Non-destructive estimation of soil evaporative losses using oxygen and hydrogen stable isotopes techniques in mulched soil-columns

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Abstract

To understand the soil evaporation variability affected by different mulching, isotope-based non-destructive estimation quantifies the soil evaporation and vapor exchange processes. We investigated a soil-column experiment in Kyoto University, Japan to examine the soil evaporative losses considering isotopic fluctuation (enrichment) processes using stable water isotope techniques under two plastic (black and white) mulching and bare soil treatments. Mulched soil had lower $\delta^{18}O$ and $\delta^{2}H$ values at 0-60 cm depths than bare soil, indicating that mulching reduces soil surface evaporation. Evaporation ratio (evaporation to irrigation) was lower for mulching (19%) and higher for bare soil (61.5%). The isotopic estimation of evaporative loss fraction quantified the relative differences between the plastic mulch and bare soil. The stable isotope techniques could be an effective tool for estimating soil evaporation losses under different mulching methods.

Keywords: Isotope fractionation, Plastic film, Soil water balance

1. Introduction

Mulching is the practice of covering the surface of soil with a layer of material which to help conserve moisture in the soil by reducing soil evaporation losses (Kader et al., 2017). However, the physical processes controlling the moisture exchange between topsoil and mulching such as the vapor exchange and its quantification remain uncertain. Isotope-based non-destructive estimation of soil evaporation robust effectively which reduces soil water evaporation and provides a theoretical basis for water management and optimization of water-saving methods in agriculture (Rothfuss et al., 2015).

In this study, we conducted a soil column experiment including continuous monitoring of soil hydrologic and isotopic parameters and examined the soil evaporative loss based on modified Craig-Gordon model using stable water isotope techniques under two (black and white) mulching and bare soil treatments. The specific objective is to clarify whether evaporation can be estimated from stable isotope ratios of oxygen and hydrogen.

2. Materials and methods

The study was conducted in a greenhouse experimental station during 15 June to 25 August 2023 at the Kyoto University, Japan using PVC columns (20-cm diameter, 60 cm height). The experiment was designed with three treatments of biodegradable black color plastic mulch (BPM), white color plastic mulch (WPM) and no-mulch (NM, control). Schematic diagram of the column experimental setup is shown in Figure 1. Daily soil water evaporation rates were determined by measuring weight losses for each soil column using an electronic scale machine. The bottom of the column was hole with an 18 mm diameter and inserted a PVC pipe to collect seepage water. The soil was loam type with sand, silt and clay were 47%, 35% and 18%, respectively.

Weather data measured by automatic weather station. Soil moisture was measured from 5, 20 and 35 cm soil depths using the sensors and data are recorded in every 10-minutes interval. Moreover, access tubes were installed at 5, 20 and 35 cm depths to collect liquid soil water from each depth by providing suction manually.

Liquid soil water samples were collected weekly 1 day after irrigation events. Soil water samples and ambient air vapors were analyzed for water stable isotopes ($\delta^{18}O$ and $\delta^{2}H$) by Water Isotope Analyzer (PICARRO, L2130i, USA).

The formula of soil evaporative loss rate (*f*; %) is as follows (Skrzypek et al., 2015).

$$f = 1 - \left[\frac{(\delta_s - \delta^*)}{(\delta_p - \delta^*)}\right]^{\frac{1}{m}} \qquad (1)$$

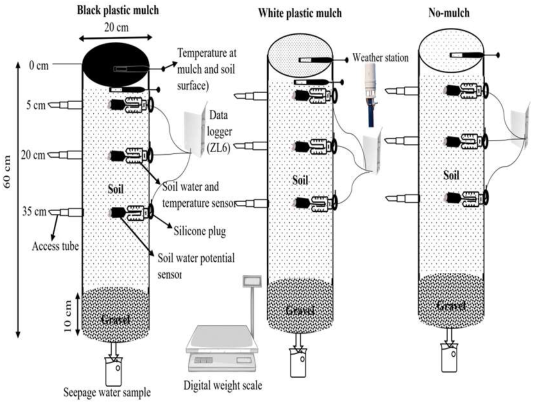

Figure 1. Detail experimental design of soil column and sensor setup.

where δ_s and δ_p are the isotopic composition for the soil water of each soil layer, and the irrigation water, respectively. δ^* is the limiting isotope enrichment factor and m is the enrichment slope.

3. Results and discussions

Soil evaporation

Figure 2 shows the cumulative soil evaporation from each treatment during the study period. Mulching treatments reduced the soil evaporation than no-mulch treatment which ranked was no-mulch (195.7 mm) > white mulch (61.0 mm) > black mulch (60.0 mm). This study confirmed that actual evaporation ratio (evaporation to irrigation) was lower for plastic mulching (BPM:18.9%, WPM:19.2%) and higher for bare soil (61.5%).

Isotopic composition of soil water

Figure 3 presents the mean value of δ^{18}O and δ^2H within the 0-60 cm soil profile for plastic-mulched and non-mulched soil during the study periods. The δ^{18}O and δ^2H values at 60 cm depth represent seepage water. The δ^{18}O and δ^2H of soil water is mainly influenced by two independent processes, which are evaporation and irrigation.

The isotope compositions of mulched soil profiles are lower than those no-mulch profile, due to evaporative enrichment of stable isotopes is inhibited by mulching treatments.

Fractionation of soil evaporative loss

Figure 4 presents the soil evaporative loss fraction (*f*) estimated by δ^{18}O and δ^2H for each depth. For *f* value of δ^{18}O) in the 20, 35 and 60 cm depths, NM exhibited the higher *f* compared to BPM and WPM, which signifies substantial evaporation. The higher value of *f* at deeper soil layer may be due to the evaporation-affected water in the upper layers infiltrating downward. The average value of *f* of δ^{18}O for all depths (including seepage water) was 12.2%, 15.9% and 20.3% for BPM, WPM, and NM, respectively. These values are small compared to the actual values of the ratio of evaporation to irrigation water (BPM: 18.9%, WPM: 19.2%, NM: 61.5%), but they do reflect the relative differences between mulch and bare soil. The differences between measured evaporation ratio and isotopic (δ^{18}O and δ^2H) values in soil water require further investigation.

4. Conclusions

We investigated whether the differences in evaporation between mulch and bare soil columns could be explained by the stable isotope of δ^{18}O and δ^2H. The results did not provide a precise estimate of the ratio of actual evaporation to irrigation water, but the relative differences were explained. The accuracy of the result could be improved by coupling the water flow simulation with the isotopic variations.

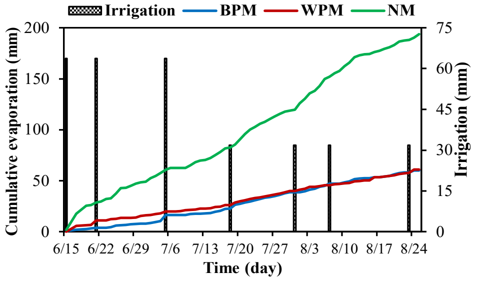

Figure 2. Cumulative water loss from each treatment during the study period.

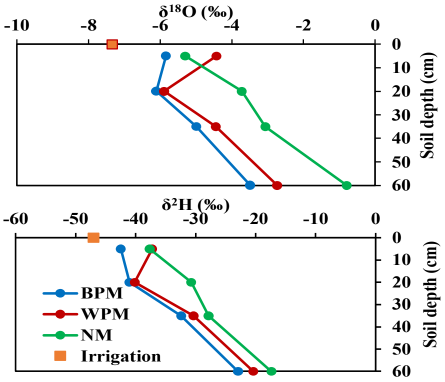

Figure 3. Average profiles of isotope composition of δ^{18}O and δ^2H of different soil column treatments.

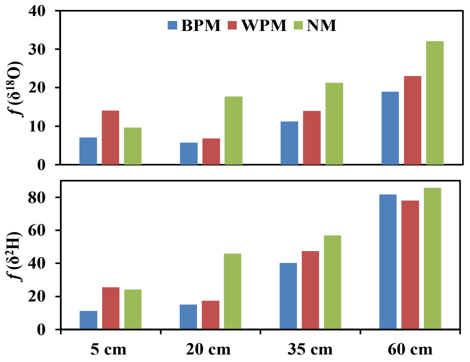

Figure 4. Average soil evaporative loss fraction (*f*) of δ^{18}O and δ^2H at 5, 20, 35 and 60 cm depths.

References

Kader, M.A., Senge, M., Mojid, M.A., & Ito, K. (2017). Recent advances in mulching materials and methods for modifying soil environment. *Soil and Tillage Research*, *168*, 155–166.

Rothfuss, Y., Merz, S., Vanderborght, J., Hermes, N., Weuthen, A., Pohlmeier, A., … Brüggemann, N. (2015). Long-term and high-frequency non-destructive monitoring of water stable isotope profiles in an evaporating soil column. *Hydrology and Earth System Sciences*, *19*(10), 4067–4080.

Skrzypek, G., Mydłowski, A., Dogramaci, S., Hedley, P., Gibson, J. J., & Grierson, P. F. (2015). Estimation of evaporative loss based on the stable isotope composition of water using Hydrocalculator. *Journal of Hydrology*, *523*, 781–789.