass leaves (Fig. 3).

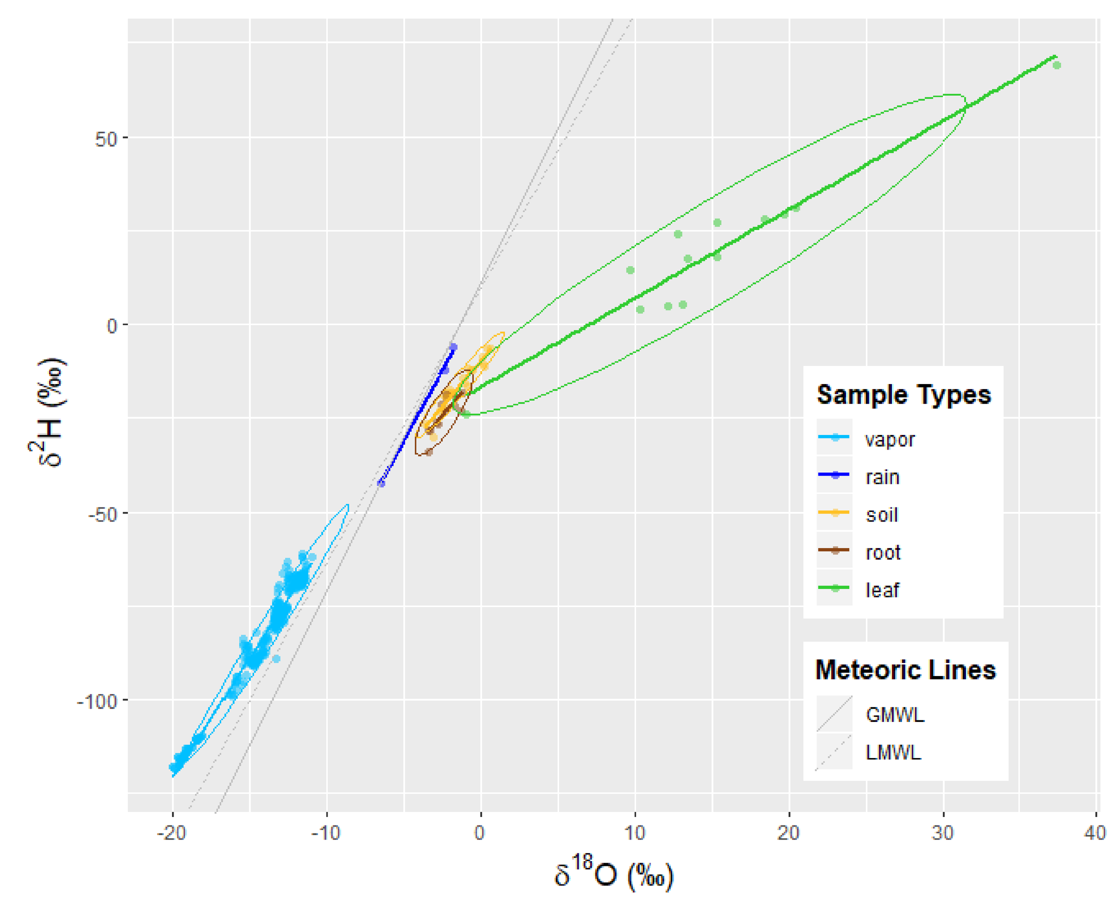

Figure 3: Dual-isotope plot of the meteoric water line and sampled waters from various ecohydrologic pools (phases and states)

The diurnal pattern of isotopic composition of atmospheric water vapor showed strong difference between treated and control sites. During midday, plant physiological activities exert strong influence on the isotopic dynamics of water vapor in the near-ground atmosphere.

Figure 4: Diurnal dynamics of isotopic compositions of atmospheric water vapor

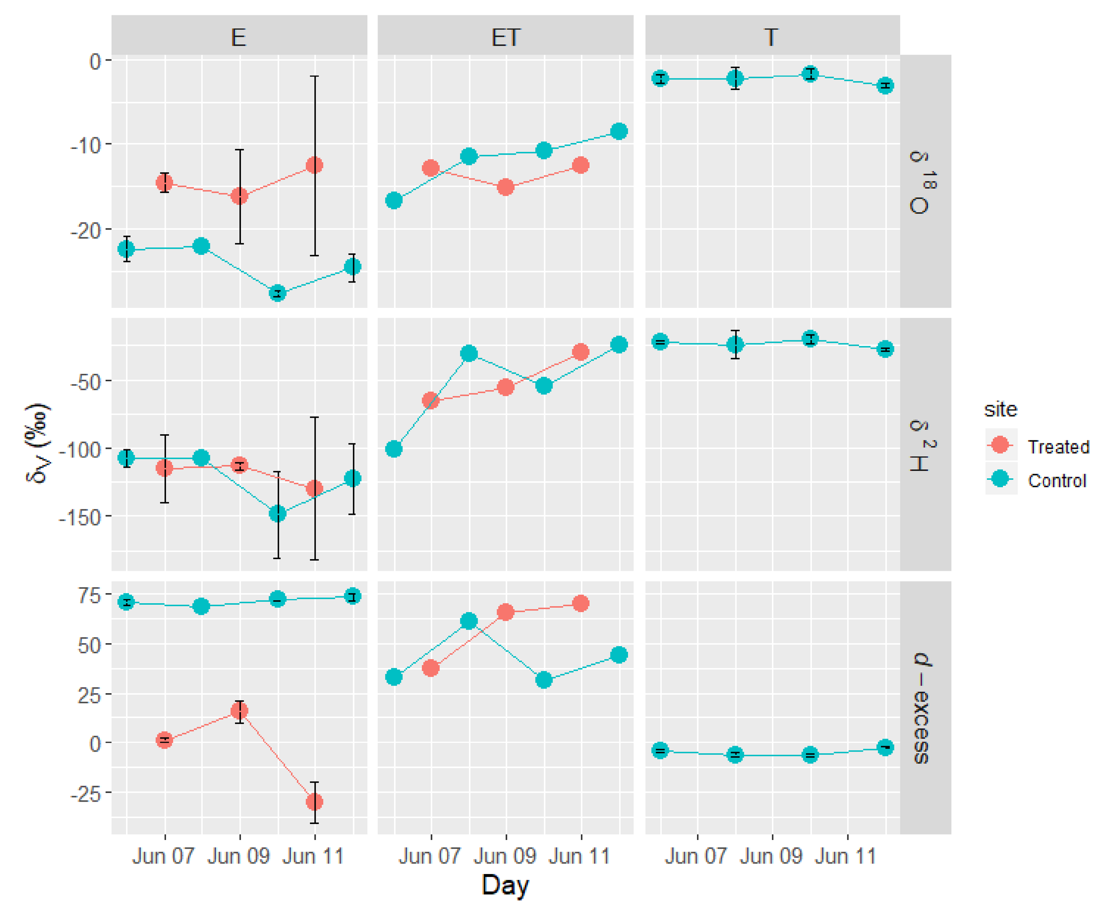

Figure 5: Comparison of δ_{2H}, δ_{18O}, and d-excess among two contrasting sites

- In treated site, δ_E and δ_{ET} are similar for ^2H and ^{18}O, but not for d-excess.
- In control site, δ_{ET} are distributed between δ_E and δ_T, but the order was stitched for d-excess.
- δ_E has high variance within a day.

With the daily averaged isotopic values of E, T, and ET, we calculated the T/ET according to Eq. 4, and the results are shown in Table 1.Results from different isotopic approaches show variations in the ET partitioning results. The ET partitioning results have high variance among different days.

Date	δ_{2H}	δ_{18O}	d-excess
2016-06-06	0.0743	0.278	0.510
2016-06-08	0.914	0.533	0.104
2016-06-10	0.730	0.650	0.519
2016-06-12	1.02	0.743	0.388
Mean	**0.680**	**0.551**	**0.380**

Table 1: Daily ET partitioning (T/ET) in control site

References

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