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Seasonal variations in the influence of vegetation cover on soil water on the loess hillslope

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Abstract: Soil water is the key factor that restricts the restoration of the local ecological systems in the Loess Plateau of China. Studying the effects of vegetation types on soil water and its seasonal variation helps to understand hydrological characteristics and provides insights into the sustainable restoration of vegetation. Therefore, the Caijiachuan watershed was chosen as the research object to investigate the water status of a 0-10 m soil layer under different vegetation types including *Pinus tabulaeformis*, *Robinia pseudoacacia*, *Platycladus orientalis*, apple orchard, natural forestland, farmland and grassland. By comparing the difference between soil water of different land use types and that of grassland during the same period, the seasonal changes of soil water status of different types were judged. The results show that (1) in the 0-10 m soil layer, the largest value of soil water content was in the 0.3-0.4 m layer, and the lowest was in the 5.6-5.8 m layer. The depths at which the vegetation cover influenced the soil water were up to 10 m; (2) among summer, fall and spring, the soil water storage was the highest in the fall. In addition, the lowest value of relative accumulation was in the fall, which was the period in which the soil water recovered; (3) the soil water in the 0-10 m layer was in a relatively deficient state in the artificial forestlands, apple orchards and native forestlands, while the relative accumulation was in the farmland. In addition, the relative deep soil layers (8-10 m) had more serious deficits in the areas in which *P. tabulaeformis*, *R. pseudoacacia* and the apple orchard grew; (4) during the study period, the farmland in the summer had the largest relative accumulation (182.71 mm), and the land under *R. pseudoacacia* in the fall had the lowest relative deficit (512.20 mm). In the Loess Plateau, vegetation cover will affect the change of deep soil moisture and artificial forest will cause soil water loss in different degrees.

Keywords: Seasonal variation; Soil water; Vegetation cover; Hillslope; Loess Plateau

Introduction

Soil water is an indispensable component of

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the soil-plant-atmosphere continuum and plays a critical role in hydrological processes (Botter et al. 2007; Wang et al. 2010; Gao and Shao 2012; Li et al. 2016; An et al. 2017). Soil water is the primary factor that restricts the growth of vegetation in semiarid and arid areas. Soil water in different layers has different functions for the restoration of vegetation. Shallow soil water is closely related to the surface environment affected by precipitation and evaporation that is the direct water resource that the plants utilize (Suo et al. 2018). The soil water in the deep layers serves as a soil reservoir that aids the hydrologic cycle by moving under the drive of vapor pressure (Fang et al. 2016). Thus, the characteristics of the distribution of soil water could directly affect the ecological restoration in areas in which water is limited. Previous studies have shown that the temporal and spatial variation was primarily affected by climatic factors (Zhao et al. 2011;Zhu et al. 2014), topographic factors(Wang et al. 2011; Mei et al. 2019), soil properties (Cantón et al. 2004; Fang et al. 2016; Zhang et al. 2019) and vegetation traits (Gao et al. 2018; Wang et al. 2019). These environmental factors affect jointly the temporal and spatial changes of soil water. Based on the principle of matching tree species with the site, choosing the appropriate type of vegetation is the key for the effective restoration of vegetation and the sustainable development of ecosystems.

The Loess Plateau in China is the most concentrated and largest loess area in the world. It has been the subject of close attention because of its serious soil erosion. Large-scale afforestation by the "Grain and Green" project has increased the vegetation cover and reduced the loss of soil and water (Cerdà et al. 2017). Taking Ji County of Shanxi Province as an example, the proportion of forest land coverage increased from 19.15% in 1995 to 45.68% in 2012, while that of farmland and shrub grassland decreased significantly (Wang 2016). However, a large amount of exotic vegetation has changed the character of the soil water (Zhao et al. 2019). In the Loess Plateau, the depth of infiltration of the annual rainfall rarely reaches 2 m (Chen et al. 2008a; Yang et al. 2014). The recharge of deep soil water is difficult when the precipitation is limited, leading to the degradation of plant growth and the formation of "dwarf aged trees." In turn, the long-term growth of vegetation affects the characteristics of temporal and spatial distribution with soil water. As is well known, trees and shrubs have a deep root depth (Fu et al. 2016). When the shallow soil water content is too low to meet the needs of vegetation, the trees and shrubs could change the water uptake patterns by switching to deeper soil layers (Huo et al. 2018; Zhao and Wang 2018), which could significantly alter the distribution of soil water. Therefore, understanding the characteristics of the consumption and utilization of soil water by vegetation and the temporal and spatial changes of soil water under vegetation coverage are instrumental for the reasonable allocation of vegetation and its management based on the soil and water resources in the Loess Plateau.

During the initiation of the "Grain for Green" project, the effect of the types of vegetation on the soil water has been concerned about ecological restoration in the Loess Plateau of China. Recent studies have identified the impact of artificial forestland on the hydrological cycle and ecosystem services (Wang et al. 2011; Yang et al. 2014). Planting vegetation on a large scale could control soil erosion and improve the resistance to soil erosion by blocking and storing runoff. However, the introduced vegetation with its high density requires more water to maintain its growth, leading to a decrease in soil water, the formation of dried soil layers (Li 1983; Giorgi and Bi 2005; Shangguan 2007; Wang et al. 2010) and a threat to the local ecological environment. Wang et al. reported that the soil moisture content of arbor forests and shrubbery is lower than that of grasslands and farmland (Wang et al. 2009a). Fang et al. found that the soil moisture required by the introduction of deep-rooted vegetation would use more soil water (Fang et al. 2016). To improve the conservation rate, deep-rooted trees are often used to restore the vegetation in the Loess Plateau. The artificial vegetation not only has a distribution of deep roots, but it also changes the depth of water use depending on the rainfall conditions. However, traditional studies on the depths of soil moisture were primarily too shallow to clearly reveal the influences of vegetation on soil water. Moreover, the response of soil water with time on the types of vegetation has been concerned. Yu et al. analyzed the deep soil moisture under different land uses among three seasons and found that afforestation

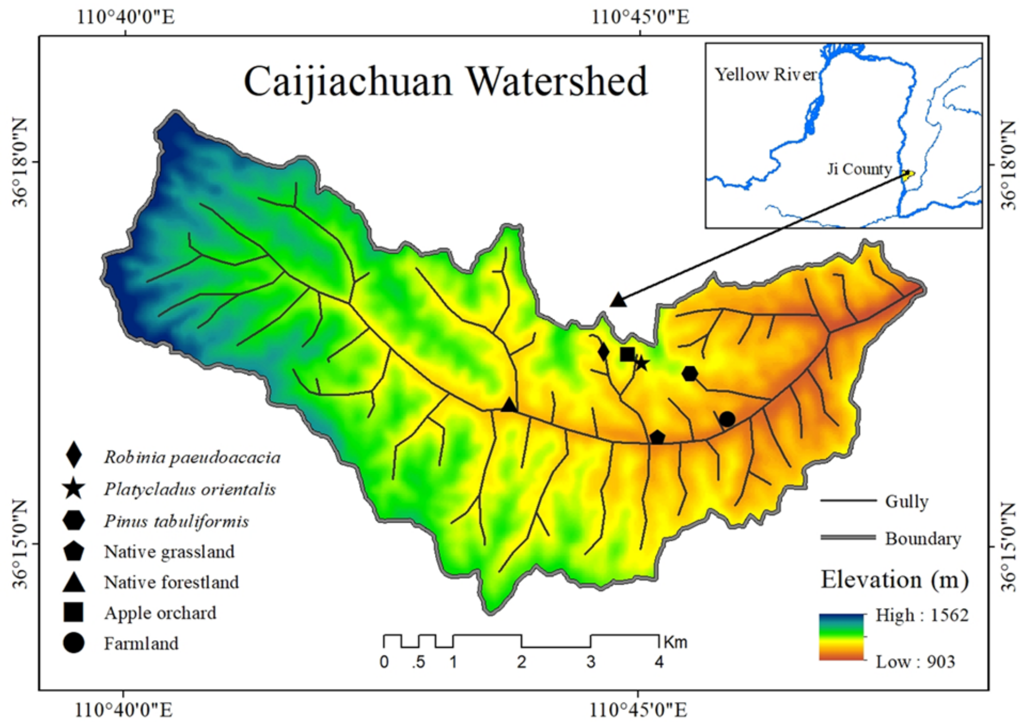

Figure 1 Location of the study area and experimental sites of the Caijiachuan Watershed in Ji County, Shanxi province, China.

drastically decreased most of the deep soil moisture in the summer (Yu et al. 2019). Mei et al. found that time and vegetation had a significant effect on soil water, and the different degree of soil water deficiency occurred in different hydrological years (Mei et al. 2018). However, few studies have excluded the impact of environmental change on soil water that is unable to accurately evaluate the impact of land use types on soil water.

In our study, we investigated the seasonal variation of soil water at the depth of 10 m under artificial forestland, apple orchard, farmland, native forestland and native grassland. The study aimed to (1) examine the characteristics of the distribution of the profile of soil moisture in the 0-10 m profile, (2) reveal the seasonal change of the soil water character, and (3) compare the depletion of the storage of soil water among different vegetation cover during three seasons.

1 Materials and Methods

1.1 Study area

The study area located in the Caijiachuan catchment (110°39'110°47'E, 36°14'—36°18'N) in the southwest of Shanxi Province (Figure 1). Its elevation ranges from 900-1513 m, and the primary soil type is classified as an alfisol. The climate of the Caijiachuan catchment is semiarid continental, and the long-term mean annual air temperature is 10°C. The annual average evaporation is 1723.9 mm. The annual average precipitation was 494.7 mm during 1985-2016, and 85% of the rainfall occurs primarily between May and October (Mei et al. 2018). The rainfall during the sampling period was shown in Figure 2.

1. 2 Sampling locations and data collection

We selected *Pinus tabulaeformis* (PT), *Robinia pseudoacacia* (RP), *Platycladus orientalis* (PO), apple orchard (AO), native forestland (NF), farmland (FL) and native grassland (NG) on the hillslope to investigate the soil water content. The crop species in the farmland is maize. The aspect of the slopes of all the sampling sites is sunny. Detailed information of the experimental locations is provided in Table 1. Soil samples were collected in the soil layer at depths of 0-10 m using a soil drill with 20 cm increments. The sampling period was from July 2018 to April 2020. The whole sampling period was divided into two periods, July

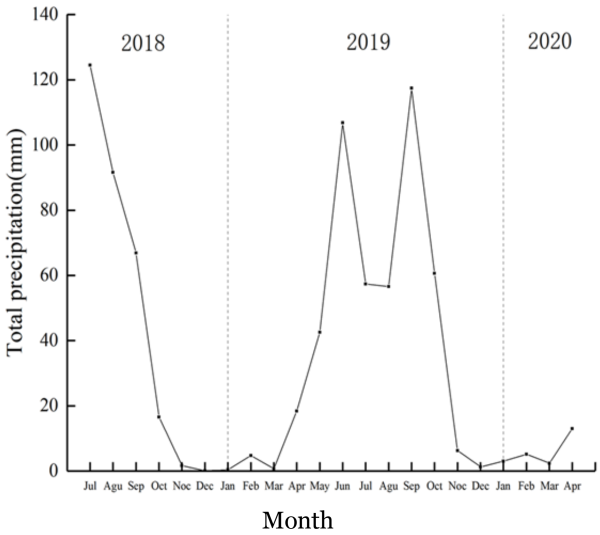

Figure 2 Precipitation during the whole study period in the Caijiachuan Watershed.

20 to 25, 2018 (summer), October 26 to November 1, 2018 (fall) and April 23 to 29, 2019 (spring) for the first period, and July 21 to 26, 2019 (summer), October 22 to October 27, 2019 (fall) and April 23 to 28, 2020 (spring) for the second period. No precipitation occurred during the sampling periods. Fifty soil samples were collected at each sampling site. All the soil samples were taken to the laboratory and oven-dried to determine the gravimetric soil water content. Three replicates of undisturbed soil cores were obtained using a ring knife (5 cm diameter and length) in a 0-2 m soil layer with 20 cm increments near each sampling site to measure the bulk density (BD).

1.3 Data analytical methods

The soil water storage at depth i for each season or land use type was calculated using the following equation (Liu et al. 2014):

$$\mathrm{SWS} = \sum \frac{10\theta_i d_i h}{\rho} \quad (1)$$

where SWS indicates the cumulative soil water storage (mm) at a depth of i; θ_i is the gravimetric soil moisture (%) in depth i, d_i indicates the soil bulk density (g/cm3); h is the soil layers thickness (20 cm in our study), and ρ represents the density of water (1 g/cm3).

Grassland will form naturally if there is no human management because of the limited rainfall in the Loess Plateau (Zhang 2007; Yu et al. 2015; Yao et al. 2020). Thus, the SWS in the native grassland should be regarded as a standard to analyze the effect of afforestation on soil water. A new indicator called the depletion of soil water storage (SWSD) is proposed to quantify the degree of influence of the artificial vegetation on soil water and can be calculated as:

$$\mathrm{SWSD}_{z,i} = \mathrm{SWS}_{z,i} - \mathrm{SWSD}_{0,i} \quad (2)$$

where $\mathrm{SWS}_{z,i}$ represents the soil water storage in depth i at land use type z, z=1, 2, 3, 4, 5 and 6 representing PT, RP, PO, AO, FL and NF, respectively. $\mathrm{SWS}_{0,i,}$ represents the soil water storage in depth i in the native grassland. If the SWSD > 0, it indicates that the soil water in the forestland is in a state of relative accumulation (RA), which indicates that afforestation benefits the accumulation of water. If the SWSD < 0, it indicates that the soil water in the forestland is in a state of relative deficit (RD), which indicates that afforestation could accelerate water consumption.

Multiple comparisons were made using the least significant different (LSD) method to compare the average soil water content among different land use types at the 0.05 level. All the statistical analyses were performed using SPSS (version 19.0, Chicago, IL, USA). All tables and figures were completed using Microsoft Excel

Table 1 Basic information of the sampling sites. DBH= diameter at breast height.

Sampling site	Altitude (m)	Slope	Primary vegetation type	DBH (cm)	Tree height (m)	Stand density	Canopy density
Artificial forestland	1124.0	21.1°	*Pinus tabuliformis*	9.830	5.120	2.5 m×3.5m	65%
	1140.0	24.1°	*Robinia pseudoacacia*	12.860	9.950	2.0m ×4.5m	50%
	1147.0	26.3°	*Platycladus orientalis*	7.510	6.045	3.0m ×3.0m	60%
Orchard	1196.0	24.8°	Apple	8.780	3.155	2.8m ×6.0m	18%
Native forestland	1074.3	21.8°	*Populus davidiana, Quercus wutaishansea* and *Acer buergerianum*	11.565	8.990	1475 plants in per ha	55%
Farmland	934.0	-	Maize	-	-	-	-
Native grassland	940.0	20.2°	*Carex humilis Leyss* and *Bothriochloa ischcemum*	-	-	-	85%

(version 2016) and Origin (version 2017, OriginLab, Northampton, MA, USA).

2 Results

2.1 Summary statistics of soil moisture

The summary statistics of the soil water content (SWC) at the various depths are listed in Table 2. The profile distribution of the SWC, standard deviation (SD) and coefficient of variation (CV) is presented in Figure 3 and Table 2. As indicated, the SWC, SD and CV were highly dependent on the depth. The highest value of the SWC (11.95%) was in the 0.3-0.4 m depths; the lowest (8.63%) was in the 5.6-5.8 m depths. However, both the distributions of SD and CV consistently changed with increasing depth. The highest values of both SD and CV were 5.07% and 0.47, respectively, at 0-0.1 m, which reflected the higher variability at this depth due to the effects of the surface environment. Moreover, the lowest values occurred at 5.4-5.6 m, which indicated that the variability was relatively lower at this soil depth. In the 0-10 m soil depth, the skewness (S) and kurtosis (K) values of the distribution curves of the SWC changed at different soil layers. The values of S were positive at 0.8-0.9, 2.8-3.0 m, 5.4-5.6 m, 6.2-6.8 m and 7.0-7.2 m, indicating that the distribution curves were right skewed at these depth ranges. The values of K were negative at 2.8-3.0 m and 3.6-3.8 m, indicating that the distribution curves of the SWC at these depth ranges were flatter than that of the normal distribution curve. The Kolmogorov-Smirnov test indicated that the distribution curves of the soil water content were normally distributed.

The SWC under different vegetation types is shown in Figure 4. The mean SWC under the different vegetation covers decreased in the following order: NG>FL>NF>PO>PT>AO>RP. In addition, the depth-mean SWC of the native grassland and farmland were significantly higher

Table 2 Summary statistics of the soil water content in different depths. SD, standard deviation. CV, coefficient of variation. S and K, skewedness and kurtosis of the distribution curves, respectively. K-S, Kolmogorov-Smirnov test value; N, normal distribution (significance level is 0.05), and the Kolmogorov-Smirnov value is in parentheses.

Depth (m)	Mean (%)	Max. (%)	Min. (%)	SD (%)	CV	S	K	K-S	Depth (m)	Mean (%)	Max. (%)	Min. (%)	SD (%)	CV	S	K	K-S
0.1	10.79	26.45	4.78	5.07	0.47	-0.70	0.87	N(1.608)	4.8	9.01	11.95	6.67	1.33	0.15	-0.76	0.14	N(1.196)
0.2	11.21	24.23	5.56	4.10	0.37	-0.31	0.83	N(1.013)	5.0	8.94	12.59	6.70	1.43	0.16	-0.27	0.44	N(0.943)
0.3	11.78	23.18	5.23	4.04	0.34	-0.93	0.62	N(0.791)	5.2	8.91	11.88	6.14	1.36	0.15	-0.52	0.28	N(0.959)
0.4	11.95	21.88	5.44	3.91	0.33	-0.99	0.59	N(1.137)	5.4	8.73	12.10	5.89	1.39	0.16	-0.13	0.26	N(1.041)
0.5	11.83	20.80	5.64	3.74	0.32	-0.82	0.56	N(1.111)	5.6	8.67	18.13	5.09	1.14	0.13	7.07	1.82	N(1.382)
0.6	11.84	18.78	6.98	3.29	0.28	-0.65	0.68	N(1.069)	5.8	8.63	12.31	5.82	1.59	0.18	-0.47	0.48	N(1.25)
0.7	11.46	17.40	7.29	2.98	0.26	-0.79	0.65	N(0.875)	6.0	8.67	11.93	5.71	1.66	0.19	-0.49	0.07	N(1.123)
0.8	10.86	15.79	7.24	2.36	0.22	-0.85	0.56	N(1.057)	6.2	8.98	13.31	5.98	1.64	0.18	0.38	0.44	N(0.999)
0.9	10.59	18.52	6.24	2.56	0.24	1.02	1.05	N(1.128)	6.4	9.39	13.26	6.18	1.61	0.17	0.20	0.46	N(0.78)
1.0	10.18	14.64	6.32	2.08	0.20	-0.47	0.31	N(0.672)	6.6	9.72	15.36	5.76	2.10	0.22	0.21	0.65	N(1.012)
1.2	9.81	14.33	6.39	1.93	0.20	-0.42	0.47	N(1.085)	6.8	9.57	15.51	5.71	2.23	0.23	0.22	0.58	N(1.054)
1.4	9.44	13.03	6.78	1.72	0.18	-0.94	0.40	N(1.03)	7.0	9.68	15.50	5.97	2.45	0.25	-0.20	0.53	N(0.865)
1.6	9.26	13.10	6.99	1.69	0.18	-1.21	0.34	N(1.047)	7.2	9.50	15.75	5.96	2.44	0.26	0.18	0.80	N(1.054)
1.8	9.13	13.02	5.89	1.86	0.20	-0.90	0.18	N(1.13)	7.4	9.49	15.86	5.63	2.50	0.26	-0.22	0.50	N(0.877)
2.0	9.25	14.47	5.83	1.93	0.21	-0.61	0.04	N(0.828)	7.6	9.58	15.69	5.61	2.56	0.27	-0.56	0.41	N(1.092)
2.2	9.14	12.93	6.61	1.66	0.18	-0.85	0.26	N(0.807)	7.8	9.58	14.88	5.47	2.73	0.28	-0.88	0.46	N(1.12)
2.4	9.09	14.24	6.38	1.93	0.21	-0.03	0.51	N(0.877)	8.0	9.78	15.75	5.22	2.78	0.28	-0.68	0.42	N(0.791)
2.6	8.97	12.62	6.34	1.92	0.21	-1.06	0.38	N(0.995)	8.2	9.90	15.56	5.16	2.76	0.28	-0.76	0.27	N(0.725)
2.8	9.13	13.59	6.29	2.06	0.23	-0.67	0.54	N(1.117)	8.4	9.71	15.47	5.26	2.74	0.28	-0.82	0.32	N(0.89)
3.0	9.02	14.06	-4.62	2.31	0.26	9.32	-2.21	N(1.045)	8.6	9.66	15.87	5.37	2.87	0.30	-0.62	0.56	N(1.239)
3.2	9.26	15.06	5.77	2.14	0.23	-1.10	0.24	N(1.11)	8.8	9.83	16.72	5.28	2.87	0.29	-0.46	0.52	N(0.854)
3.4	9.04	13.24	5.96	2.02	0.22	-0.96	0.36	N(0.889)	9.0	9.78	15.21	5.51	2.67	0.27	-0.83	0.27	N(0.943)
3.6	9.12	13.93	5.66	1.99	0.22	-1.18	0.10	N(0.744)	9.2	9.77	15.36	5.64	2.60	0.27	-0.59	0.41	N(0.816)
3.8	9.04	16.00	5.28	2.05	0.23	-1.05	-0.02	N(1.171)	9.4	9.97	16.22	5.53	2.66	0.27	-0.16	0.70	N(0.817)
4.0	9.21	14.84	6.53	1.82	0.20	-0.84	0.42	N(1.38)	9.6	10.08	17.18	5.71	2.79	0.28	-0.29	0.71	N(0.783)
4.2	8.94	12.85	6.38	1.48	0.17	-0.26	0.50	N(1.475)	9.8	9.99	16.78	4.61	2.81	0.28	-0.19	0.54	N(0.83)
4.4	9.08	12.81	6.69	1.42	0.16	-0.66	0.09	N(1.5)	10.0	10.14	16.92	5.44	2.72	0.27	-0.36	0.60	N(0.799)
4.6	9.23	12.36	6.48	1.37	0.15	-0.47	0.22	N(1.076)									

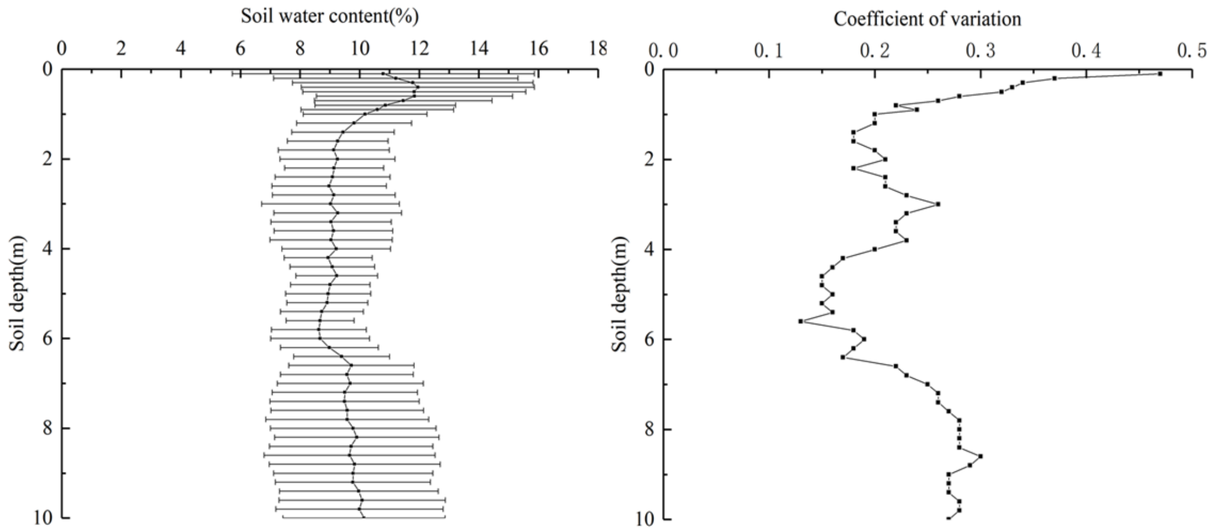

Figure 3 Vertical distribution of soil water content and the coefficients of variation. The error bars indicate the standard deviation.

Table 3 Soil water storage at different soil layers during the three seasons

Soil depth(m)	Summer			Fall			Spring		
	Mean(mm)	Min(mm)	Max(mm)	Mean(mm)	Min(mm)	Max(mm)	Mean(mm)	Min(mm)	Max(mm)
1	143.83	81.59	212.52	158.62	110.83	203.79	120.24	94.97	203.74
2	126.07	100.88	164.82	127.16	101.72	168.85	113.00	63.89	168.52
3	122.17	90.86	156.54	121.73	93.83	162.63	110.82	82.11	154.66
4	122.33	90.47	186.00	122.17	92.01	155.41	110.82	79.54	157.04
5	121.64	92.27	165.56	119.71	94.47	166.45	108.28	66.71	142.32
6	117.00	96.81	152.73	120.73	85.35	163.84	99.98	50.68	157.18
7	126.00	79.46	185.00	127.68	77.12	175.90	111.85	59.38	160.06
8	129.18	76.56	194.31	132.45	80.67	192.48	108.90	55.30	148.72
9	130.85	71.75	201.71	137.58	78.66	195.69	110.51	44.62	162.19
10	136.09	84.51	220.20	146.36	86.98	229.81	109.80	41.88	161.96

than those of the other types of vegetation (p<0.05). The average SWC of the introduced forestland was lower than that of the native forestland. In particular, the mean soil moisture in *Robinia pseudoacacia* had the significantly lowest value (p<0.05). These results indicated that artificial afforestation could lead to a deficit in the soil water, and *Robinia pseudoacacia* had the highest water consumption among the introduced types of vegetation studied.

2.2 Distribution of the profile of soil water storage during different seasons

The distribution of the profile of the soil water storage in the 0-10 m depth of soil under different seasons is shown in Table 3. The changes in the trends of the soil water storage were similar to those of the soil layer during the three seasons. Typically, it decreased first and then increased.

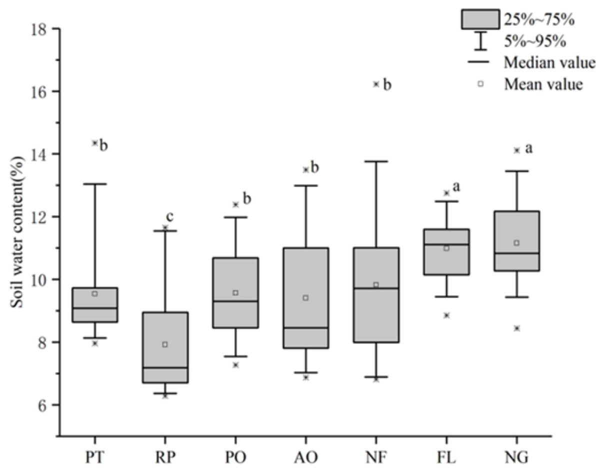

Figure 4 Average soil water content for the different types of vegetation. PT, RP, PO, AO, FL, NG and NF represent *Pinus tabuliformis*, *Robinia pseudoacacia*, *Platycladus orientalis*, apple orchard, farmland, and native grassland and native forest, respectively. Different lowercase letters indicate significant differences among the types of vegetation.

However, in the spring, the soil water storage under 7 m appeared to fluctuate.

At 0-2 m and 6-10 m, the soil water storage in fall was the largest, 5.55% and 3.86% higher than that in the summer, and 18.38% and 18.62% higher than that in spring, respectively. At the soil layer of 3-5m, the largest amount of soil water storage was in the summer, and the lowest was in spring. Overall, the SWS along the 0-10 m profile exhibited the following order: Fall (1314.18mm) > summer (127 5.16mm) >spring (1104.20mm). These results indicated that the character of the distribution of the SWS with the different soil layers varied among the three seasons.

2.3 Seasonal variation of the soil water storage deficit

The vertical distribution of the SWSD in the different seasons is presented in Figure 5. Figure 5a shows that the values of the SWSD in the summer were positive in the 0-1 m and 2-6 m layers, indicating that the soil water in these soil layers was in a state of relative accumulation. Moreover, the SWSD in the spring was positive in the 5-7 m. However, the SWSD in the 0-10 m profile was negative in fall. Figure 5b shows that the positive value of the SWSD was only present at 0-1 m during the second period of study, indicating that the soil water under 1 m was in a relative deficit. In addition, the changing trend of SWSD under 4 m was similar in fall and spring .During the two periods of study, the value of SWSD could be ordered as follows: summer > spring > fall.

2.4 Depletion of the soil water storage under different vegetation types

Among the three seasons, the profile of the variation of the SWS under the different types of vegetation displayed different characteristics (Figure 6, Table 4).

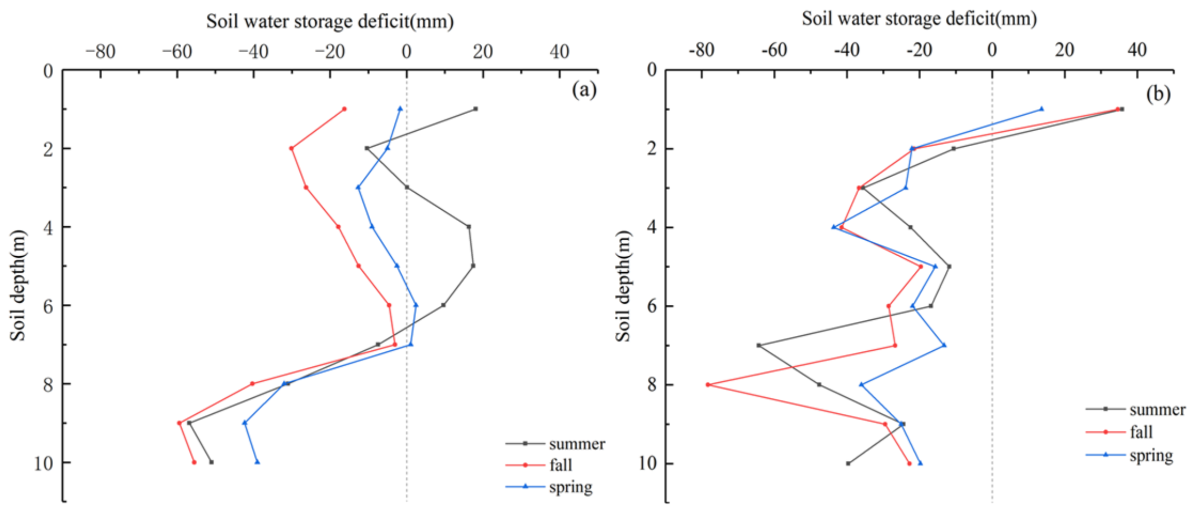

Figure 5 Vertical distribution of the depletion of the soil water storage in different seasons in the first (a) and second (b) periods, respectively.

Table 4 The profit and loss of soil water storage under different types of vegetation. RA, relative accumulation. RD, relative deficit. SWSD, depletion of soil water storage. PT, RP, PO, AO, FL, NG and NF represent *Pinus tabuliformis*, *Robinia pseudoacacia*, *Platycladus orientalis*, apple orchard, farmland, native grassland and native forest, respectively.

Vegetation types	Summer			Fall			Spring		
	RA (mm)	RD (mm)	Total SWSD (mm)	RA (mm)	RD (mm)	Total SWSD (mm)	RA (mm)	RD (mm)	Total SWSD (mm)
PT	48.50	-279.41	-230.90	23.87	-356.46	-332.59	0.52	-231.76	-231.24
RP	38.20	-423.87	-385.67	1.15	-513.35	-512.20	0.00	-418.97	-418.97
PO	23.58	-97.63	-74.05	0.00	-215.17	-215.17	9.29	-154.05	-144.75
AO	65.48	-329.97	-264.49	23.08	-354.82	-331.74	37.14	-270.61	-233.47
FL	182.71	0.00	182.71	101.18	-72.85	28.33	140.23	-19.24	120.99
NF	12.88	-365.18	-352.31	36.52	-292.36	-255.84	20.78	-164.68	-143.90

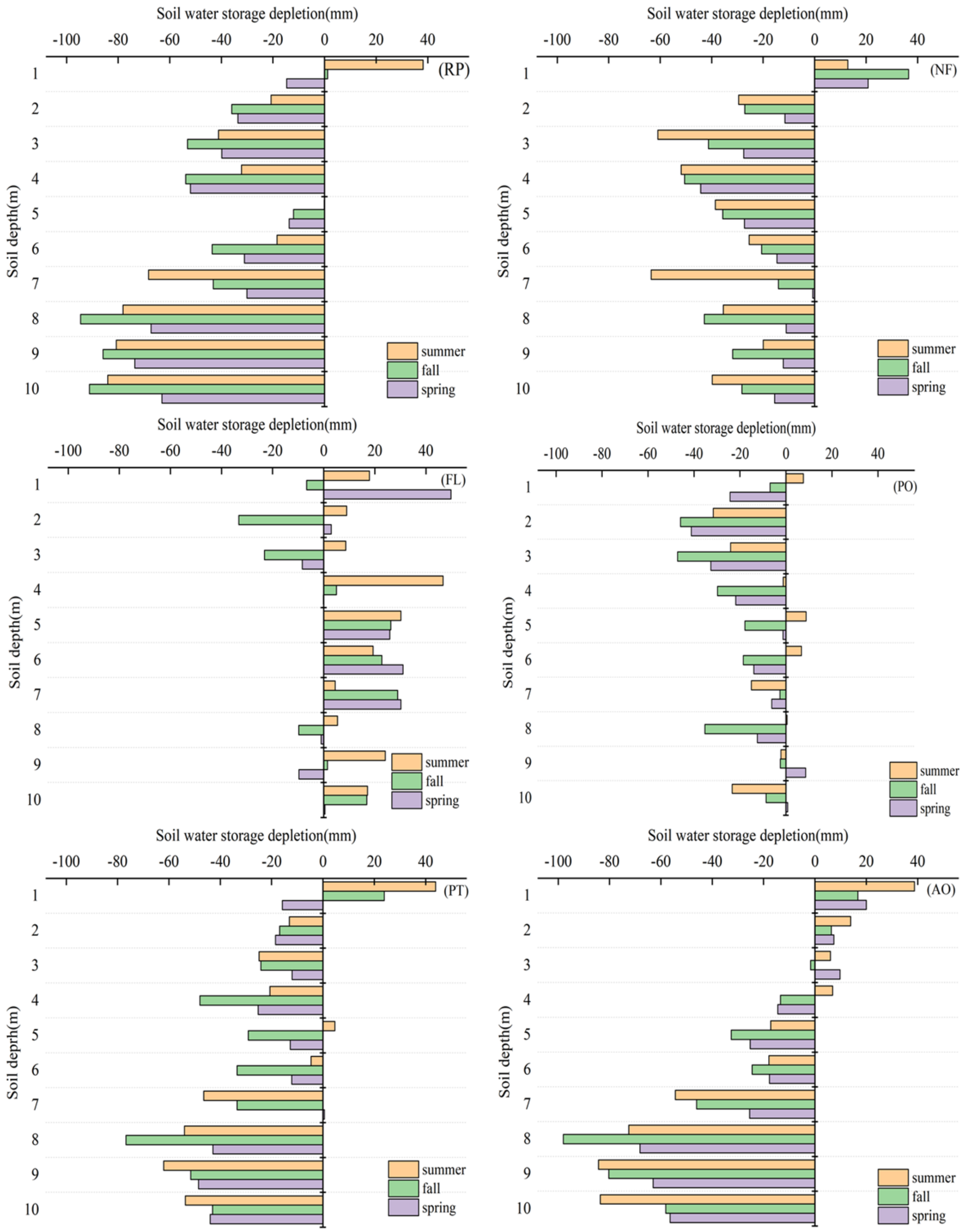

Figure 6 Profile of the distribution of soil water storage depletion under different vegetation types. PT, RP, PO, AO, FL, NG and NF represent *Pinus tabuliformis*, *Robinia pseudoacacia*, *Platycladus orientalis*, apple orchard, farmland, and native grassland and native forest, respectively.

In PT, the soil water was in a state of relative accumulation at the depths of 0-1 m and 4-5 m in the summer, and the value of relative accumulation was 48.50 mm. In the fall, the depth of the soil water accumulation was 0-1 m, while the values of the SWSD (356.46 mm) in the other layers were negative, which was the largest value of the relative deficit among the three seasons. Furthermore, the lowest value of relative deficit occurred in spring.

In RP, the value of the SWSD in the 0-1 m was positive in the summer and fall, and the relative accumulation was 38.20 mm and 1.15 mm, respectively. However, the values of the SWSD were negative among the entire profile in the spring, which illustrated that compared with the native grassland. *Robinia pseudoacacia* would consume more soil water in the 10 m depth if no rainfall occurred. Moreover, the greatest relative deficit (512.20 mm) was in the fall.

In PO, the values of the SWSD in the summer were positive at the depths of 0-1 m and 4-6 m, and the relative accumulation was 23.58 mm. The values of the SWSD were negative among the entire profile in the fall, while the depth of the relative deficit was 0-8 m in the spring. The lowest relative deficit (74.05 mm) was in the summer.

In AO, the soil water was in a state of relative accumulation at the depth of 0-4 m in the summer, 0-2 m in the fall, and 0-3 m in the spring, respectively. The relative accumulation in the summer was 42.40 mm higher than in the fall and 28.35 mm higher than that in the spring. The highest amount of water consumption was in the fall, and the relative deficit was 331.74 mm.

In FL, the values of the SWSD were positive among the entire profile in the summer, which showed that the soil water was in a state of relative accumulation in the 10 m soil depth. In the fall, the depths of relative accumulation of the soil water were 3-7 m and 8-10 m. The soil water at 2-4 m and 7-9 m was in a relative state of consumption. Among the entire profile, the sum of the SWSD was the lowest in the fall (28.33 mm) and the largest in the summer (182.71 mm).

In NF, the depths of the relative accumulation of soil water were 0-1 m during the three seasons, which illustrated that the water consumption of natural forest under 1 m was higher than that of native grassland. The total SWSD was ordered as follows: summer (-352.31 mm) < fall (-255.84 mm) < spring (-143.90 mm).

Overall, the depths of influence of all the cover types of vegetation on the soil water in the study sample plots were up to 10 m. In addition, there were different degrees of water deficits in 8-10 m under different land use types among the three seasons. Moreover, the soil deficit of PT, RP and AO was more serious in the deeper layers than in the shallow layer, while those of PO were the opposite. Only FL had a positive value of the total SWSD, indicating that the soil water in the whole soil layer had accumulated. Because of the negative values of the total SWSD in the artificial forestland, apple orchards and native forestland, the soil water was in a relative deficit state. In addition, the largest relative accumulation was in the farmland in the summer, and the largest relative deficit was in the fall of RP.

3 Discussion

3.1 Features of the distribution of the soil water in the Loess Plateau

The features of the distribution of the soil water content in the selected study sites varied with the increasing depth. The highest value of the depth-averaged soil moisture (11.95%) was observed at depths of 0.3-0.4 m. The lowest (8.63%) was observed at depths of 5.6-5.8 m in which the mean soil moisture was almost constant (Figure 3 and Table 2). The shallow soil water exhibited a higher coefficient of variation, which was largely due to the strong influences of precipitation, temperature and evapotranspiration. The fluctuating trend of the CV in the 2-4 m soil layers indicated that the degree of the mean soil moisture varied inconsistently. Possible explanations for these results may be the differences in the water use patterns of the vegetation. In general, different vegetation types produce different root systems and adjust their utilization of the depth of soil water to respond to seasonal changes (Wang et al. 2017). Thus, the 2-4 m soil layer might be the primary depth of water use in the study area.

In the Loess Plateau, the groundwater hides so deeply below the surface of the ground that is difficult for vegetation to be absorb it, and the limited rainfall is the only source of accessible soil water (Wang et al. 2013; A et al. 2018). Therefore, the features of the distribution of soil water are affected by rainfall with large inter-annual variability (Wei et al. 2009; Zhang et al. 2016). Moreover, the biorhythms of the growth of vegetation and the seasonal changes of temperature could further aggravate the seasonal change in soil water. In our study, clear seasonal differences of 0-10 m were found in the SWS. The highest value of SWS was in the fall (1314.18 mm), while the lowest was in the spring (1104.20 mm) (Table 3). In general, the precipitation of the Loess Plateau primarily occurs during the growing season (May to September) (Shi and Shao 2000), and the water required for plant growth might be reduced with the decrease in the atmospheric temperature in the fall (Hu et al. 2012; Xiao et al. 2014; Shao et al. 2018).

Thus, the soil water could recover in the fall because of the relatively high degree of precipitation and lower evapotranspiration. In this study, our findings that the SWS is the lowest in spring is inconsistent with a previous study, which found that the lowest soil water content was in the summer (Yu et al. 2019). This divergence was probably caused by the differences in precipitation during the summer and winter. If there is more snowfall in the winter, a large amount of melted snow will infiltrate into the soil layer to increase the soil moisture content, but if the amount of rainfall in summer is lower, this difference might lead to lower soil moisture in the summer than in the spring. In contrast, compared to the spring, the soil moisture in the summer was higher when there was more precipitation in the summer and less in the winter.

3.2 Effects of different vegetation cover on the depletion of soil water storage

The soil water storage deficit caused by the water consumption of the vegetation varied between the seasons (Figure 5). The lowest values of SWSD are in the fall, indicating that compared with native grassland, the differences of soil water storage recovery in fall is the largest under different vegetation types. This result illustrated that even in the fall with the accumulation of more soil water, the amount of accumulation of soil water under these cover types of vegetation was less than that in the native grassland. Overall, planting vegetation not only consumes soil water under the growth period resulting in soil water with seriously deficient conditions but reduces the amount of soil water recovery in cumulative periods. Therefore, the artificial vegetation is in a state of deficit for a long time.

In general, there are differences in the soil water among different land use types (Burylo et al. 2012; Zhao et al. 2017). In this study, the depth-averaged soil moisture in the artificial forestlands was significantly less than that in the native grassland and farmland, and the depth-averaged soil moisture in the native forestlands was higher than that in the artificial forestlands (Figure 4). This result fully shows that the man-made forests have consumed more soil water. The rationale for this might be that the vegetation chosen had a deep root system and rapid growth to achieve a high survival rate and cover the bare ground quickly during the implementation of the "Grain and Green" project in the Loess plateau. As a result, artificial vegetation absorbs and consumes more soil water. Compared with the artificial vegetation, the native secondary forest is the result of natural recovery and natural selection. Its consumption of soil water could match the local precipitation resources, which is more suitable for the local ecological environment.

The consumption of soil water primarily depends on the amount of evaporation; thus, different types of vegetation showed different traits of water deficit (Figure 6). This result is inconsistent with that observed by Yang et al., which showed that the soil water did not differ significantly under different types of vegetation (Yang et al. 2012). The difference likely occurred because the mean annual precipitation was greater in our study area (494.7 mm) than that of Yang et al. (2012) (386 mm). The lower amount of precipitation did not fully supply the soil water, which caused the relatively consistent situation of a deep soil water deficit under various vegetation types. In general, the root depth is primarily located in the 0-0.5 m soil layers in the grassland (Han et al. 2009), and the selected grassland in our study had barely been affected by human disturbances (Yang et al. 2012). Therefore, selecting the same period of grassland as a standard can better reflect the soil water deficit caused by the planting of vegetation. In this study, in the 0-10 m soil layers of artificial forestland, an apple orchard and native forestland, the accumulation of water was far less than the deficit during the study periods, indicating that the different degrees of deficit in the entire 0-10 m soil layer occurred because of the growth of forests. Moreover, the values of the SWSD were less than 0 at the depth of 8-10 m, showing that the depths of influence on the recovery of vegetation on soil water had reached a depth of 10 m. The result is likely because the artificial vegetation types have deeper root systems, particularly since the depth of the *R. pseudoacacia* roots could be 7 m (Wang et al. 2009) and utilize the deep soil water. However, the recharge depth of the rainfall is relatively shallower. To maintain the water balance of the soil layer, the deeper soil water moves to the upper layer driven by the water potential gradient to supply the water deficiency of the upper layer, which will inevitably lead to the intensification of the depth at which there is a deficit of soil water. Moreover, compared with artificial forestland, the SWSD of the native forestland was lower, indicating that artificial vegetation consumes more soil water, which is in deeper soil layers. Therefore, it may be difficult to recover the soil water consumed by artificial vegetation by depending only on rainfall.

3.3 Implications for vegetation recovery

After large-scale afforestation in the Loess Plateau, the ecological environment has been improved, and soil erosion has been effectively controlled. However, the soil water deficit caused by afforestation may affect the function of vegetation in ecological service and threaten the sustainability of the environment (Chen et al. 2008b; Wang et al. 2012; Jia et al. 2015; Yan et al. 2015). Due to the deep and loose soil layer in the Loess Plateau, the limited rainfall can not restore the water content of the whole soil layer. Thus, maintaining the balance of soil water replenishment and consumption is the key to ensuring sustainable and stable benefits during ecological restoration periods. According to this study, the soil moisture of the artificial forestland was significantly lower and compared with the grasslands, the forestland caused a water deficit. Thus, local tree species should be selected as much as possible based on the local soil water carrying capacity and environmental conditions. Moreover, the degree of the soil water deficit decreased gradually with time (Figure 6), showing that the native forest can adapt more effectively to environmental changes by adjusting the demand for water and then achieve a balance between water consumption and the local soil water supply capacity. Thus, the best choice to ensure the sustainable development of vegetation construction in the Loess Plateau will be by closing hillsides to facilitate afforestation to recover the vegetation naturally. Similarly, native grass with capacities of low water consumption could be chosen at the locations with less precipitation or slight soil erosion. Moreover, the control of vegetation to raise the diversity of species by thinning could be an effective measure to improve the soil water under artificial forestlands with a serious soil water deficit.

4 Conclusions

This study focused on the seasonal changes of soil water influenced by different types of vegetation. There were some vertical changes in the content of soil water and a change in the degree of different soil layers, and the soil water content of the shallow layer was the highest. During the three seasons, fall had the largest amount of soil water storage, since it served as the soil recovery period. However, the values of the water storage caused by the vegetation cover were lower than those of the native grassland. Compared with the native grassland, the depth of influence of the vegetation coverage on soil water had reached as far as 10 m. In addition to that of farmland, the soil water of forestlands was in a relative deficit state in a soil layer of 10 m, and the deep soil loss in the lands on which *Pinus tabulaeformis*, *Robinia pseudoacacia* and the apple orchard were located was greater than that in the shallow layer. In this study, the relative accumulation of the soil water in the summer was the largest in the farmland, and the relative deficit of the soil water in the fall is the smallest in the land under *R. pseudoacacia*. Therefore, in future vegetation management, the selection of appropriate vegetation and reasonable stand management should be conducted to achieve the maximum stand efficiency based on the local soil moisture, human activities and economic needs.

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