Analysis of Soil Moisture Characteristics and Deficit Compensation of Forest Land in Nanxiaohegou Watershed

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Abstract: Exploring the soil water characteristics of typical afforestation species Robinia pseudoacacia and Platycladus orientalis in the gully region of the Loess Plateau, and analyzing the compensation situation of soil water storage deficit before and after the rainy season, it provides reference for the selection of planting tree species in the process of water and soil conservation. The analysis results show that, the soil moisture content of different vegetations is different, and the soil moisture in different slope directions also shows differences. Soil water storage has the same change rule. Soil moisture continued to increase in the range of 0-30cm. It keeps decreasing in the range of 30-60cm, it fluctuates within 10% below 60 cm depth. DSW of robinia pseudoacacia forest was lower than that of platycladus orientalis, and CSW was higher than that of platycladus orientalis. The DSW of the shady slope is lower than the sunny slope, and the CSW is higher than the sunny slope.

1. Introduction
The Nanxiaohegou River Basin is located in Xifeng District, Qingyang City, Gansu Province, and belongs to the typical gully region of the Loess Plateau. There is less precipitation in the basin, and local crops are mainly rain-fed agriculture. Water shortages have become the biggest constraint to the environment and development of the region. Soil moisture is an important component of water balance and heat balance in the water cycle, as well as an important indicator of soil properties and a controlling factor for crop growth. As a link between surface water, groundwater and atmospheric water, soil water is also an important factor in determining the material migration process in the soil-vegetation-atmosphere continuum (SPAC) system [1-2]. Therefore, the study of the dynamic characteristics of soil moisture has been a key issue in the field of hydrology [3]. Returning farmland to forests as the main way to control soil erosion and water conservation has been widely applied and popularized in the Loess Plateau [4]. The growth of vegetation in the basin is closely related to the soil and water conservation effect. It is necessary to study the soil water distribution characteristics of the artificial forest land and the soil water consumption deficit and restoration compensation during the growth period. At present, the basin has carried out a lot of research on soil water movement. Li Lanjun et al. [5] have analyzed the dynamic characteristics of soil moisture in the side of the basin. However, the research on soil water deficit compensation before and after different vegetation growing seasons in the study area is not comprehensive enough. Based on the analysis of soil water distribution characteristics, this paper discusses the effects of vegetation restoration on the typical afforestation tree.
species of Robinia pseudoacacia and Platycladus orientalis on different slopes before and after the rainy season, in order to promote the relationship between vegetation and water in this basin.

2. Research area and research methods

2.1. Research area
Nanxiaohegou basin is located in the middle of the gully region of the loess plateau, It is a branch of the left bank of the Puhe River (107°30'~107°37'E, 35°41'~35°44'N). The drainage area is 36.3 km$^2$ and the altitude is between 1050~1423 m. According to the analysis of precipitation data from Xifeng Center Meteorological Station from 1954 to 2017, the average annual precipitation is 524.5 mm, the annual maximum precipitation is 750.2 mm in 2003, and the annual minimum precipitation is 290.2 mm in 1982. The average annual precipitation from May to October is 440.1 mm, accounting for 83.65% of the annual precipitation. The average annual temperature is 9.3 °C, the highest temperature is 39.6 °C, and the lowest temperature is -22.6 °C. The average frost-free period was 155 days and the evaporation amount was 1474.6 mm.

2.2. Test layout and method

2.2.1. Test area layout. Typical vegetation in the Nanxiaohegou watershed includes arborvitae, hedgehog, farmland, alfalfa and grass et al. The main types of landforms are slopes and valleys. This paper comprehensively considers the existing observational experimental data, vegetation characteristics and other factors. Finally, two typical afforestation species, Slope Hedgehog and Platycladus orientalis, were selected for different slope directions. The tree species and topographical characteristics of the test plots are shown in Table 1.

| Species                  | Tree height(cm) | Tree diameter(cm) | Crown (cm) | Canopy closure | Altitude | Terrain | Slope |
|-------------------------|-----------------|-------------------|------------|----------------|----------|---------|-------|
| Robinia pseudoacacia    | 564.1±29.6      | 15.9±2.4          | 293.1±15   | 0.61           | 1206     | Terrace | 26    |
| Platycladus orientalis  | 499.4±27.9      | 17.4±3.7          | 211.4±11   | 0.44           | 1242     | Terrace | 22    |

2.2.2. Test methods. Soil moisture was observed using a tubular time domain reflectometry system (Trime TDR, Germany). Select 4 plots of shady slope, sunny slope Robinia pseudoacacia and Platycladus orientalis. Two plants were randomly selected from each sample plot. A TDR measuring tube with a depth of 220 cm was laid respectively at a distance of 50 cm from the trunk. The observation interval within the depth of 0~100 cm is 10 cm, and the observation interval within the depth of 100~220 cm is 20 cm. Taking the average of two measuring points at the same depth as the observed value of soil water content at the measured depth of each plot, The observation interval is 3-5 days. The data used in this article was tested from June 2nd to October 8th, 2017.

2.3. Test layout and method
This article mainly uses Excel2010 to preprocess data. Difference analysis using Duncan multiple comparisons, Data analysis was performed using SPSS 17.0 using Origin 2019.

Soil water storage calculation The volumetric water content of each soil layer was measured by TDR. The soil water storage capacity of each layer is:

\[ W_i = \theta_i \times D_i \]  (1)

\[ W = \sum W_i \]  (2)
In formula (1), $W_i$ is the water storage capacity of the $i$-th layer (mm); $\theta_i$ is the soil water content of the $i$-th layer (cm$^3$/cm$^3$); $D_i$ is the thickness of the $i$-th layer of soil (mm). In formula (2), $W$ is the total water storage (mm) of the 0-220 cm soil layer.

#### Calculation of Soil Water Storage Deficit and Compensation for Soil Water Storage Deficit

In order to reflect the deficit and compensation of soil moisture, the compensation and recovery of soil water deficits are described by soil water storage deficit and soil water storage deficit compensation \[6\].

**Soil water storage deficit $DSW$ (%)**:

$$DSW(\%) = \frac{D_a}{Fc} \times 100\%$$  \hspace{1cm} (3)

In formula (3), $D_a$ is the soil water storage deficit (mm), $D_a=Fc-Wc$; $Fc$ is soil field water capacity (mm); $Wc$ is the actual water storage capacity of soil (mm).

**Compensation degree of soil water storage deficit $CSW$ (%)** :

$$CSW(\%) = \frac{\Delta W}{Dac} \times 100\%$$  \hspace{1cm} (4)

In formula (4), $\Delta W$ is the soil water storage increment at the end of the rainy season (mm), $\Delta W=Wcm-Wcc$; $Wcc$ is the actual water storage capacity (mm) of the soil at the beginning of the rainy season; $Wcm$ is the actual water storage capacity of the soil at the end of the rainy season (mm); $Dac$ is soil water storage deficit at the beginning of rainy season (mm), $Dac=Fc-Wcc$.

### 3. Results and analysis

#### 3.1. Watershed precipitation characteristics

The study area is a typical semi-arid area. The annual precipitation is less, and more concentrated in the flood season may to October. The total precipitation of the basin in 2017 was 613.8 mm, among which the precipitation from June to October during the study period was as high as 491.7 mm, accounting for 80.11% of the annual precipitation. The monthly rainfall distribution is shown in table 2. As can be seen from the table, Precipitation in June and August was relatively sufficient during the study period. In particular, the precipitation in August accounted for 43.6% of all the study periods. Daily rainfall statistics show that, Rainfall in August is mainly concentrated in the middle and late part, Rainfall is intense and lasts for a long time. Rainfall decreased in September and October.

**Table 2 Rainfall in the study area from June to October**

| Month  | June | July | August | September | October |
|--------|------|------|--------|-----------|---------|
| Rainfall (mm) | 118.1 | 39.8 | 214.3 | 61.3 | 58.2 |

#### 3.2. Watershed precipitation characteristics

The soil water storage in different depth ranges of the shady and sunny slopes of the robinia pseudoacacia and lateral cyperus is shown in Figure 1. As can be seen from the figure 1, From June to October, the fluctuation range of soil storage water of 0-20cm in the surface layer of robinia pseudoacacia is 19.4-37.8 mm and 18.4-34.2 mm. The soil storage capacity of 0-20cm on the surface of lateral cyperus on shady and sunny slopes from June to October is 14.7~25.1 mm and 13.1~24.9 mm. The minimum appeared in August and the maximum appeared in October. Within the depth range of 20-40cm, the minimum value of soil storage water of robinia pseudoacacia on the shade slope appeared in August at 22.0 mm, the maximum value appeared in September at 40.1 mm, the minimum value of robinia pseudoacacia on the sunny slope appeared in August at 22.1 mm, and the approximate value of both September and October was 33 mm. The change of lateral cyper in 20-40 cm on the shady slope and the sunny slope is basically the same as that of the robinia pseudoacacia. The minimum value of the shady slope is 20.9 mm in August, and the soil water storage in September and October is nearly 33 mm. The sunny slope is close to 18.5 mm in July and August, and the maximum is 26.3 mm in
September. its soil water storage capacity of Robinia pseudoacacia and lateral cypress on shady slope and the sunny slope during the 40-60cm depth study period was 21.5-36.5mm, 14.7-25.3mm, 20.2-27.2mm and 15.9-21.0mm, respectively. Soil water storage in the depth below 60cm gradually becomes stable. They are 42.3-63.8 mm, 39.2-51.2 mm, 39.9-49.9 mm, and 31.4-40.1 mm, respectively. Within the depth of 100-220cm, the forest water storage capacity of Robinia pseudoacacia is between 133-145mm. The difference between the shady slope and the sunny slope is small. The lateral cypress on the sunny slope is stable at 125mm and the shady slope is 101mm. According to the calculation results of soil water storage, we can know that, within the range of 0-60cm, there was a general trend of first increasing and then decreasing, and the change below 60cm was small and gradually tended to be stable.

As can be seen from the above analysis, During the study period, the distribution of soil water content in different vegetation directions was similar. But the water storage capacity of Robinia pseudoacacia soil in each depth is higher than that of Platycladus orientalis. It indicates that vegetation type is the reason for the difference in soil moisture [7]. Based on the influence of water bearing capacity, the distribution and growth of forest vegetation have obvious differences in slope direction and slope position [8]. In this study, the differences in slope orientation between the two species of Robinia pseudoacacia and Platycladus orientalis showed that the soil moisture content of the shady slope was higher than that of the sunny slope. This is consistent with the research results of Kong Lingxiao et al [9].

3.3. Analysis of compensation for soil water deficit

The compensation status of water consumption and soil water storage deficit under different vegetation growth conditions is shown in table 3.

As can be seen from table 3, during the study period, both robinia pseudoacacia and platycladus orientalis had significant water deficit. Within the depth of 0-220cm, robinia pseudoacacia is in the state of water deficit before and after the rainy season. Before the rainy season, the loss of soil layer 0-60cm was serious, and DSW on the surface layer of robinia pseudoacacia on the overlying slope was up to 82%. DSW of 10-60cm is between 36% and 46%. After the rainy season, the surface layer DSW was reduced to 42% DSW is between 6% and 38% in the range of 10-60cm, which is lower than before the rainy season, especially the deficit of 10-40cm. A sunny slope is similar to a cloudy one, the DSW of the soil surface layer decreased from 86% to 62% after the rainy season. Within the range of 10-50cm, the deficit before the rainy season is between 50% and 60%. The DSW in this depth range after the rainy season is 12%-48%. Under 60cm was basically unaffected by rainfall, and DSW was stable at 40-50%. DSW of Platycladus orientalis is larger than that of Robinia pseudoacacia. Before
the rainy season, the surface DSW of shady slope and sunny slope reached 97% and 95% respectively. DSW at the depth below is all higher than 70%, and the precipitation in the rainy season greatly replenishment water in the 0-40cm soil layer. After the rainy season, DSW decreased to 50%-60% in 10-40cm depth in shady slope and 60%-70% in sunny slope. Wang Jinxin et al [10] also studied the compensation of soil water deficit before and after the rainy season in the Loess Plateau. The results also show that the soil water deficit compensation degree of robinia pseudoacacia is higher, the conclusion of this paper is consistent with its conclusion.

Table 3 Spatial distribution of DSW and CSW at the beginning of the rainy season and at the end of the rainy season /%

| Depth | Robinia pseudoacacia | Platyclus orientalis |
|-------|-----------------------|---------------------|
|       | Shady slope           | Sunny slope         | Shady slope | Sunny slope |
| 0cm   | DSW Early | DSW End | CSW Early | CSW End | DSW Early | DSW End | CSW Early | CSW End |
| 10cm  | 85.85     | 61.72   | 28.11    | 97.00   | 84.70   | 12.68   | 95.12    | 78.31   |
| 20cm  | 6.07      | 11.97   | 74.47    | 73.92   | 55.35   | 25.13   | 76.57    | 65.42   |
| 30cm  | 46.89     | 52.25   | 46.53    | 70.44   | 52.40   | 25.62   | 72.88    | 66.89   |
| 40cm  | 57.80     | 39.19   | 32.20    | 71.03   | 61.11   | 13.97   | 73.27    | 69.73   |
| 50cm  | 61.09     | 47.59   | 22.10    | 72.63   | 70.99   | 2.27    | 79.19    | 79.77   |
| 60cm  | 54.57     | 53.24   | 2.43     | 73.37   | 75.23   | 2.53    | 79.12    | 81.90   |
| 70cm  | 51.19     | 55.31   | 8.04     | 71.63   | 71.85   | 0.31    | 77.27    | 77.66   |
| 80cm  | 48.41     | 48.62   | -0.43    | 72.23   | 71.04   | 1.64    | 77.92    | 77.25   |
| 90cm  | 44.38     | 45.32   | -2.11    | 71.57   | 70.81   | 1.06    | 77.84    | 77.05   |
| 100cm | 48.80     | 46.05   | 5.65     | 70.37   | 70.33   | 0.07    | 76.18    | 77.84   |
| 120cm | 40.65     | 40.92   | -0.68    | 69.12   | 68.48   | 0.94    | 76.38    | 77.24   |
| 140cm | 40.04     | 42.25   | -5.51    | 68.20   | 64.59   | 5.29    | 74.60    | 74.46   |
| 160cm | 40.23     | 47.54   | -18.15   | 68.00   | 64.76   | 4.77    | 73.94    | 73.34   |
| 180cm | 36.29     | 37.53   | -3.42    | 67.69   | 65.58   | 3.12    | 73.95    | 73.06   |
| 200cm | 36.69     | 38.77   | 2.56     | 65.73   | 65.10   | 0.96    | 72.06    | 72.20   |
| 220cm | 35.60     | 35.60   | 2.27     | -0.88   | 0.17    | 119.21  | 66.78    | 67.41   |
| Average| 47.74     | 38.78   | 18.78    | 72.34   | 67.20   | 7.11    | 77.16    | 73.94   |

4. conclusion

(1) The variation of soil water content in the shady and sunny slopes of Robinia pseudoacacia and Platycladus orientalis during the study period decreased first in June to August, and then increased sharply in August-September, and then decline in September to October.

(2) Spatial variation law of soil water storage is, the longitudinal changes of the two species are consistent, both in the surface layer 0-30cm, the soil moisture continues to increase, continuously decreasing within the range of 30-60cm, and the fluctuation below 10cm is about 10%, and the fluctuation range is within 2%.

(3) The analysis of soil water storage deficit compensation under the cover of the two plants shows that, during the study period, both robinia pseudoacacia and Platycladus orientalis had serious water deficit, and the rainy season greatly compensated the soil water storage within 0-40cm. The compensation degree of precipitation for soil water storage deficit in Robinia pseudoacacia forest is higher than that of Platycladus orientalis, and the compensation for deficit on shady slope is higher than that of sunny slope.
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