Variability of δ²H and δ¹⁸O in Soil Water and Its Linkage to Precipitation in An East Asian Monsoon Subtropical Forest Plantation

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1. Introduction

a) The linkage between δ^2H and δ^{18}O in soil water and precipitation is useful for the understanding of **precipitation infiltration**, **residence time**, and **soil water source**.

b) The **replenishment of soil water** occurs only via precipitation that **exceeds the critical threshold**—the amount that is lost to canopy interception or litter retention.

c) Knowledge of the **residence time of precipitation** in the soil profile helps to better understand hydrological processes and timescales of transport, and to improve hydrological models.

d) Soil water may be recharged by precipitation from the past rather than recent seasons due to the interactions between the mixtures of two soil water pools and variations in flow pathways, and the understanding of the **seasonal origins of soil water** remains limited.

e) The objectives of our study were: (1) to investigate **how much** precipitation could pass through the canopy and litter, and infiltrate into the soil; (2) to determine **seasonal variability in the residence times of precipitation** at different soil depths; (3) to compare the regression-based and Craig and Gordon model-based approaches for **estimating Soil Water Evaporation Lines (SEL)**, and analyze the **seasonal origins of soil water**.

2. Materials and Methods

a) Sample Collection and Measurements

This study was conducted at **Qianyanzhou Ecological Experimental Station** of the Chinese Ecosystem Research Network, a member of ChinaFLUX, located in southern China.

Soil at 0–5, 15–20, and 40–45 cm depths were collected 2–3 times per week from 2012 to 2015, and 2 times per month from 2015 to 2017. Event-based precipitation from 2011 to 2017were collected in a subtropical forest plantation.

δ^2H and δ^{18}O of soil water extracted from soil samples with a cryogenic vacuum distillation sys-tem, and precipitation, were analyzed using an Isotopic Ratio Infrared Spectroscopy system.

b) Data Analysis

- **Critical Thresholds for Precipitation Recharge of Soil Water**: Correlations between the δ^{18}O of soil water and precipitation on the same day.
- **Determining Residence Times of Precipitation in Soil**: Correlations between the δ^{18}O of soil water and cumulative precipitation for periods of 0, 2, 7, 15, 30, 45, 60, 75, 90, 105, 120, 135, and 150 days before sampling during winter, spring, summer, and autumn.
- **Calculations of δ^2H and δ^{18}O in Soil Water Source**:

✓ **Soil Water Evaporation Lines (SEL)**:

(1) Regression-based approaches: $\delta^2H = a_{SEL} \times \delta^{18}O + b_{SEL}$

(2) Craig and Gordon model-based approaches:

h is relative humidity; δ_P is δ^2H and δ^{18}O in precipitation; δ_A is δ^2H and δ^{18}O in ambient atmospheric vapor; α^+ is the liquid-vapor equilibrium fractionation factor, $\varepsilon^+(‰) = (\alpha^+ - 1) \times 10^3$; ε_K is the kinetic fractionation factor.

$$S_{SEL} = \frac{\left[\dfrac{h(\delta_A - \delta_P) + (1+\delta_P)(\varepsilon_K + \varepsilon^+/\alpha^+)}{h - \varepsilon_K - \varepsilon^+/\alpha^+}\right]_2}{\left[\dfrac{h(\delta_A - \delta_P) + (1+\delta_P)(\varepsilon_K + \varepsilon^+/\alpha^+)}{h - \varepsilon_K - \varepsilon^+/\alpha^+}\right]_{18}}$$

✓ **δ^2H and δ^{18}O in Soil Water Source**:

$$\delta^{18}O_{intersect} = \frac{b_{SEL} - b}{a - a_{SEL}} \qquad \delta^2H_{intersect} = a\delta^{18}O_{intersect} + b$$

a_{SEL} and b_{SEL} represent the slope and intercept of SEL, and a and b represent the slope and intercept of Local Meteoric Water Lines.

3. Results and Discussion

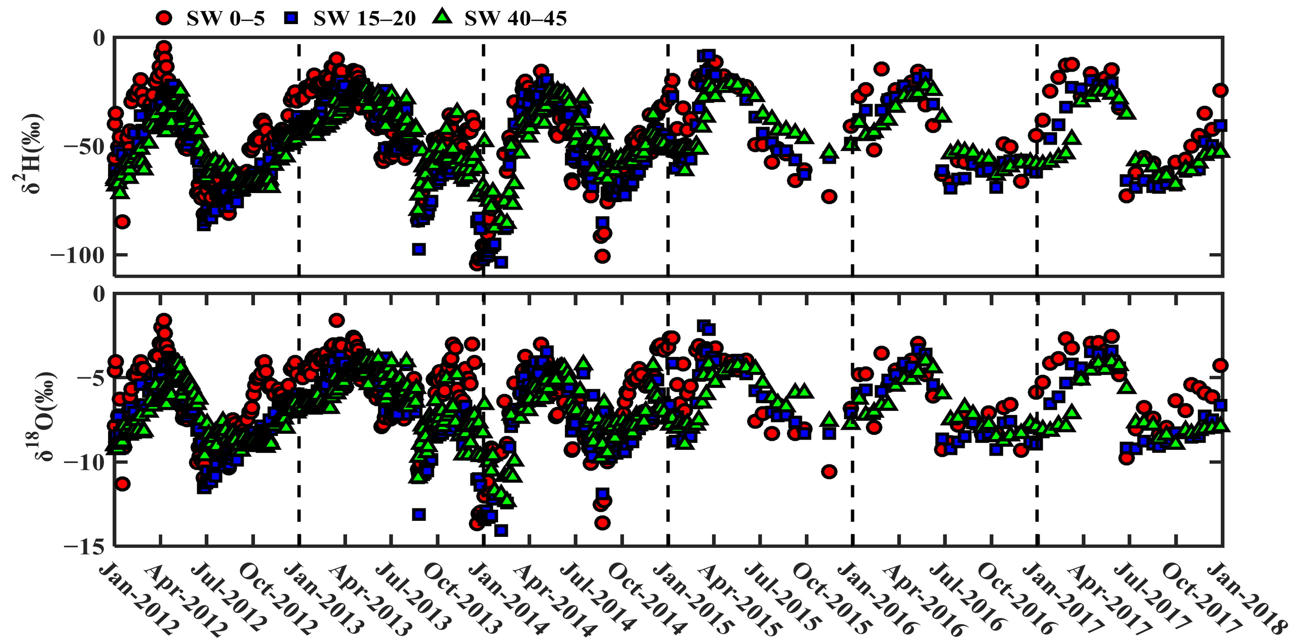


Figure 1. Temporal variability of δ^2H and δ^{18}O in soil water at depths of 0–5 (SW 0–5), 15–20 (SW 15–20), and 40–45 (SW 40–45) cm.

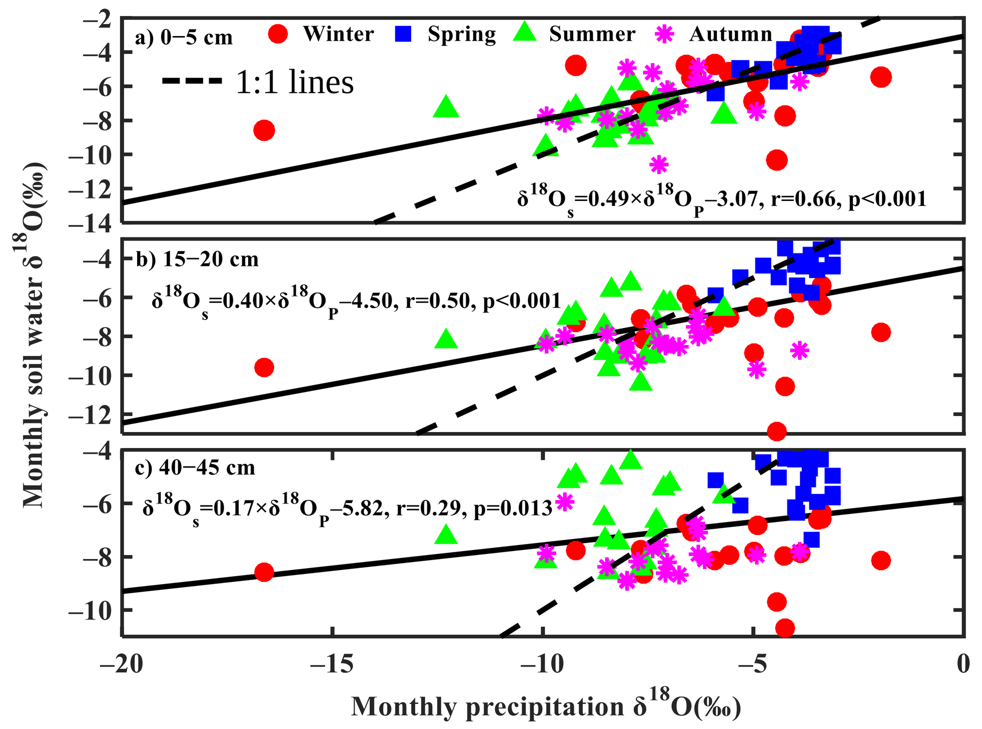


Figure 2. Relationships between monthly precipitation (weighted means by amount of precipitation, $\delta^{18}O_P$) and soil water (weighted means by soil water content, $\delta^{18}O_S$) for δ^{18}O at depths of (a) 0–5, (b) 15–20, and (c) 40–45 cm.

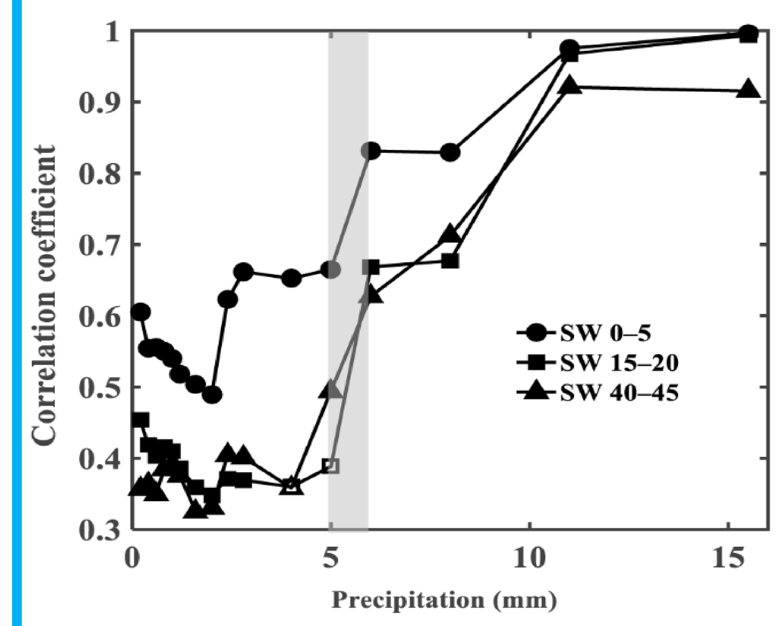
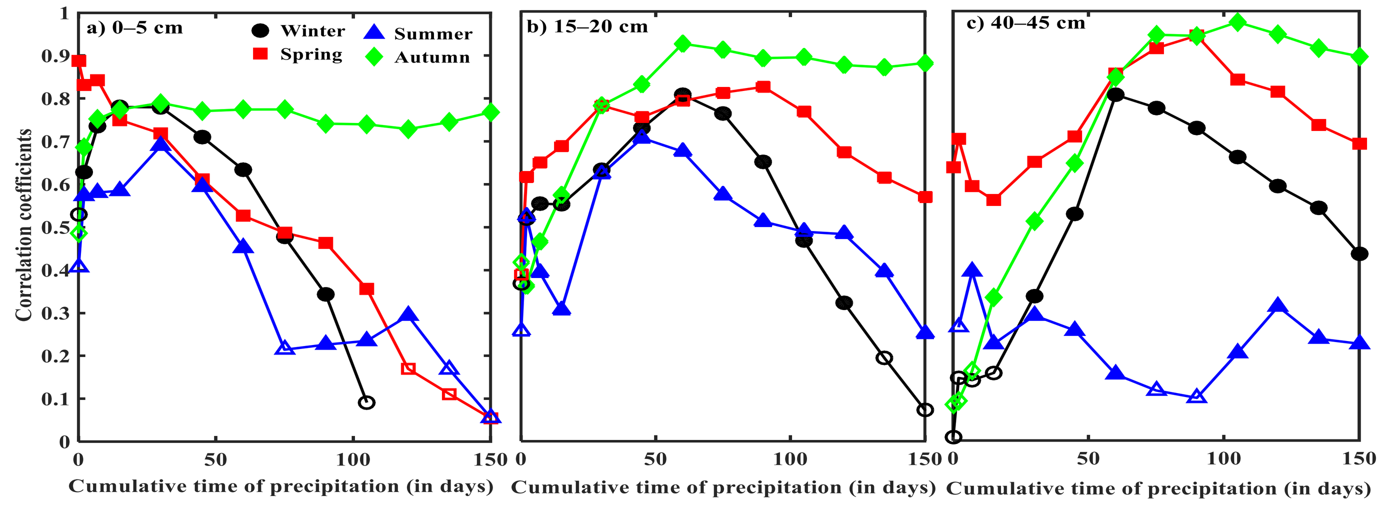


Figure 3. Correlation coefficients between δ^{18}O in soil water at depths of 0–5, 15–20, and 40–45 cm, and precipitation on the same day for determining the critical thresholds of precipitation for infiltration into the soil profile.



Open symbols indicate non-significant correlation, and solid symbols indicate significant correlation at $p < 0.05$.

Figure 4. Correlation coefficients between δ^{18}O in soil water at depths of (a) 0–5 cm, (b) 15–20 cm, and (c) 40–45 cm, and δ^{18}O in cumulative precipitation (precipitation amount > 5 mm) before sampling during winter, spring, summer, and autumn, for determining residence times. X-axis represents cumulative time of precipitation, and x = 0 represents correlation coefficient between δ^{18}O in soil water and precipitation in the same period.

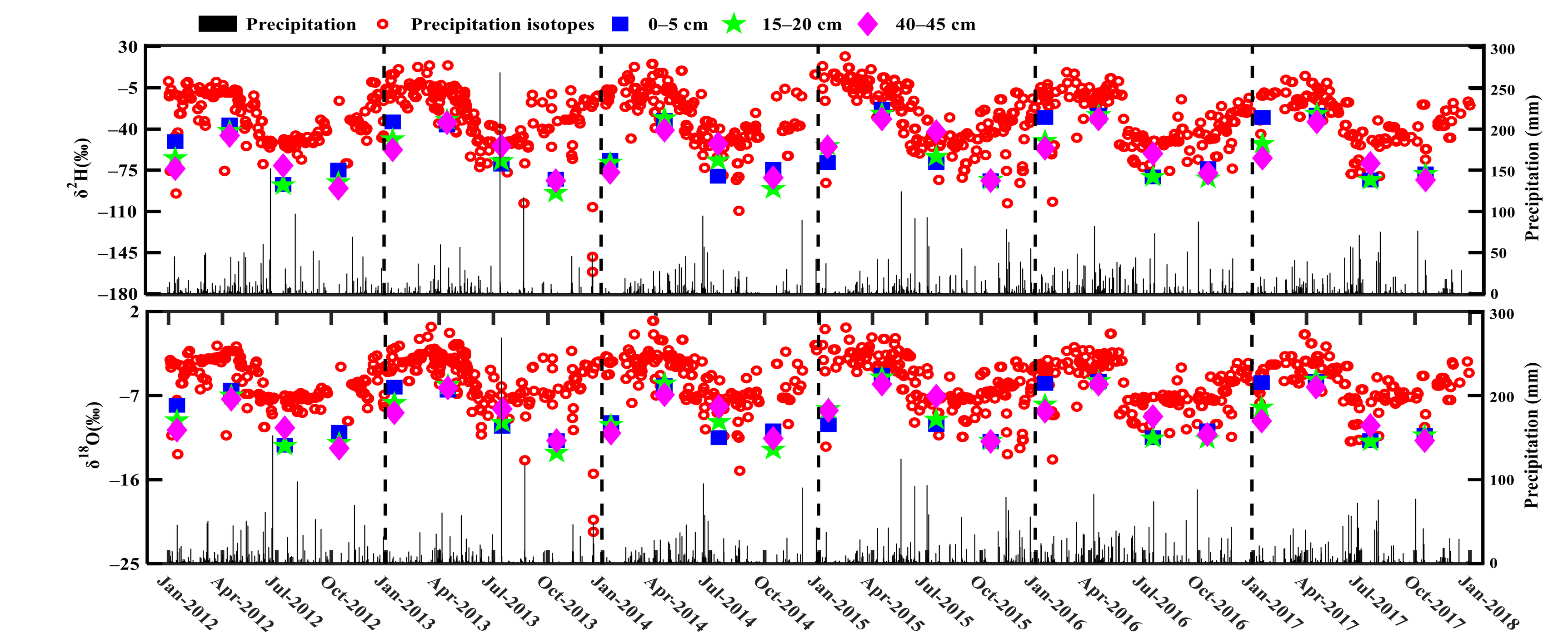


Figure 5. Temporal variability of the amount of precipitation, δ^2H and δ^{18}O in precipitation, and weighted average δ^2H and δ^{18}O in soil water source during winter, spring, summer, and autumn, at 0–5, 15–20, and 40–45 cm depths.

5. Conclusions

a) Precipitation in this area need to be **larger than 5–6 mm** to pass through the canopy and litter layer, and then infiltrate into the soil.

b) Residence times varied from **a few days to several months**, and **increased with soil depth**, due to the connectivity of soil pores for precipitation infiltration, soil evaporation, plant transpiration, and the seasonal pattern of precipitation in the East Asian monsoon region.

c) The model-based approach for SEL estimation were **more robust than** the regression-based approach due to the inverse variability in the δ^2H and δ^{18}O of soil water source and soil evaporative fractionation. SEL calculated with the two approaches differed little **in autumn**.

d) Soil water at a 0–5 cm depth originated mainly from precipitation **in the current season**, while those at 15–20 and 40–45 cm depths originated mainly from precipitation **in the previous season**.

e) Our results highlight that precipitation in the previous season is important for alleviating the decreasing water availability **during the autumn and winter seasons** in the East Asian monsoon region.

References

1. Lyu, S. Variability of δ^2H and δ^{18}O in Soil Water and Its Linkage to Precipitation in An East Asian Monsoon Subtropical Forest Plantation. Water, 2021, 13, 2930.
2. Lyu, S.; Wang, J.; Song, X.; Wen, X. The relationship of δD and δ^{18}O in surface soil water and its implications for soil evap-oration along grass transects of Tibet, Loess, and Inner Mongolia Plateau. J. Hydrol. 2021, 600, 126533.

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