

Article

The Stable Isotopic Composition of Different Water Bodies at the Soil–Plant–Atmosphere Continuum (SPAC) of the Western Loess Plateau, China

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Abstract: Understanding the isotopic composition and interrelations of different water bodies at the soil–plant–atmosphere continuum (SPAC) is crucial to reveal the processes and mechanisms of regional water cycles. Rainfall, river water, plant, and soil samples from Lanzhou City, China, were collected from April to October 2016. The hydrogen ($\delta^2\text{H}$) and oxygen ($\delta^{18}\text{O}$) of the local precipitation, river water, soil water, plant xylem water, and leaf water were determined. We found that trees mainly uptake the middle (30–60 cm) and deep (60–100 cm) layer soil water during the growing season, and the shrubs mainly uptake the middle soil water. All herbs uptake the shallow soil water (0–30 cm) during the growing season. The $\delta^{18}\text{O}$ of shallow soil water was found to be isotopic-enriched because of evaporation and exhibited a decline from the shallow soil layer towards the deeper layer. The variation of $\delta^{18}\text{O}$ and soil water content (SWC) was remarkable in shallow soil, which was mainly due to evaporation and precipitation infiltration, while water in the middle and deep layer was less affected by these phenomena.

Keywords: stable isotopes of hydrogen and oxygen; SPAC; precipitation; Lanzhou City

1. Introduction

The hydrogen and oxygen stable isotopes of water have been widely used as “fingerprints” of different reservoirs in ecological and hydrological field studies [1–3]. Precipitation is a key part of the water cycle, especially in arid and semi-arid regions. The stable isotopic composition of precipitation can be used to deduce the regional water vapor sources, sub-cloud secondary evaporation, and water vapor recycling [4–6]. Furthermore, comparisons with the isotopic composition of different water bodies, like soil water, river water, and plant water, can help us to understand the recharge relationship between them, as well as the precipitation infiltration mechanism at the regional and local scale [7,8].

Soil waters are the link between surface waters and groundwater. Some studies have demonstrated that the mechanism of soil water migration includes piston-type flow and preferential flow in unsaturated soil [8,9], and the contribution rate of soil water at different depths to plants can also be investigated by comparing the isotopic composition of plant xylem water and soil water [10,11]. In the relationship between different water bodies, infiltration and evaporation have a dominating and significant effect on the vertical profiles of the isotopic content of soil water that results from the water mixing of different precipitation events [9,12]. Soil water is recharged by precipitation, and plants uptake water for their growth from different soil depths [10,11]. The plant xylem water and leaf water are also vital components of the water cycle; their isotopic variation can reflect valuable information concerning the interactions between plants and the surrounding environment [13]. Recently, those

aspects, including the evaporation fractionation intensity of soil water, the transpiration rate of plant leaves, and the varying water utilization of plants at different ages in the desert-oasis ecotone have also been explored [12,14,15]. The ability of different plant species to adapt to environmental changes can be evaluated by studying the transpiration rate of plants, and the extent to which plants uptake soil water and precipitation [15].

In summary, regional water cycle processes can be understood by analyzing the isotopic variation at the soil–plant–atmosphere continuum (SPAC). Currently, the study of the isotopic composition of the SPAC focuses mainly on natural regions or on regions that are only slightly disturbed by human activities [9,12,15–18]; but there are few studies on urban ecosystems. Our study area focuses on the Lanzhou City, the capital of Gansu Province in China. We used the results of isotope analysis of precipitation, river water, soil and plant water from samples collected from four sampling sites during the plant growing season of 2016. The isotopic composition and the relationship of different water bodies at the SPAC of Lanzhou City were established. We investigated the isotopic composition and relationship of different water bodies, which is crucial to explore the regional water cycle processes and mechanisms further, and could improve the utilization of water resources in Lanzhou City. The results of our study can be easily extrapolated to other urban ecosystems.

2. Materials and Methods

2.1. Study Area

Lanzhou (1500 m) presents a geomorphic type of the narrow river valley basin in the east and west [19], located in the transitional zone between the Qinghai-Tibet Plateau and the Loess Plateau of China. Within the boundary of this city, the altitude generally declines from west to east, and the Yellow River flows across the whole city (Figure 1). Ocean water vapor does not easily reach this area directly because of its inland location far away from the sea and blocking of water vapor by the Qinghai-Tibet Plateau. Consequently, this area is a snow climate with a dry winter (Dw) according to the Köppen–Geiger climate classification system [20]. The annual average air temperature is 7.4 °C, and the annual average precipitation is 312.9 mm. Precipitation occurs mainly from June to September, accounting for more than 60% of the annual precipitation [21,22]. The zonal soil is mainly composed of chestnut soil and sierozem soil developed on the loess parent material [23]. The vegetation type is dominated by perennial grasses, dry shrubs, and small trees. The proportion of trees and shrubs among the green plant species is larger, with a minority of herb plants [24].

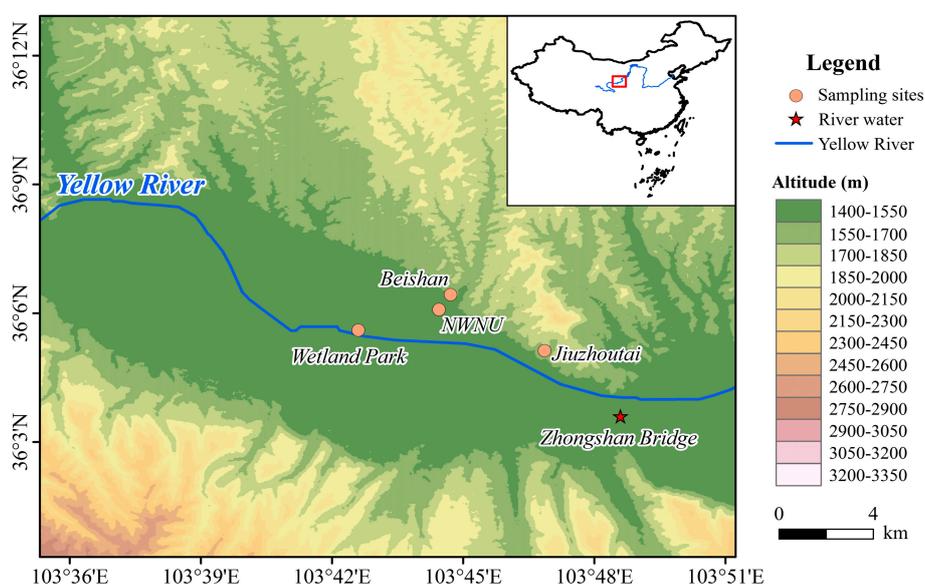


Figure 1. Spatial distribution of the sampling sites of different water bodies in Lanzhou City.

2.2. Sampling Design and Analysis

2.2.1. Water Sampling

Samples in all sampling sites were collected on a monthly basis from April to October 2016, except for precipitation, which was sampled during the same period on an event basis. Three replicate samples of soil and two replicate samples of plant xylem and leaves were collected. The sampling protocols are described here:

- (1) **Plant samples:** We selected four sites of twig xylem and leaf samples of representative trees, such as *Platyclusus orientalis*, *Sophora japonica*, *Salix babylonica*, shrubs *Caragana korshinskii*, *Rose xanthina* and herbs *Agropyron cristatum*, *Shamrock*, *Phragmites australis*. These were sampled from the sites of Beishan, Jiuzhoutai, Wetland park and the Northwest Normal University (hereinafter referred to as the NWNNU) (Table 1). The selected plant samples were in good growth condition, thus, eliminating any external “noise signal”, due to plant growth conditions [15]. In order to avoid leaf transpiration and any residual dew on the leaves that could affect the isotopic composition of the plants, all samples were strictly taken between 08:00 and 11:00 a.m. [25]. A total of 186 plant xylem samples and 270 plant leaf samples were collected.
- (2) **Soil samples:** A 1 m soil profile was excavated, and we collected samples at 10 cm intervals in four sites in order to determine the vertical profile variation of soil water isotopes. The samples were collected from 2 cm below the surface, to avoid the soil samples being influenced by the free atmosphere [25]. The soil samples were divided into two categories: (1) Samples collected into self-contained aluminum boxes and used for measuring the soil water content (SWC); three replicate samples were taken from each layer. (2) Samples collected in 10 mL glass bottles and sealed with parafilm in order to avoid evaporation, which were used to determine the isotopic composition of soil water. Three replicate samples from each layer were also taken. A total of 633 soil samples were collected.
- (3) **Precipitation samples:** Rainwater was collected by placing a standard rain collector in the NWNNU Meteorological Park. In order to avoid evaporation, the sample was collected immediately after the event, placed in an HDPE plastic bottle, and sealed with parafilm. A total of 35 precipitation samples were collected.
- (4) **River water samples:** The Yellow River water was sampled near the Zhongshan Bridge in Lanzhou City; river water samples were collected at a depth of 20 cm below the surface, and stored in HDPE bottles sealed with parafilm. Seven river water samples were collected in total.

Table 1. Details of sampling sites in Lanzhou City.

Sampling Sites	Latitude (°N)	Longitude (°E)	Altitude (m)	Sample Type
Beishan	103.73	36.11	1667	Plant, soil
Jiuzhoutai	103.78	36.09	2054	Plant, soil
Wetland Park	103.72	36.08	1519	Plant, soil
NWNNU	103.73	36.10	1553	Plant, soil, precipitation
Zhongshan Bridge	103.81	36.06	1515	River water

2.2.2. Laboratory Analysis

The experimental work of this study was conducted by the Stable Isotope Laboratory of the Geography and Environmental Science College, Northwest Normal University. The refrigerated soil and plant samples were thawed at room temperature. The analyses were conducted within one week after sampling in order to prevent microbial activity in the glass bottles [12]. Water from the xylem and leaves of the plants and from the soil was extracted using an LI-2100 fully automated cryogenic vacuum extraction system. All water samples were analyzed using a DLT-100 liquid water isotope analyzer developed by Los Gatos Research, USA. We used LWIA-Spectral Contamination Identifier (LWIA-SCI)

software to review spectral contamination for the measured plant water data [25,26]. The measurement precision of the instrument was $\pm 0.6\text{‰}$ for the $\delta^2\text{H}$ and $\pm 0.2\text{‰}$ for the $\delta^{18}\text{O}$, respectively [25–28].

The measured $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values were expressed as per mil unit with respect to the Vienna Standard Mean Ocean Water (VSMOW):

$$\delta = \left(\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right) \times 1000\text{‰}, \quad (1)$$

where R_{sample} is the $^{18}\text{O}/^{16}\text{O}$ or $^2\text{H}/^1\text{H}$ ratio in the sample and R_{standard} is the respective ratio in the VSMOW.

Each sample and standard sample was injected and analyzed six times using a microliter syringe; the first two times were eliminated, due to the memory effect of isotopes, and the mean values of the measurements were calculated by the last four injections. We used the LWIA Post Analysis software, developed by Los Gatos Research (LGR). The isotope standards were provided by Los Gatos Research. According to the isotope ratio range of our samples, three standards were selected from the LGR standards (expressed relative to the V-SMOW), and the precision of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ were 3c: $-97.3 \pm 0.5\text{‰}$ and $-13.39 \pm 0.15\text{‰}$, 4c: $-51.6 \pm 0.5\text{‰}$ and $-7.94 \pm 0.15\text{‰}$ and 5c: $-9.2 \pm 0.5\text{‰}$ and $-2.69 \pm 0.15\text{‰}$, respectively [25,27].

The soil samples used for SWC measurement were shipped to the laboratory, where they were immediately weighed using an electronic balance (precision of 0.0001 g). Then, the sample was dried inside a constant temperature oven at $105 \pm 2\text{ °C}$ for about 12 h and left to cool at room temperature before the weight loss was calculated.

3. Results

3.1. Relationship Between $\delta^2\text{H}$ – $\delta^{18}\text{O}$ of Different Water Bodies

As shown in Figure 2 (panels a and b are the hydrogen and oxygen isotopic composition using the box figures shown, respectively, and panel c is the water line equation of different water bodies, similarly hereinafter), from April to October 2016, the variation of hydrogen and oxygen isotopes in the precipitation in Lanzhou City ranged from -74.26‰ to 34.81‰ and from -12.47‰ to 4.44‰ , with mean values of -22.18‰ and -3.99‰ , respectively (Figure 2a,b). The local meteoric water line (LMWL) is described by the equation $\delta^2\text{H} = (7.08 \pm 0.34) \delta^{18}\text{O} + (5.12 \pm 1.90)$ ($R^2 = 0.93$, $p < 0.0001$, $n = 35$). The slope is smaller than the global meteoric water line (GMWL), indicating relatively low humidity and strong kinetic fractionation, due to evaporation in Lanzhou City [25,27,29]. The variation of hydrogen and oxygen isotopes in the river water ranged from -71.90‰ to -60.31‰ and from -10.51‰ to -9.20‰ , respectively, with very little variation. Their mean values were -66.82‰ and -9.80‰ , respectively. The river water line (RWL) equation is: $\delta^2\text{H} = (7.35 \pm 1.69) \delta^{18}\text{O} + (5.34 \pm 16.61)$ ($R^2 = 0.79$, $p < 0.0074$, $n = 7$). We can see that the river water isotope values are distributed at the lower left of the LMWL (Figure 2c), very close to the LMWL, illustrating that river water in Lanzhou City is recharged by precipitation [8,27]. The soil water hydrogen and oxygen isotope ranged from -94.35‰ to 1.87‰ and from -13.19‰ to 6.79‰ , with mean values of -60.75‰ and -7.24‰ , respectively. Soil water isotopic signatures are mainly scattered in the lower left of the LMWL. The soil water line (SWL) equation is $\delta^2\text{H} = (5.18 \pm 0.08) \delta^{18}\text{O} - (23.16 \pm 0.64)$ ($R^2 = 0.85$, $p < 0.0001$, $n = 633$); the slope and the intercept are smaller compared to the LMWL, indicating that the $\delta^{18}\text{O}$ and $\delta^2\text{H}$ in soil water were mainly influenced by mixing with precipitation and undergoing evaporation [8,16,25]. The hydrogen and oxygen isotopic values of plant xylem water were more enriched compared to soil water, ranging from -88.67‰ to 1.57‰ and from -12.10‰ to 13.80‰ , with mean values of -60.59‰ and -5.87‰ , respectively. The equation of the plant xylem water line (PWL) is $\delta^2\text{H} = (3.78 \pm 0.13) \delta^{18}\text{O} - (38.32 \pm 1.00)$ ($R^2 = 0.80$, $p < 0.0001$, $n = 186$). The slope and intercept are smaller than those of the LMWL and the SWL, indicating that the soil water moisture of plant uptakes in Lanzhou is influenced by evaporation [16]. The hydrogen and oxygen isotopic composition of plant leaf water

were the most enriched (Figure 2a,b); they ranged from -75.28‰ to 60.32‰ and from -9.02‰ to 50.77‰ , respectively. Their mean values were -7.09‰ and 12.18‰ , respectively. The leaf water evaporation line (LEL) [30] is $\delta^2\text{H} = (1.89 \pm 0.07) \delta^{18}\text{O} - (30.19 \pm 1.14)$ ($R^2 = 0.73$, $p < 0.0001$, $n = 270$); the slope and intercept are far smaller than those of the LMWL, indicating that the moisture has undergone strong evaporation during the transition from the plant to the atmosphere [16].

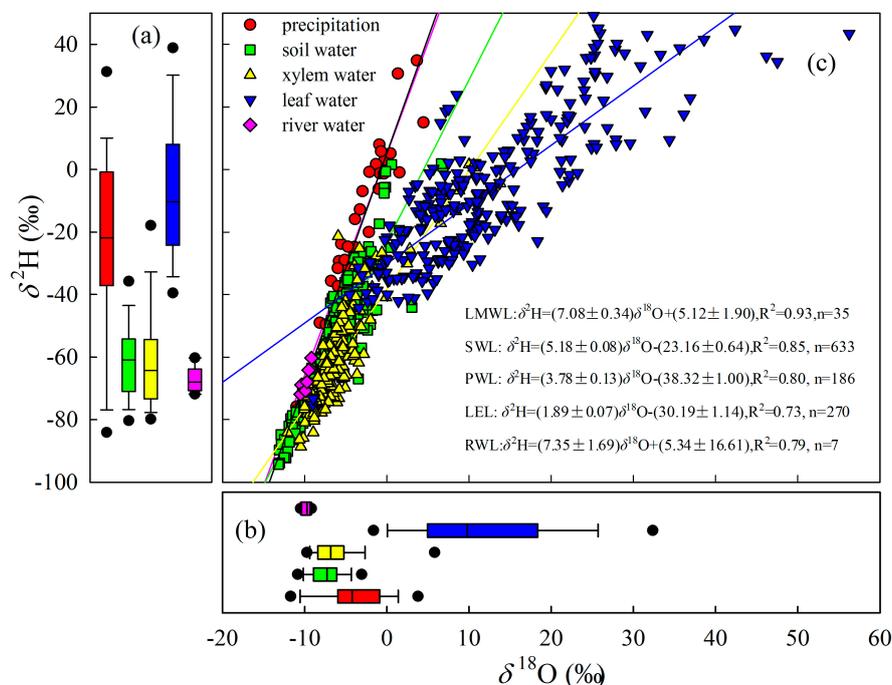


Figure 2. Relationships between $\delta^2\text{H}$ and $\delta^{18}\text{O}$ of precipitation, soil water, xylem water, leaf water and river water. (a,b) are the hydrogen and oxygen isotopic composition of different water bodies, respectively, and c is the water line equation of different water bodies.

Isotopic Composition of Plant Xylem Water and Leaf Water

Here, evaporation fractionation intensity and other hydrological process are different for different plant types, so both the xylem water and leaf water were distinguished by the type of plant. As shown in Figure 3c, for the same type of plant, the slope of the PWL and the LEL of trees were 3.66 and 1.83, respectively, and the intercepts were -39.23‰ and -30.37‰ ; the slopes of the PWL and the LEL of shrubs were 4.23 and 1.70, respectively, and the intercepts were -37.67‰ and -30.04‰ ; the slope of the PWL and the LEL of herbs were 2.94 and 2.00, respectively, and the intercepts were -36.19‰ and -27.11‰ . A smaller slope indicates a stronger non-equilibrium kinetic fractionation process, due to evaporation [7]. We also compared the isotopic composition of xylem water and leaf water of different types of plants. The hydrogen and oxygen isotopic compositions of xylem water in trees, shrubs and herbs plants were -62.05‰ and -6.22‰ , -67.56‰ and -7.06‰ , -39.29‰ and -1.05‰ , respectively (Figure 3a,b). The difference in the hydrogen and oxygen isotopic composition between trees and shrubs is very small. However, herbs are remarkably enriched, with the slopes of the PWL being 3.66, 4.23 and 2.94, respectively. It was observed that the evaporation fractionation of the xylem of herbs is stronger than that of trees and shrubs in the same zone. The isotopic composition of leaf water of different plant types also differs. The mean values of hydrogen and oxygen isotopes of leaf water in trees, shrubs and herbs plants were -12.09‰ and 9.97‰ , -2.42‰ and 16.16‰ , and -1.21‰ and 12.89‰ , respectively. The slopes of the LEL were 1.83, 1.70 and 2.00, respectively. The difference of slope in LEL may be related to factors, such as the plant height, leaf morphology, and the length of the moisture transport path within the plant [19].

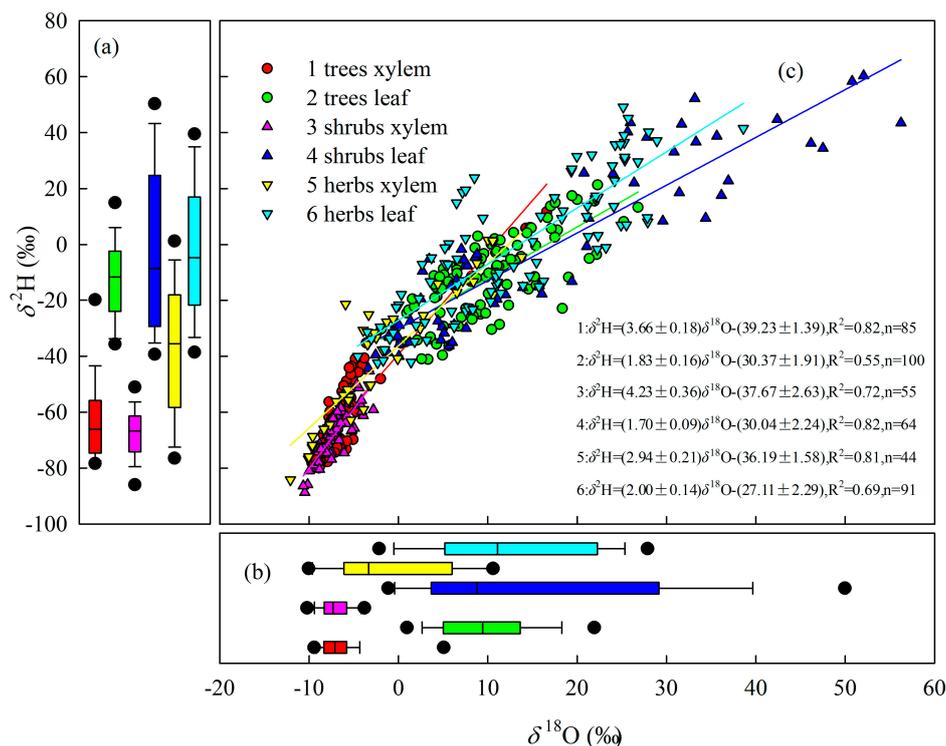


Figure 3. Relationships between $\delta^2\text{H}$ and $\delta^{18}\text{O}$ of xylem water and leaf water in different plant types. (a and b) are the hydrogen and oxygen isotopic composition of different plant types, respectively, and c is the water line equation of different plant type.

3.2. Changes of Soil Water Isotopes and SWC as a Function of Soil Depth

In this study, we divided the soil into layers depending on the SWC and the isotopic composition of the soil water of each layer. The isotopic composition of each soil layer was determined by the SWC-weighted mean approach [17,31,32]. Three layers are, thus, defined—namely the:

- (1) Shallow soil layer (0–30 cm): Where the SWC and the isotopic composition of water shows a significant seasonal dependency;
- (2) Middle soil layer (30–60 cm): Where the isotopic composition is more depleted, and the monthly changes are less pronounced than the shallow soil layer;
- (3) Deep soil layer (60–100 cm): Where the SWC and the isotopic composition are relatively stable, showing very small seasonal fluctuations.

We calculated the average vertical profiles of $\delta^{18}\text{O}$ (and also $\delta^2\text{H}$, since $\delta^2\text{H}$ and $\delta^{18}\text{O}$ have the same variation and correlativity it is not shown here) in the soil water. The $\delta^{18}\text{O}$ profiles, together with the monthly variation of the SWC, are shown in Figure 4. From Figure 4a₁–d₁, we see that the $\delta^{18}\text{O}$ becomes depleted with depth. The shallow layer soil water is the most enriched, and the deep layer the most depleted, while the soil water in the middle layer has isotope values ranging between those of the shallow and deep layers. This variation is mainly caused by kinetic fractionation, due to evaporation. During evaporation, the light isotopes evaporate first, so the remaining water becomes enriched in heavy isotopes. As depth increases, the kinetic fractionation gradually decreases, and the isotopic composition of the soil water tends to become constant [12,33]. Moreover, as can be seen from Figure 4, the soil water $\delta^{18}\text{O}$ and the SWC change more sharply across the surface layer, change less across the middle layer, and across the deep layer, the change is very small. Besides the effects of kinetic fractionation, which are mainly related to the infiltration of precipitation in the soil matrix, precipitation infiltration recharges the soil water, along with mixing of antecedent soil water with downward migration, with the increasing soil depth and the gradually decreasing recharge [8,33].

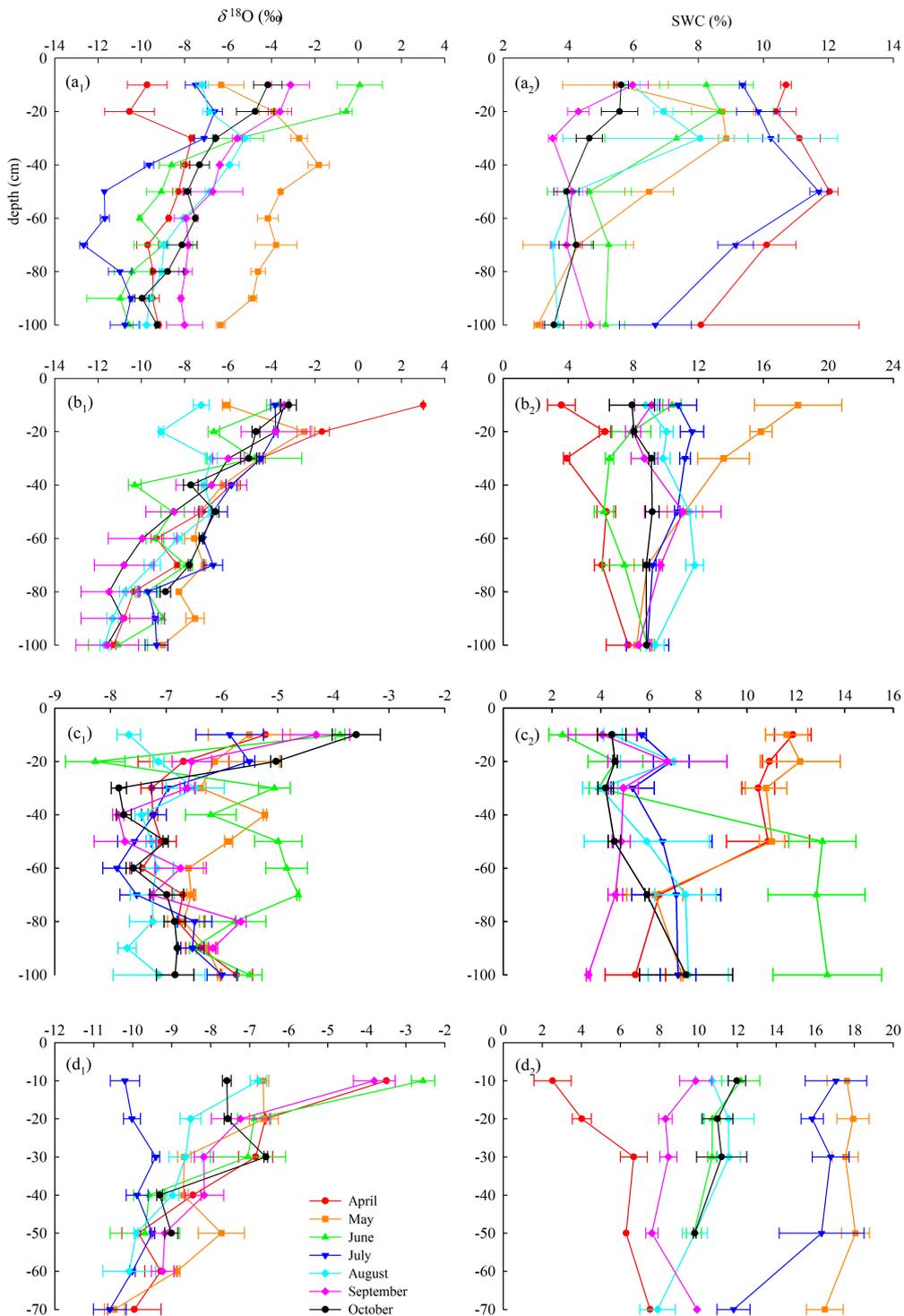


Figure 4. Monthly variation of soil water $\delta^{18}\text{O}$ and SWC in Lanzhou ((a–d) represent Jiuzhoutai, Northwest Normal University, Beishan and Wetland Park, $_1$ and $_2$ represent soil water $\delta^{18}\text{O}$ and SWC, respectively, and the horizontal crossbar represents standard deviation, $n = 3$).

3.3. The Relationship between Plant Xylem Water of Different Types and Soil Water

It is well known that, except for certain halophytic or xerophytic plants [10,34,35], during water uptake from the roots and transport in the plant xylem the isotopic composition generally does not change (there is no isotope fractionation) in terrestrial plants [36]. Hence, we can use the isotopic composition between the soil water and plant xylem water to analyze the depth of water uptake by

a plant, and we may see reflected in the plant water depth whether there is an intersection between different depths of soil water and plant xylem water [1,10–12,37–39].

Here, we divided April to October into the dry season (April, May and October) and wet season (from June to September), according to the difference in precipitation [21,22]. As shown in Figure 5a,e, trees mainly uptake 80–90 cm soil water during the dry season and uptake 30–40 cm soil water during the wet season in Jiuzhoutai. The reason for this may be that the dry season has less precipitation, so trees mainly uptake deep soil water to grow during this time. Shrubs mainly uptake 60–70 cm soil water during the dry season and uptake 30–50 cm soil water during the wet season in Jiuzhoutai. The reason for this is also related to the difference in precipitation during the growing season. This phenomenon indicates that plants can transform their water use strategy according to different environmental conditions [37–39]. As shown in Figure 5b,f, trees mainly uptake 20–30 cm and 90–100 cm soil water during the dry season in Beishan, and uptake 30–40 cm and 90–100 cm soil water during the wet season. The roots of trees are deep, so we deduced that trees mainly uptake deep layer soil water, while shrubs mainly uptake 10–30 cm soil water during the growing season in Beishan. As shown in Figure 5c,g, trees uptake 50–60 cm soil water during the growing season in NWNNU, and shrubs uptake 30–40 cm soil water during the growing season. Herbs uptake 20–30 cm soil water during the dry season, and uptake 10–20 cm soil water during the wet season. As shown in Figure 5d,h, trees mainly uptake 60–70 cm soil water during the dry season and uptake 40–60 cm soil water in wet season in Wetland Park; shrubs uptake 40–60 cm soil water during the dry season and uptake 30–40 cm soil water during the wet season; herbs uptake 0–10 cm and 10–20 cm soil water during the dry and wet seasons, respectively. These findings are also in accordance with the fact that herbs mainly use shallow soil water in other regions [40,41].

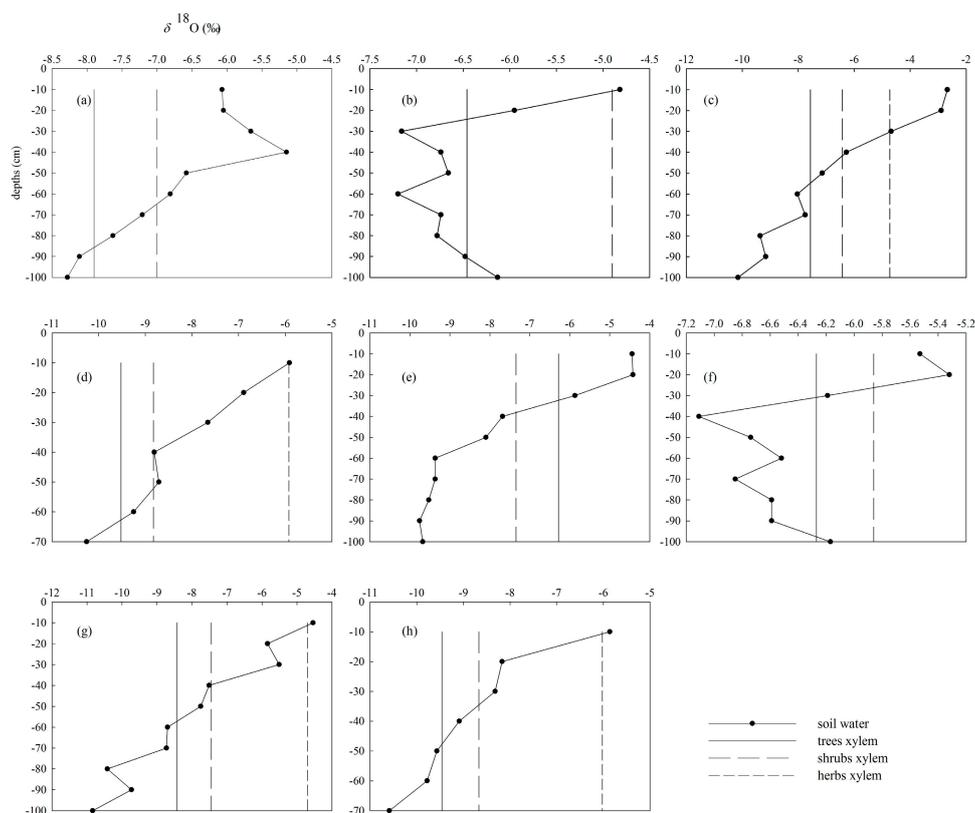


Figure 5. The relationships of $\delta^{18}\text{O}$ among soil water and tree, shrub and herb xylem ((a–d) represent Jiuzhoutai, Beishan, Northwest Normal University and Wetland Park in the dry season, respectively, while (e–h) represent Jiuzhoutai, Beishan, Northwest Normal University and Wetland Park in the wet season respectively).

In summary, trees mainly uptake the middle (30–60 cm) and deep (60–100 cm) layer soil water during the growing season, and shrubs mainly uptake the middle soil water in Lanzhou City. However, all herbs uptake the shallow soil water (0–30 cm) during the growing season.

4. Discussion

4.1. Isotopic Composition of Precipitation and Soil Water of Different Depths

The isotopic compositions of the monthly variation of precipitation and soil water of different depths are shown in Figure 6. Considering that the soil water is recharged by the infiltration of precipitation, it is necessary to discuss the mechanism linking precipitation and soil water of different depths. It is also crucial to understand the recharge relationship of different water bodies.

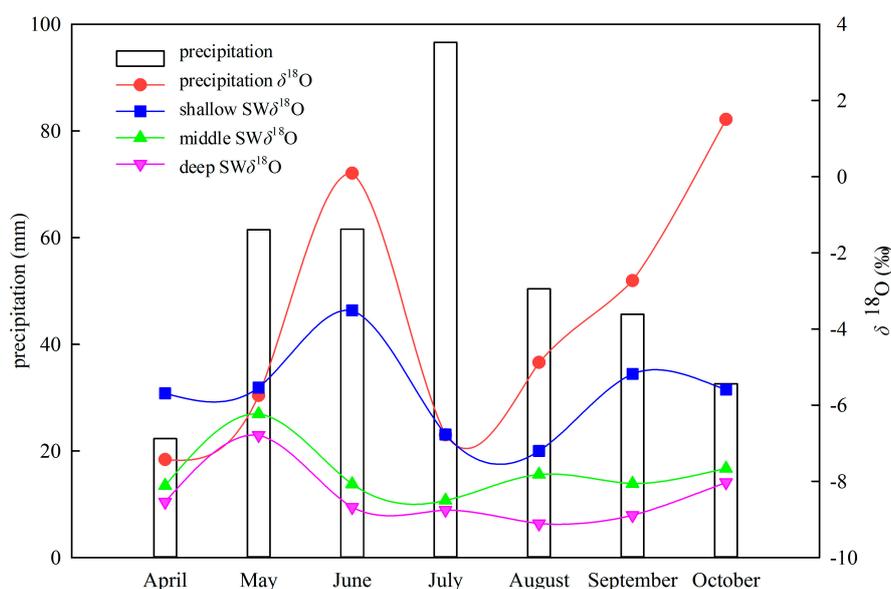


Figure 6. The monthly variation of precipitation and different depth soil water isotopes in Lanzhou.

As shown in Figure 6, the variation of the isotopic composition of precipitation each month and the soil water isotopes at different depths are different. The general tendency is that $\delta^{18}\text{O}$ (and of $\delta^2\text{H}$, not shown here) in precipitation is the most enriched, followed by that of the shallow soil water secondly; the soil water $\delta^{18}\text{O}$ is gradually depleted with depth, and the deep soil water $\delta^{18}\text{O}$ has the smallest monthly variation. Soil water is recharged by precipitation; Schwinning [42] pointed out that the recharge depth is related to the precipitation amount. The precipitation infiltration recharges the soil water and mixes with the antecedent soil water to promote the migration of mixed soil water to the deep layer. As shown in Figure 6, the monthly variation of the $\delta^{18}\text{O}$ in precipitation and in shallow soil water reaches the maximum in June for both; the minimum is observed in July for precipitation and in August for shallow soil water. This phenomenon is not observed in the variation of monthly $\delta^{18}\text{O}$ in the middle and deep soil water. From the above, we may deduce that precipitation mainly recharges shallow soil water, which also corresponds with the conclusion above that roots of herbs are shallow, and the infiltration of precipitation mainly affects the shallow soil water; consequently, herbs mainly uptake shallow soil water recharged by precipitation [40,41]. Moreover, from the variation of $\delta^{18}\text{O}$ in the soil water versus depth (Figure 6), it can be seen that the $\delta^{18}\text{O}$ variation in shallow soil water is more remarkable, due to strong kinetic fractionation caused by evaporation and precipitation infiltration. Nonetheless, the middle and the deep soil are less affected by evaporation, and relatively more by precipitation. Consequently, the $\delta^{18}\text{O}$ variation in the middle and deep depths varies smoothly, and the curve fluctuation is small.

4.2. Determination of the Water Line Equation

Craig [43] proposed the GMWL: $\delta^2\text{H} = 8\delta^{18}\text{O} + 10$. Due to the differences in water vapor source, air humidity, or the water vapor path in different regions, the correlation between hydrogen and oxygen isotopes in local precipitation, termed the LMWL, can also be established. The slope of the LMWL reflects the type of fractionation of the sampled water; a slope equal to 8 corresponds to equilibrium fractionation, and deviations from this value indicate a non-equilibrium fractionation. In our study, we established different water line equations by the ordinary least squares regression (OLSR) method, and identified evaporation fractionation intensity by the slope of the water line equation and recharge relationship. The OLSR is the major method to establish the water line equation, and the results are credible [44]. Therefore, our study may contribute to the assessment of the isotopic composition and relationship of different water bodies at the SPAC in other areas.

4.3. Comparison of Hydrogen and Oxygen Isotopes of Different Water Bodies

The layering method was used to analyze the soil water in this study. We concluded that soil water is recharged by precipitation, and the shallow soil water undergoes more remarkable kinetic fractionation, due to evaporation. In addition, we concluded that shallow soil water is more influenced by precipitation than middle and deep soil by comparing the isotopic composition between precipitation and different depth soil water. Moreover, we found uptake water depth of different types of plants by comparing the isotopic composition between the soil water and plant xylem water, which is also significant to study when considering the relationship between plant water and soil water. In the future, combining these measurements with the plant water isotopic composition to quantitatively analyze the water use strategy will also be an important next step.

Finally, it should be noted that with only a one-year dataset, our ability to analyze the long-term water cycle process through the stable hydrogen and oxygen isotopes method is relatively limited. In future sampling, we should consider extending the observation time and using more sampling sites in order to obtain a more significant conclusion. Moreover, predicting the stable isotopic composition of precipitation using an event basis is also a concern in the current study. Using a day basis, hour basis, and even minute basis to analyze the relationship of different water bodies using the water line equation and relative model could be explored in future research.

5. Conclusions

In this study, we selected precipitation, river waters, soil waters, and plant samples at four sampling sites in Lanzhou City from April to October 2016, from which the isotopic composition and relationship of different water bodies at the SPAC were determined and analyzed. The slope of the LMWL is smaller than the GMWL, indicating low relative humidity and a kinetic fractionation process, due to evaporation. The slope of the RWL and the LMWL are relatively close to each other, revealing that river water is recharged by precipitation. The slope of the SWL is smaller than that of the LMWL, illustrating that soil water was mainly influenced by mixing with precipitation and undergoing evaporation.

Trees mainly uptake the middle and deep layer soil water during the growing season, and shrubs mainly uptake the middle layer soil water in Lanzhou City. However, all herbs uptake the shallow soil water during the growing season. The isotopic composition of soil water is most enriched in shallow soil, and gradually depleted with the increase of soil depth. The variation of $\delta^{18}\text{O}$ and SWC is remarkable in shallow soil, while they tend to be similar in deep soil. The main reason for this is that the shallow soil is most affected by kinetic fractionation, due to evaporation and precipitation infiltration, while water in the middle and deep depths is less affected by these phenomena.

Author Contributions: Conceptualization, M.Z. and C.C.; Validation, C.C.; Formal analysis, C.C.; investigation, P.Z.; Methodology, Q.D., P.Z. and Z.M.; data curation, M.Z.; Writing—original draft, C.C.; Writing—review and editing, A.A.A. and S.W.; Funding acquisition, M.Z.

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Conflicts of Interest: The authors declare no conflict of interest.

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