Research Article

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Characterization of soil water by the means of hydrogen and oxygen isotope ratio at dry-wet season under different soil layers in the dry-hot valley of Jinsha River

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Abstract: The soil water was stratified sampling and analyzed with 0–100 cm by three plantation (*Leucaena Benth* Forest land, *Dodonaea angustifolia* Shrub land and *Heteropogon contortus* grassland) at the dry-hot Valley in Jinsha River, at June, September, December of 2016, which were to know about the variation and mechanism of soil water movement. The results showed that (1) soil water in different soil layers is significantly different, and the overall performance is shrub land (11.65%) > grassland (8.29%) > forest land (6.76%); (2) the δD isotope ratio of the soil water from all samples ranged from -146.359% to -54.628% and the $\delta^{18}O$ isotope ratio ranged from -20.272% to -2.148% , and there is a good linear relationship between isotope ratios of soil water of three different soils; (3) there is a change with season: the intercept of the isotopes ratio at different months decreased in turn, June < September < December. While the shrub lands and grassland had the same pattern but slightly different, the isotope ratio of soil moisture in December was lower, and the intercepts of shrub land in September were significantly larger than in December; (4) there is a change in space: the total difference isotopes ratio of soil water is larger at the shallow soil layer and changed sharply at all positions of the forestland, while those in the shrub land and grassland changed became relatively weakly. This study provides the theoretical basis for the key problems of plant water using mechanism, ecological water demand, vegetation recovery and so on.

Keywords: dry-hot valley, soil water, hydrogen and oxygen isotopes ratio

1 Introduction

Soil water is the link between the biological earth cycle, the groundwater and the atmospheric water, and it plays an important role in the transformation of precipitation–soil water–ground water and even the process of soil–plant–atmosphere interface [1]. There were many methods to study the distribution and the transport of soil water at present, for example, Li et al. [2] used the classical method to study the characteristics in the hydrodynamic parameters with the infiltration process by establishing the soil water movement model. Huang and He [3] calculated the harmonic expansion of the soil water content at all levels by using Popper's method, predicting the change of the soil water content. In recent years, Jin et al. [4] used the stable isotope ratio as a natural indicator to study the mechanism of soil hydrology. The current stable isotope ratio method has been widely used in hydrology, ecology and other fields and has also been used to quantify the source of soil water, to calculate the efficiency of water use, to split evapotranspiration components and for other water transport processes [5]. When compared with other traditional methods, it has high sensitivity and accuracy [6–8]. Studying the characteristics of its composition and the recharge process of soil water and groundwater were not only important for the evaluation of regional water resources but also helpful for studying the hydrological process [9,10]. In particular, when used as a geochemical tracer, which was used for traceability characteristic analysis of the stable isotope ratio in the soil water [11–14], good results have been achieved.

The hydrogen and oxygen isotope ratios in soil water are applied overseas earlier for studying the characteristics of profile isotope composition, infiltration mechanism of soil water and groundwater recharge process. For example, Bengtsson et al. [15] studied the seepage of soil water, based on the natural isotopes ratio, and artificial tritium incorporation in the Espola Basin, Uppsala, and found that the particle velocity, the rate of progress and the soil water flux were dissimilar from each other. Hsieh et al. [16] analyzed the

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trend of evaporation and transpiration in water balance quantitatively according to the composition of oxygen isotopes ratio in soil water. Hu et al. [17] found that the evaporation of isotopic enrichment by the Poyang Lake basin was a secondary component. The domestic research on the stable isotope ratio of soil water started relatively late, but it developed rapidly, and many studies have been carried out in fields and laboratory experiments. For example, Tian et al. [18] studied the composition of the stable isotope ratio and the relationship in water migration at different soil profile layers in the central region of the Qinghai–Tibet Plateau. Cheng and Liu [19] discussed the characteristics of the isotope ratio of soil water and movement mechanism in 0–20 m of loess section under three vegetation types of Loess Plateau, Shanxi Province. During rainfall infiltration, the coexistence of dominant flow, the occurrence of preferential flow and the use of land have a certain relationship. Xu et al. [20] used the oxygen isotope ratio to trace the dynamic transform of precipitation, canopy penetration and interflow in the subalpine dark coniferous forest under different rainfall conditions in Balang Mountain, Sichuan Province, and then studied the movement characteristics of soil water in different coniferous forest communities. Chen et al. [21] analyzed the component of the hydrogen and oxygen isotope ratio at the Loess area and then analyzed the sources of water vapor. However, there were few researches on the isotope ratio of soil water at the dry-hot valley. The dry-hot valley was one of the main ecologically fragile zones in the world, and its ecological environment was a hot issue in international geosciences [22]. In particular, the shortage and rational utilization of water resources were serious problems at the dry-hot valley [23]. It was located at the northern part of Yunnan, and due to the impact by the effect of high heat, less rainfall, evaporation, and uneven distribution, there is a lack of soil water. The key to solve this issue is to explore the mechanism of water circulation and analyze the characteristics of soil water isotopic ratio by different plants, which is the prerequisite for the application of isotope technology to study the mechanism of the water cycle. Currently, there were some progress in the study of the relationship between hydrogen and oxygen isotope ratio in soil water, main influencing factors and water vapor sources in the dry-hot valley area. However, there was a lack of deeper understanding of the temporal and spatial variation characteristics in soil water hydrogen and oxygen isotope ratio at this area.

Therefore, in this article, hydrogen and oxygen isotope tracer method was applied to study all soil samples of *Leucaena Benth* (forest land), *Dodonaea angustifolia* (shrub land) and *Heteropogon contortus* (grassland) in soil and water conservation demonstration area of the dry-hot valley in Jinsha river, as the research objective, and the soil

samples of 0–100 cm in different seasons were collected and the hydrogen and oxygen isotope ratio was analyzed. The mechanism of the soil water movement in different soils was discussed from the perspective in temporal and spatial variation and the component of the hydrogen and oxygen isotope ratio, which laid the foundation for further study on the ecological hydrological process in this area.

2 Materials and methods

2.1 The study area

The research district is the typical representative location at the dry-hot valley in Yuanmou, Jinsha. The administrative region is designated as the county of Yunnan province and is a typical south subtropical monsoon valley dry-hot climate zone. The geographical coordinates of the study area are N25°36′–N25°33′ and E101°53′–E101°51′. The climate in this region is not obvious all the year round. The dry-wet months are distinct, the average rainfall is more than 800 mm annually, the average temperature is 21.9°C annually, and $\geq 10^{\circ}\text{C}$ accumulated temperature is 7791.6°C. The average evaporation is as high as 3847.8 mm, while the average rainfall is 634 mm annually. The total rainfall in is from June to October. The maximum absolute temperature is $>40^{\circ}\text{C}$. That is such a site environment that with sparse tree, thin and dry soil. There are many kinds of herbs, including *Heteropogon contortus*, *Enlariopsis binata*, *Cymbopogon martinii*, *Aristida adscensionis*, and *Bothriochloa pertusa*. Shrubs are mostly *Dodonaea angustifolia*, *Phyllanthus emblica*, and *Zizyphus yunnanensis*. The trees are mainly *Leucaena Benth*, *Eucalyptus*, and *Acacia mangium*.

2.2 Sample collection and method

2.2.1 Sampling method

Three vegetation types (*Leucaena Benth* in forest land, *Dodonaea angustifolia* in shrub land, and *Heteropogon contortus* in grassland) were selected in the dry-hot valley, Jinsha, according to the altitude gradient set 5 position. A total of 20×20 m fixed sample plots were laid, the soil drilling or profile method was used in June, September, December 2016, and soil samples at different depths were taken from all fixed plots (Table 1). Soil samples were taken from forest land (*Leucaena Benth*), Shrub land (*Dodonaea angustifolia*) and grassland (*Heteropogon contortus*);

0–100 cm) at a depth of 0–20, 20–40, 40–60, 60–80, and 80–100 cm. To avoid the isotope fractionation caused by evaporation, samples were collected in 8 mL isotope glass bottles and sealed tightly, and the samples were placed in a low-temperature ice sample box and transported to the laboratory for cryopreservation. Vacuum extraction of soil water and determination of the hydrogen and oxygen isotope ratio were accomplished by Picarro L2130-i/L2140-I water vapor isotope analyzer at the central Stable Isotope Laboratory of China Academy of Forestry Sciences.

2.2.2 Sample analysis

The moisture content of soil was measured by the traditional 105° drying weighing method. In determining the soil moisture by the low-temperature vacuum extraction condensing method, we should ensure that the entire device in the extraction process is placed in vacuum and does not leak and it no longer produces water vapor, which shows that it has sufficient pumping water. The extraction of the soil water was accomplished by the MAT 253 isotope ratio mass spectrometer connected to the Flash EA/HT, and the error can be $\pm 1\%$ and $\pm 0.2\%$, respectively. The results of all water samples are determined based on the V-SMOW micrometer. In the extraction process, it is necessary to ensure that the whole device is in a vacuum state [11].

$$\delta^{18}\text{O} = \left[\frac{{}^{18}\text{O} / {}^{16}\text{O}_{\text{sam}}}{{}^{18}\text{O} / {}^{16}\text{O}_{\text{V-SMOW}}} - 1 \right] \times 1,000$$

$$\delta D = \left[\frac{(D/H)_{\text{sam}}}{(D/H)_{\text{V-SMOW}}} - 1 \right] \times 1,000$$

Ethical approval: The conducted research is not related to either human or animal use.

3 Results

3.1 Variation of soil water in different soil

In this study, soil water at different layers has significantly different dynamic characteristics. The overall characteristics were as follows: shrub land (11.65%) > grassland (8.29%) > forest land (6.76%). It showed that the thin shrub grass was the zonal vegetation in the region, and the large amount of tree transpiration in the forest land led to large total evapotranspiration, less environmental precipitation and more soil water loss in the dry-hot valley in Jinsha River, and the moisture of soil water at forest land was low. However, compared with the forest and grass, the

Table 1: Basic features of different soils

Vegetation	Geographical coordinate	Gradient (°)	Slope direction	Altitude (m)	Soil type	Plantation types	Vegetation coverage (%)	Soil average water moisture (%)
Forest land	25°35'48.76"N, 101°52'49.93"E	19	Southwest	1,321	Dry red soil	<i>Leucaena Benth</i>	80	6.76
Shrub land	25°36'85.77"N, 101°53'53.94"E	22	Northwest	1,323	Dry red soil	<i>Heteropogon contortus</i>	80	11.65
Grassland	25°35'53.23"N, 101°52'47.88"E	25	West	1,313	Dry red soil	Corn, pumpkin	85	8.29

Figure 1: Characteristics of soil moisture of different soils with position.

tree roots were deeper and the water consumption of canopy transpiration was larger, which led to the decrease in the soil water with the root distribution in the arbor forest and hence, the soil water is lower.

The statistical characteristics of the change in soil moisture in different soils are shown in Figure 1. In June and September, the maximum soil water content appeared in the mid-slope position and the minimum appeared in the downhill and mid-downhill, respectively, while the maximum appeared in the upper slope in December and the lowest appeared in the downhill Bit. The maximum soil water content in September and December in the shrub land appeared in the mid-down slope position and mid-slope position, respectively, and in the up-slope position and mid-uphill position in the lowest position. In the grassland, the maximum of soil water content appeared in the downhill position in June and December, while the maximum value appeared in the uphill position in September and the minimum value appeared in the uphill position in June and the downhill in September and December. In addition to the shrub land in December and the grassland in September, the soil water content of woodland, shrub land and grassland all increased at first and then decreased. The soil water content of all three soil types in December was relatively stable and fluctuated less. The soil moisture of three plantations in June is highest, September is lower, and December is lowest; the forest and shrub land at different soil positions differ significantly ($P < 0.05$).

Figure 2 shows the statistical characteristics of soil moisture variation in different soil layers. The soil water

at each layer in December decreases in different soils because the Jinsha River dry-hot valley started to enter the dry season in November due to very little rainfall and large dry evaporation. As the soil evaporates, the soil water gradually decreases and the soil water content is lower, but fluctuates greatly. The soil water above the level of 30 cm gets evaporated quickly, and the water evaporation in the lower level of the soil water is slow and mixed with the original soil water until gradually evaporated, and the water in the lower layer moves up. This may be related to the existence of macropores in the soil layer and the occurrence of “preferential flow” of soil water. It began to enter the rainy season in June, and the rainfall was abundant. The water content of different soil was higher, and the change was more stable. With the deepening of soil depth, the fluctuation of the water content of different soils gradually decreased, and at 60–100 cm, there was the most significant performance. The plantation, month and soil depth all differ significantly ($P < 0.05$).

3.2 Characteristics of hydrogen and oxygen isotope ratio in different soil water

3.2.1 Overall change characteristics

The characteristic analysis by temporal and spatial diversity of the isotope ratio in soil water not only has a tracing effect

Figure 2: Characteristics of the soil moisture of different soils at various soil depths.

on analyzing infiltration of groundwater from the surface to the ground but also plays an important role in analyzing the process of upward movement in soil water or groundwater under evaporation. A total of 250 soil samples were collected from 0 to 100 cm soil profiles in June, September and December 2016 in forest land, shrub land and grassland. The δD isotope ratio of the soil water from all samples ranged from -146.359% to -54.628% , and the maximum and the minimum isotopes ratio all appeared in the forest land samples. The $\delta^{18}O$ isotope ratio of the soil water from all samples ranged from -20.272% to -2.148% , and the maximum and the minimum isotopes ratio appeared in the grassland samples. The mean isotope ratios of δD for the forest land, shrub land and grassland were -106.010% , -100.525% and -104.048% , respectively, and the mean isotope ratio of $\delta^{18}O$ is -12.967% , -10.662% and -12.128% , respectively. Also, the isotope ratio of δD and $\delta^{18}O$ in the forest land and grassland were similar, and it was slightly less in the shrub land than that of the forest land and grassland. The regression analysis was carried out on the δD and $\delta^{18}O$ isotope ratio of the soil

water of different soil types, and the multiple regression equation was obtained using the δD and $\delta^{18}O$ isotope ratio of the soil water in June, September and December 2016 of forest, shrub and grassland forest land by the regression analysis:

$$\delta D_F = 5.147\delta^{18}O_F - 39.274 \quad (R^2 = 0.974, n = 90),$$

$$\text{Shrub land: } \delta D_S = 4.591\delta^{18}O_S - 51.568 \\ (R^2 = 0.928, n = 60),$$

$$\text{Grassland: } \delta D_G = 3.872\delta^{18}O_G - 57.083 \\ (R^2 = 0.952, n = 90).$$

where n is the sample number and R^2 is the correlation coefficient.

Table 2 presents the effects of evaporation and evapotranspiration in soil water, which have resulted in a strong isotope fractionation. However, the hydrogen and oxygen isotope ratio of the forest land was larger than that of the grassland, and shrub land has the lowest hydrogen and oxygen isotope ratio. This may be related to woodland arbors. The canopy density is large, which

Table 2: Statistical characteristics of isotopes ratio in soil water of different soils

Different soil	δD (%)				$\delta^{18}O$ (%)			
	Maximum	Minimum	Average	Standard deviation	Maximum	Minimum	Average	Standard deviation
Forest land	-54.628	-146.359	-106.01	22.974	-4.526	-20.058	-12.967	4.349
Shrub land	-56.64	-133.987	-100.525	16.202	-4.391	-18.344	-10.662	3.148
Grassland	-64.21	-146.048	-104.048	16.255	-2.148	-20.272	-12.128	3.800

affects soil evaporation to a certain extent. As shown in Figure 2, in the same soil, the change of soil water in the upper soil layer is intense. As the depth increases, the change of degree of the soil water shows a significant decreasing trend; and the variation in the soil water isotope ratio is strongly influenced by the soil depth, precipitation infiltration and evaporation. The distribution of soil moisture will be different due to the difference of soil water distribution, such as the seasonal growth of soil, the physical and chemical properties of soil.

3.2.2 Change of time

As shown in Figure 3, the δD and $\delta^{18}O$ isotope ratio of soil water in June, September and December of three different soils fall on the Global Meteoric Water Line. Therefore, on the one hand, during the rainfall in the study area, the evaporation of water enriched isotopes of ratio in the soil water. On the other hand, the isotopes ratio of the soil moisture was affected by precipitation and other water bodies such as groundwater.

The isotope ratio of δD and $\delta^{18}O$ of soil water were the smallest in June, followed by September and the largest in December with time, and the enrichment of isotope ratio in the soil water was enhanced, that is, the dry season was more enriched. The reason may be that in June, the vegetation belonged to the initial stage. The soil surface was bare, and the soil evaporation was strong. By December, although the rainfall was less, the litter was mostly covered by the surface and the soil evaporation was weak. By ANOVA, the isotope ratio of δD and $\delta^{18}O$ in different seasons showed obvious seasonal effects, that is, the summer was light, the autumn was the second and the winter was the heaviest. Specifically, the isotope ratio of δD and $\delta^{18}O$ in September and December was similar, but both were less in June. This may be due to the abundance of rainfall in the early rainy season in June, and the average relative humidity was greater than that of September and December, and the shrub land and grassland also had this rule, but slightly different. The isotope ratio of δD and $\delta^{18}O$ in grassland in September and December was less than that in June, but it was lower in December. This may be due to the entry into the dry season in December, with shallow roots and insufficient supply of rainwater and obvious evaporation, and the intercept of the shrub land in September was significantly greater than that in December. Therefore, it was indicated that precipitation and evaporation were important elements to the

composition in isotopes ratio of soil water at this study area. Intercepts in the isotope ratio of δD and $\delta^{18}O$ in June, September and December in dry-hot valley were all larger than the global precipitation (10%). This may be due to the dry-hot climatic zone of the South Subtropical Monsoon Valley in the dry-hot valley of Jinsha River, and GMWL Sampling data from all over the world are derived from precipitation data in arid and wet areas.

3.2.3 Change of space

As shown in Figure 4, although the rainfall infiltration and evaporation conditions were changing, the δD and $\delta^{18}O$ isotopes ratio of soil water change trend with soil depth were the same, but different in magnitude.

The analysis of different soil depths of different soils was carried out: (1) in three different soils, there is fluctuation in stable isotope ratio of soil water at each soil layer and the surface layer is the most fluctuated. With the increase in the soil layer depth, there is a decrease in fluctuation. Changes in isotopes ratio of soil water of the forestland and shrub land were consistent, especially the change of 50–100 cm was small and stable, while the range of grassland was slightly different. The obvious was the soil layer of 80–100 cm. The oxygen isotope ratio appeared to decrease, and the trend of hydrogen stable isotope ratio was relatively increased. This was probably because the isotope ratio of the size in soil water was not only influenced by the isotopes ratio of precipitation but also influenced by precipitation and evapotranspiration in different soils. (2) The isotope ratio of soil water of the forest land increased by the soil depth and then decreased first, then increased, and then decreased slowly, while that of shrub land and grassland tended to increase slowly and then decreased relatively slowly. This is different from the forest land. (3) In three different soils, the isotope ratio in the surface soil water was enriched, which reflected the effect of isotopic fractionation, such as soil evaporation. Especially, the change of 0–50 cm soil layer was obvious, and the hydrogen and oxygen isotope ratio in each layer at 50–100 cm was relatively close and gradually tend to be stable. As the depth increases, the influence of evaporation on soil was less, which, to a certain extent, reflected the stratification of the isotope ratio in the soil profile.

The analysis of at different soil positions show that the isotopes ratio of soil water of forest land and grassland changed with the same amplitude, which increased at the same time and decreased. However, there was a minimum value in the downhill of forest land and the change was obvious, which may be related

Figure 3: Characteristics of isotope ratio of different soil waters.

Figure 4: Composition of δD and $\delta^{18}O$ in the different soil water with different depths and positions.

to the presence of macropores in the soil layer and the occurrence in “preferential flow.” The presence of more root holes and maggot activities in the soil confirms the presence of macropores. While the shrub land was slightly different, for example, from mid to down-slope, the oxygen stable isotope ratio tends to increase, while the hydrogen stable isotope ratio decreases relatively.

The isotope ratio of soil water from the uphill to the downhill first increased and then decreased, and the maximum isotope ratio appeared in the mid-slope position, while the grassland continued to increase slowly from the uphill position to the downhill position, and the maximum isotope ratio appears in the downhill position.

4 Discussion

The change in soil water is the transformation of precipitation–soil water–ground water and even the process of soil–plant–atmosphere interface. The hydrogen and oxygen stable isotope ratio in the soil water can reflect the transport characteristics of the soil water. The changes in the soil water were related to precipitation infiltration, soil evaporation, soil water sports, vegetation types and other factors [24,25], in particular, the complex effect of vegetation types on soil water [26]. The special climate background and the unreasonable man-made land use of the Jinsha River dry-hot valley made the phenomenon of drought and water shortage increasingly prominent in this area, and the contradiction between social development and environmental protection was even more acute. Also, it is important to clarify the temporal and spatial distribution of isotope ratio of the soil water by different soil, which is of great significance for guiding the ecological restoration, reconstruction and hydrological research in this area.

The change of the isotope ratio in the soil water was affected by many elements, for example, the amount of precipitation, and the temperature of the surface will affect the evaporation and fractionation of soil moisture in the vertical movement [27–29]. During large amount of rainfall, the isotope ratio in the soil water is negative, and at the high temperature, the isotope ratio of the soil water is positive [30]. In addition, the changes in the stable isotope ratio in the soil water reveal information about the migration in the soil water [31]. The forms of water infiltration into the soil include the preferential flow and piston flow, and the infiltration method was not exactly the same for different areas and different soils [32]. The difference in the characteristics of the isotope ratio in the soil water was caused by different infiltration methods. There were many factors affecting rainfall infiltration and soil water evaporation, such as soil particle properties, land use types, rainfall and so on [33]. Generally speaking, rainfall infiltration was an important factor affecting the isotopic component of soil water, and the factors affecting rainfall infiltration include rainfall, vegetation coverage and soil properties [34,35]. Studies have shown that large-scale vegetation cover had important effects on soil hydrogen and oxygen isotopic ratio composition in the process of water circulation and infiltration [36]. Transpiration of plants and the difference in land use types also affect the composition of the stable isotope ratio of soil water [37].

In the same soil, the isotope ratio in soil water showed obvious seasonal effects in different months, that is, summer was lighter, autumn was the next and winter

was the heaviest. This seasonal variation was mainly caused by local atmospheric precipitation, atmospheric temperature and seasonal changed in vegetation growth. The results showed that the evaporation of forest land, shrub land and grassland was less than the average global evaporation, which was in agreement with the results of Wang et al. [39]. In the same soil, the difference in soil humidity and evaporation caused the difference in rainfall recharge depth, resulting in the difference of the isotope ratio in surface soil water, but consistent in the deep soil water. This is because the water in the shallow soil was easily affected by the precipitation mixing and evaporation. The isotopic composition in shallow soil was changed greatly. The water in the deep soil received limited precipitation compensation, the rainfall and soil water were mixed evenly, and hence, there was a little change in the water isotopic component in the shallow soil.

The isotope ratio of the soil water varied with the different soil layers. The isotope ratio of the soil water in forest land increased with the depth and then decreased, then again increased and then slowly decreased. The isotope ratio of the shrub land and the grassland all increased first and then decreased relatively slowly. In terms of the magnitude of change, the fluctuation of isotope ratio in the soil water of the forest land and shrub land was more consistent, especially the change of 50–100 cm was small and basically stable. However, the range of grassland was slightly different. It was obvious that in the 80–100 cm of soil layer, the oxygen isotope ratio appeared to decrease, while the hydrogen isotope ratio increased relatively. These characteristics can be explained as follows: thick litter layer and high natural water content in forest land make the surface soil less affected by evaporation, and the isotope ratio fractionation in the surface soil was not obvious. The main source of water in arbor forest may come from 10–50 cm. During plant water uptake, the hydrogen and oxygen isotope ratios were continuously enriched. Due to the mixing of water in the surface soil, it is maintained in a dynamic state. The isotopes ratio below 50 cm decreased with the depth. This can only cause the variation of isotope ratio component in the soil water, and only the mixing effect exists. Precipitation existed in the form of preferential flow rapidly through the soil profile to reach the soil depth.

The surface soil water was evaporated that causing isotopic enrichment, influencing the evaporation weakened, the soil water spread or piston flow downward movement, the old water was constantly replaced by the upper new water [39–41]. Studies by Chung and Horton [42] and Bristow and Horton [43] have shown that soil surface coverings can have a dramatic effect on the near-surface soil microenvironment, especially at depths of

more than 50 cm. Therefore, it showed that the intensity of inhibition of soil water evaporation by different soils was different. It can be seen that soil water evaporation surface at more than 50 cm of soil layer in the case of low water vapor content can be evaporated. This is due to the continuous evaporation process of soil water, the soil surface gradually became dry, then dry surface move down; and under the action of capillary force along the water gradient upward gradient in the soil surface evaporation, evaporated soil water by the effects of unbalanced fractionation on kinetics become isotopic enrichment, forming the largest isotope enrichment layer on the dried surface [44]. Therefore, it is considered that precipitation and evaporation are important factors to control the component of isotopes ratio of the forest land, shrub and grassland soil water in this study area.

5 Conclusion

- (1) Soil water was varied significantly at different layers with dynamic changes under different soil. The overall performance was shrub land (11.65%) > grassland (8.29%) > forest land (6.76%). In December, the soil water of each layer was lowest. With the increase in depth, there is less fluctuation in soil water in different soils.
- (2) The δD isotopes ratio of soil water from all samples ranged from -146.359% to -54.628% , and the $\delta^{18}O$ isotopes ratio of soil water from all samples ranged from -20.272% to -2.148% ,

$$\text{Forest land: } \delta D_F = 5.147\delta^{18}O_F - 39.274 \\ (R^2 = 0.974, n = 90),$$

$$\text{Shrub land: } \delta D_S = 4.591\delta^{18}O_S - 51.568 \\ (R^2 = 0.928, n = 60),$$

$$\text{Grassland: } \delta D_G = 3.872\delta^{18}O_G - 57.083 \\ (R^2 = 0.952, n = 90).$$

Precipitation and evaporation are important factors to control the composition of the isotopes ratio of the soil water.

- (3) By the same soil, the isotopes ratio of the soil water in each month is basically above the global atmospheric precipitation line. The intercept of the isotope ratio in different months decreased successively, which is the smallest in June, increases in September, and the

largest in December. In different months, the isotope ratio in the soil water shows obvious seasonal effects, that is, it is light in the summer, increases in the autumn and the heaviest in the winter. In forest lands, the intercept of the soil water isotope ratio in September and December were less than June, and there was also a pattern in the shrub land and grassland, but slightly different. In the grassland, the soil water isotope ratio in September and December is less than June, December performance is lower in the shrub land and the September intercept was significantly larger than in December.

- (4) In different soils, the stable isotope ratios of the soil water have the following spatial distribution characteristics: (1) the isotopes ratio was different in the shallow layer, and the soil water isotopes ratio tends to be consistent with the soil depth. The water in the shallow soil is affected by the mixture of evaporation and precipitation. The isotopic ratio change drastically with time. The deep soil water is only compensated by limited precipitation, and the precipitation is mixed with the soil water. The isotopic ratio with time has decreased or even no change. (2) By the same soil, the isotopes ratio in the soil water changed sharply in all positions of the forest land, while the position in the shrub land and grassland changed relatively weakly.

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