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ORIGINAL PAPER

Effects of Long-Term Vegetation Restoration on Distribution of Deep Soil Moisture in Semi-arid Northwest of China

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Abstract

We aim to understand the distribution of soil moisture and its controlling factors for regional vegetation restoration in a semi-arid sandy land. The top 500 cm soils of the main introduced vegetation types restored for different years in Chinese Mu Us Sandy Land were collected, and the soil moisture and influencing factors were analyzed. The results demonstrated that the total soil water storage decreased in a sequence of shrub land (S) > arbor land (A) > shifting sandy land (CK) > grassland (G). With the increase of restoration period, the soil moisture increased in arbor land and decreased first and then increased in both shrub land and grassland. Soil moisture was negatively correlated ($P < 0.05$) with root length density (RLD) in G_{56}, S_{36}, A_{21}, and S_{21}. RLD and soil moisture in S_{56} showed an extremely significant negative correlation ($P < 0.01$). Soil water content had a positive correlation with silt content ($P < 0.05$) but demonstrated a negative correlation with the sand content ($P < 0.05$) in A_{56}. Both silt and sand contents showed negative correlations with soil moisture in G_{56} ($P < 0.05$). In summary, vegetation type, restoration period, RLD, and silt and clay contents have significant effects on soil moisture. To improve the soil moisture status, arbors and bushes should be preferentially considered for vegetation restoration in semi-arid northwest of China.

Keywords Introduced vegetation · Deep vadose zone · Soil moisture · Soil water storage · Mu Us Sandy Land

Abbreviations

A_{xy}	Arbors restored for *xy* years
S_{xy}	Shrubs restored for *xy* years
G_{xy}	Grassland restored for *xy* years
RLD	Root length density

1 Introduction

Desertification is one of the hot ecological issues in the world, and China is one of the countries with the most serious desertification. The soil moisture in arid and semi-arid areas of northwestern China has attracted much attention due to the rapid expansion of desertified land (Yu et al. 2018; Liu et al. 2018a). Desertification will lead to a series of ecological and environmental problems, such as soil structural damage, nutrient loss, reduction of soil biodiversity, and soil texture coarsening. Vegetation restoration is an important measure to prevent desertification. It is known that soil moisture is one key factor controlling plant growth and vegetation carrying capacity in desert regions and is also one key factor controlling regional ecological environment (Pan et al. 2015; Wang et al. 2012a). The spatiotemporal changes of soil moisture in arid and semi-arid areas are mainly affected by precipitation, vegetation, and soil physical properties (Fu et al. 2018). Mei et al. (2018) found that after restoration, the soil water content of arbor land increases first and then decreases with increasing soil depth, and the consumption of deep soil moisture gradually increases with the forest age (Liu et al., 2018b). However, soil moisture in grassland decreased first and then increased and stabilized finally at a certain depth (Mei et al., 2018).

Meanwhile, the same vegetation type had different water use efficiency during different growth stages (Li et al.

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2017a). Previous studies mainly focused on the soil moisture status of a single vegetation type, while the difference between different vegetation types was not comprehensively considered, especially for the influence of vegetation type on deep soil moisture. The understanding of soil moisture distribution is important for the efficient use of water resources, for preventing and controlling land desertification, and for restoring degraded ecosystems in arid and semi-arid regions.

In recent years, the studies of soil moisture mainly focused on shallow soils (less than 100 cm) (Zhou et al. 2015; Gao et al. 2011; Gaines et al. 2016), and most of the studies considered the influence of vegetation type (Zheng et al. 2015; Gómez et al. 2000; Jia and Shao 2014), restoration period (Skubel et al. 2015; Wafa et al. 2018; Song et al. 2018), root biomass (Pan et al. 2015; Xiao and Huang 2016), precipitation (Li et al. 2015; Yang et al. 2018; Liu et al. 2016), or other single factors on soil moisture, but limited reports were related to the factors affecting the moisture of deep soil layers. For more than 50 years, plants have been used to restore the semi-arid northwest of China, and the land coverage, ecological environment, and soil quality are becoming better and better. However, more soil moisture may be consumed by the vegetation. Here, we hypothesized that soil moisture will decrease after vegetation restoration. Thus, in this paper, we sampled the soils under different vegetation types restored for different years in the Mu Us Sandy Land and analyzed their moisture status, aimed to explore the effects of vegetation type, restoration period, root length density (RLD), and texture on the moisture distribution of the deep soil profile (0–500 cm depth) and to determine the optimal plant type for vegetation restoration.

2 Material and Methods

2.1 Study Area

The study area is located in the introduced vegetation area of Hongshixia, Yulin City, Shaanxi Province (Fig. 1), on the southeastern edge of the Mu Us Sandy Land (38°19′–22′ N, 109°37′–49′ E) with an altitude of 1098–1158 m. This area belongs to a temperate semi-arid continental monsoon climate zone with an average annual rainfall of 250–400 mm that mainly occurs in July–September, but the potential evaporation intensity is up to larger than 2000 mm. Average annual temperature is 6.0–8.5 °C. The soil type here is weakly alkaline eolian sandy soil. The introduced vegetation mainly consists of drought-resistant species (e.g., *Pinus sylvestris* var. *mongolica* Litv., *Caragana korshinskii* Kom.,*Hippophae rhamnoides* Linn., *Artemisia lavandulaefolia* DC., and *Heteropappus altaicus* (Willd.) Novopokr.).

2.2 Sampling Sites' Selection

Three types of introduced vegetation including arbor land (A), shrub land (S), and grassland (S) were chosen, each vegetation type included 3 restoration periods (56, 36, and 21 years), the restoration years were recorded by long-term monitoring data, and bare shifting sandy land was used as the control (CK). Here, to reduce the impact of site conditions on soil moisture status, all sampling plots were selected at flat sandy land, which means that their site conditions are similar. Selected characteristics of the sampling sites are listed in Table 1, while the vegetation coverages were determined by field measurement, and they refer to the percentage of the ratio of the vertical projected area of the above-ground parts of the sampling sites to the site area. To reduce the impact of vegetation coverage, the sampling sites we selected had a similar coverage. Furthermore, all sampling plots are located in the Hongshixia Desert Botanical Garden, and the groundwater level is deeper than 20 m. Thus, we assumed that climate and groundwater have no impact on soil moisture among different sampling spots.

2.3 Sample Collection and Analysis

Soil samples were collected in early September 2017, late April 2018, and late September 2018. Soil and root samples at different depths were collected using a root auger of 6 cm diameter. Three random points were chosen for sample collection from each site every time, resulting in 9 replicates for each treatment. Soils and roots were collected at the depths of 0–5 cm, 5–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, and every 20 cm at the 40–500 cm depth. In order to reduce the spatial variation, the distance between different vegetation types of each restoration period is less than 500 m.

All samples were divided into two equal parts and transferred to the laboratory, in which one part was used to determine the water content and particle composition and another was used for RLD determination. Soil moisture was determined by mass method after drying at 105 °C for 12 h. Soil particle composition was determined by the pipette method after being air-dried and passed through a 2 mm mesh. For RLD determination, the roots were picked out using a 2 mm mesh firstly, followed by rinsing with running water and deionized water. The roots were scanned and analyzed with the WinRHIZO software to obtain the RLD.

Soil bulk density of the 0–30 cm layer was determined using a cutting ring, whereas the bulk density beneath 30 cm was assumed to be equivalent to the bulk density of shifting sand, because vegetation restoration on sandy land mainly affects the bulk density of 0–30 cm surface soil (Lan et al. 2017). Soil water storage was calculated by the following equations:

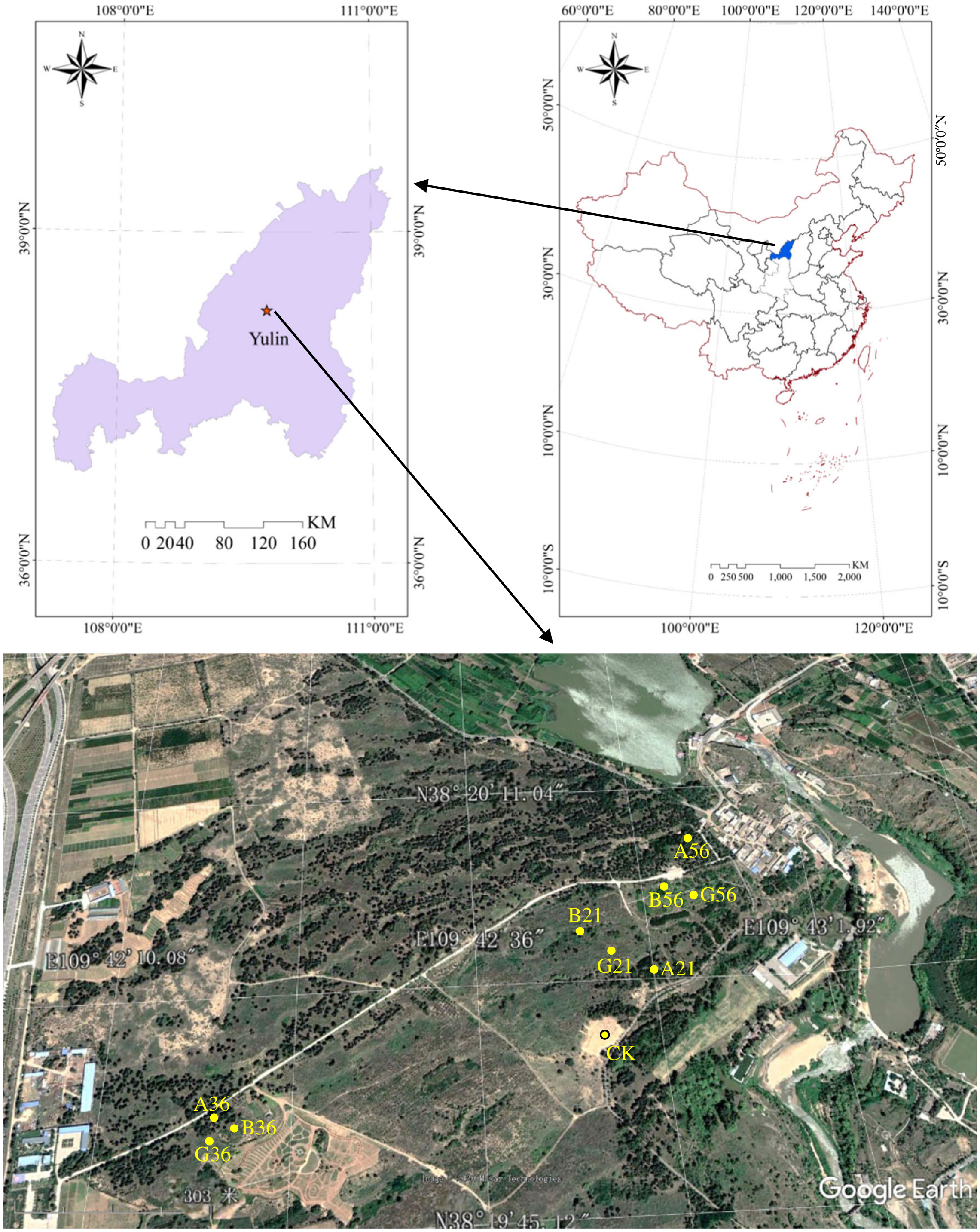

Fig. 1 Location of the study area and the sampling sites in Shaanxi Province of China. A_{56}, A_{36}, and A_{21}: arbor land restored for 56, 36, and 21 years. S_{56}, S_{36}, and S_{21}: shrub land restored for 56, 36, and 21 years. G_{56}, G_{36}, and G_{21}: grassland restored for 56, 36, and 21 years. CK: shifting sandy land. The distribution figure of sampling sites was from Google Earth Pro

$$W_i = \frac{10 \times h_i\ \gamma_i \omega_i}{\rho} \tag{1}$$

$$W = \sum W_{i,500} \tag{2}$$

$$\gamma_i = \frac{m_i}{(1 + \omega_i/100)\ V} \tag{3}$$

where W_i is the soil water storage of each layer (mm); h_i is the thickness of each soil layer (cm); ω_i is the mass water content (%) of each soil layer; ρ is the density of water

Table 1 Selected characteristics of the sampling sites

Sampling site	Description	Bulk density (g/cm^3)	Vegetation coverage (%)	Plant composition
A_{56}	Arbor planted for 56 years	1.40	90	*Pinus sylvestris* var. *Mongolica* Litv.
S_{56}	Shrub planted for 56 years	1.32	90	*Caragana korshinskii* Kom., *Artemisia halodendron Turcz.* ex Bess.
G_{56}	Grass restored for 56 years	1.33	90	*Artemisia lavandulaefolia* DC
A_{36}	Arbor planted for 36 years	1.47	90	*Pinus sylvestris* var. *mongolica* Litv.
S_{36}	Shrub planted for 36 years	1.37	85	*Caragana korshinskii* Kom., *Hippophaerhamnoides* Linn., *Hedysarum mongolicum* Turez.
G_{36}	Grass restored for 36 years	1.43	85	*Artemisia lavandulaefolia* DC, *Heteropappus altaicus* (Willd.) Novopokr.
A_{21}	Arbor planted for 21 years	1.45	85	*Pinus sylvestris* var. *mongolica* Litv.
S_{21}	Shrub planted for 21 years	1.40	80	*Caragana korshinskii* Kom., *Amorpha fruticosa* Linn.
G_{21}	Grass restored for 21 years	1.49	85	*Heteropappus altaicus* (Willd.) Novopokr., *Setaria viridis* (L.) Beauv.
CK	Shifting sandy land	1.60	< 10	—

The soil bulk density is an average of 0–30 cm

(g cm^{-3}); W is the total soil water storage in the 5 m soil profile (mm); γ_i is the soil bulk density (g cm^{-3}); m_i is the soil weight of each layer; V is the soil volume of each layer; and 10 and 100 are conversion coefficients.

2.4 Data Analysis

Data from the nine replicates were means, and the standard deviations were calculated. Statistical analysis was performed with Excel 2007 and SPSS 19.0. Correlation analysis of soil water content, RLD, and soil particle composition was done by the Pearson method. Variance analysis and multiple comparisons were done using the one-way ANOVA, Duncan, and LSD methods.

3 Results

3.1 Effects of Vegetation Type on Vertical Distribution of Soil Water

There were significant differences in the average soil water content among different vegetation types within the same restoration period (Table 2). The data showed that the average soil water content of the whole soil profile in arbor land (4.67%) was the highest, followed by shrub land (4.63%) and CK (4.20%), and the grassland (3.67%) was the lowest. The average soil water content of the arbor lands and the shrub lands were 0.47% and 0.43% higher than that of CK, respectively, and the grassland was 0.53% lower than that of CK. The soil water content of A_{56} increased firstly and then decreased with the depth (Fig. 2). The soil water contents of 0–80 cm and 100–440 cm were significantly higher than that of CK. Soil water content in shrub lands showed a fluctuant increasing trend. The soil water content at the depth of 240–500 cm was higher than that of CK. Vertical distribution of soil moisture in the grasslands showed a same trend as the shrub lands. Soil water contents at the depths of 5–240 cm, 260–320 cm, and 380–400 cm were significantly lower than those of CK. The soil water content of A_{36} increased gradually with the soil depth, and 120–160 cm and 300–400 cm soil layers were significantly higher than that of CK. Soil water content in shrub lands increased firstly and then decreased with increasing soil depth, and its value at 220–340 cm was higher than that of CK. The variation of soil water content in the whole profile of grasslands was consistent with that of the shrub lands, and its value at 220–300 cm was obviously higher than that of CK. Soil water content of A_{21} showed an increasing tendency with increasing soil depth, and the values

Table 2 Significance tests on difference of soil water content (%) among different treatments with LSD method

Restoration period (year)	Arbor land	Shrub land	Grassland
56	6.16 ± 2.47Aa	4.79 ± 2.47Bb	3.55 ± 1.22Cb
36	4.00 ± 1.55Ab	3.48 ± 1.44Bc	3.32 ± 1.81Bb
21	3.84 ± 1.52Bb	5.61 ± 2.37Aa	4.14 ± 1.79Ba

Different capital letters indicate significant differences ($P < 0.05$) of soil moisture among vegetation types restored for the same years; different lowercase letters indicate significant differences ($P < 0.05$) of soil moisture among the same vegetation under different restoration periods

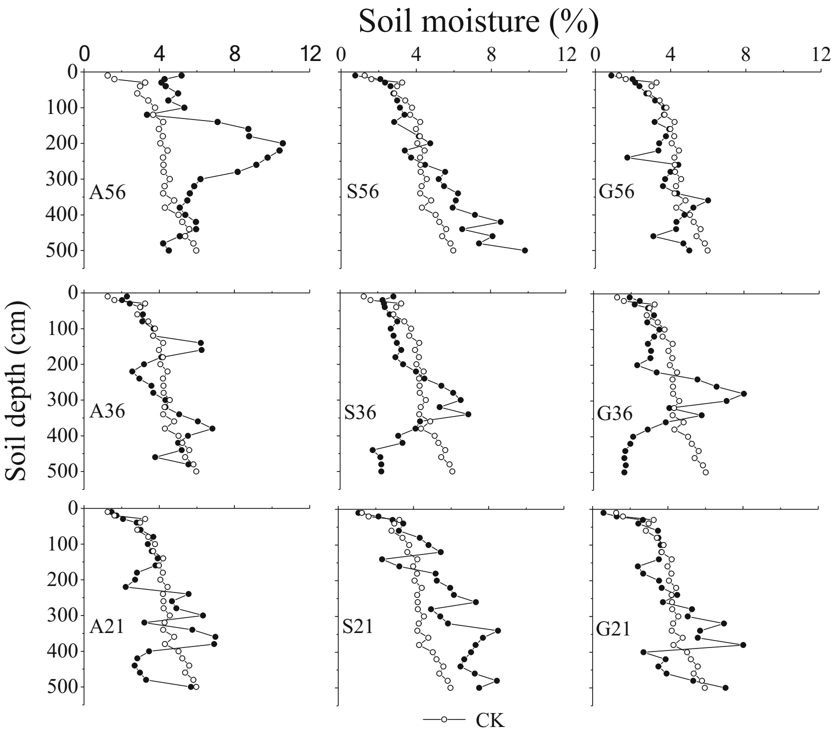

Fig. 2 Vertical distribution of soil moisture under different vegetation types restored for different years. A_{56}, A_{36}, and A_{21}: arbor land restored for 56, 36, and 21 years. S_{56}, S_{36}, and S_{21}: shrub land restored for 56, 36, and 21 years. G_{56}, G_{36}, and G_{21}: grassland restored for 56, 36, and 21 years; CK: shifting sandy land

at 220–300 cm and 320–380 cm were higher than that of CK. Soil water content in the shrub lands showed an increasing trend with soil depth; the values at 30–120 cm and 160–500 cm were significantly higher than that of CK. The change of soil water content in the whole profile of grassland was consistent with that of the shrub lands, and the moisture at 260–380 cm was obviously higher than that of CK. Surface soil water contents of the arbor lands and grasslands and S_{36} were higher than that of CK.

3.2 Effects of Restoration Period on Soil Moisture Distribution

Table 2 shows that there were significant differences in average soil water content among different restoration periods. The average soil water content of the arbor lands increased with increasing restoration period. The average soil water content of A_{56} was 1.96% higher than that of CK. However, the average soil water contents of A_{36} and A_{21} were 0.20% and 0.36% lower than that of CK, respectively. Soil moisture at the depth of 120–300 cm in A_{36} was relatively higher, and it showed a "convex" shape in the vertical direction. Soil moisture of A_{56} in the vertical direction tended to turn into a "concave" shape. However, the soil moisture of A_{21} increased fluctuantly with increasing soil depth (Fig. 2).

Average soil water content of the shrub lands restored for different years ranked in the order of S_{21} (5.61%) > S_{56} (4.79%) > CK (4.20%) > S_{36} (3.48%). Among them, S_{21} and S_{56} were 1.41% and 0.59% higher than CK, respectively, while S_{36} was 0.72% lower than CK. The surface soil (0–5 cm) water content of the shrub lands increased firstly and then decreased with restoration period. Soil water content in the vertical direction of S_{56} showed a fluctuant increasing tendency, and the soil water content of S_{36} and S_{21} changed into the vertical direction with a "convex" shape (Fig. 2).

Average water content of the whole soil profile in grasslands decreased as CK (4.20%) > G_{21} (4.14%) > G_{56} (3.55%) > G_{36} (3.32%). The average soil water content of G_{56}, G_{36}, and G_{21} was 0.65%, 0.88%, and 0.06% lower than that of CK, respectively. The Soil water content of G_{56} increased with increasing soil depth, and the soil water content of G_{36} and G_{21} showed a "convex" shape. Although water content of some soil layers in these three restoration periods of grassland was higher than that of CK, the overall average water content was less than that of CK.

3.3 Soil Water Storage

Total soil water storage of the 5 m profile in different sampling sites followed an order of A_{56} > S_{21} > S_{56} > CK (354.93 mm) > G_{21} > A_{36} > A_{21} > G_{56} > S_{36} > G_{36}. A_{56} was the highest which was 150.19 mm higher than that of CK. G_{36} was the lowest (272.10 mm) and was 82.83 mm less than that of CK. It can be seen from Fig. 3 that the total soil water storage of the 5 m profile in A_{56} was much higher than other treatments and the soil water storage of 100–420 cm was significantly higher than that of CK. S_{21} (483.18 mm) and G_{21} (352.00 mm) had the largest soil water storage in the shrub lands and the

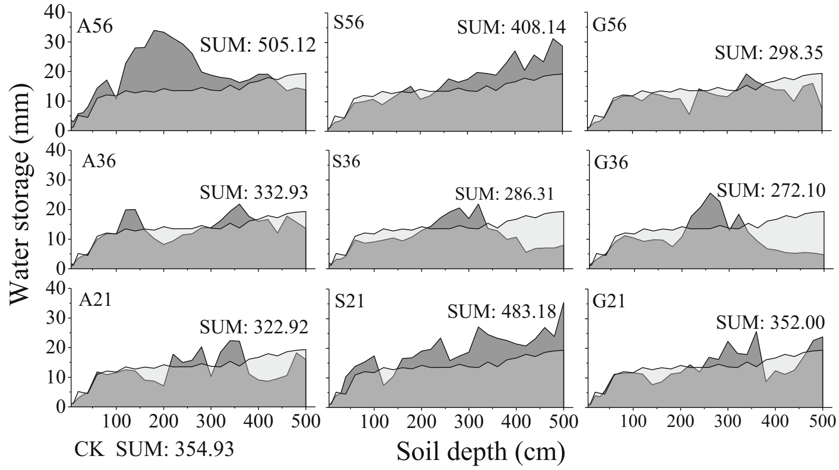

Fig. 3 Vertical distribution of soil water storage under different vegetation types restored for different years (light color is the soil water storage of CK (shifting sandy land)). SUM means the total water storage of 500 cm; A56, A36, and A21: arbor land restored for 56, 36, and 21 years. S56, S36, and S21: shrub land restored for 56, 36, and 21 years. G56, G36, and G21: grassland restored for 56, 36, and 21 years

grasslands restored for different years, respectively, while G_{36} was the lowest. The soil water storages of 220–500 cm and 140–500 cm in S_{56} and S_{21} were significantly higher than the same soil layers in CK. For G_{36}, the soil water storage of 220–320 cm was significantly higher than that of CK, but that of 320–500 cm was significantly lower than that of CK.

3.4 Effects of Root Length Density on Soil Moisture

Soil moisture and RLD of all treatments showed a negative correlation (Table 3), which means that higher RLD caused lower soil water content. Among them, RLD of G_{56}, S_{36}, A_{21}, and S_{21} was significantly negatively correlated with soil water content ($P < 0.05$), and there was an extremely significant negative correlation between RLD and soil moisture in S_{56} ($P < 0.01$). The plant roots of all treatments mainly distributed in the 0–200 cm soil layer. In this depth, RLD decreased with increasing soil depth (Fig. 4). Except for A_{56}, the soil water content was relatively low in the 0–200 cm depth, and the soil water content in the 0–260 cm depth of A_{56} was much higher than that of the other treatments. The highest soil water content of A_{56} occurred at the 160–180 cm depth, and the highest values of other treatments occurred in the soil layer below 200 cm where there were no or little roots.

3.5 Effects of Soil Texture on Water Status

Table 3 shows that the soil moisture has a certain relevance with soil particle composition. The soil moisture of B_{21} and G_{21} was extremely significantly positive correlated ($P < 0.01$) and significantly positive correlated ($P < 0.05$) with the clay content, respectively. The soil moisture of A_{56} was significantly positive correlated ($P < 0.05$) with the silt content, but the soil moisture of G_{56} was significantly negative correlated with the silt content. Furthermore, the soil moisture of A_{56} and G_{56} was significantly negative correlated ($P < 0.05$) with the sand content. However, the soil moisture of B_{56}, A_{21}, and vegetations restored for 36 years was not significantly correlated with soil particle composition. This means that for about half of sampling lands, the effect of soil texture on soil moisture was not significant.

Table 3 Correlation coefficients between soil moisture and root length density, soil particle composition

Sample plot	Root length density	Clay content	Silt content	Sand content
A_{56}	−0.321	0.261	0.399*	−0.377*
B_{56}	−0.622**	0.024	−0.314	0.273
G_{56}	−0.432*	−0.178	−0.473*	−0.454*
A_{36}	−0.166	0.043	−0.204	0.150
B_{36}	−0.455*	−0.014	0.015	−0.005
G_{36}	−0.198	−0.190	−0.201	−0.208
A_{21}	−0.374*	−0.111	−0.011	0.044
B_{21}	−0.503*	0.660**	0.076	−0.271
G_{21}	−0.323	0.450*	−0.262	0.070

*$P < 0.05$, **$P < 0.01$

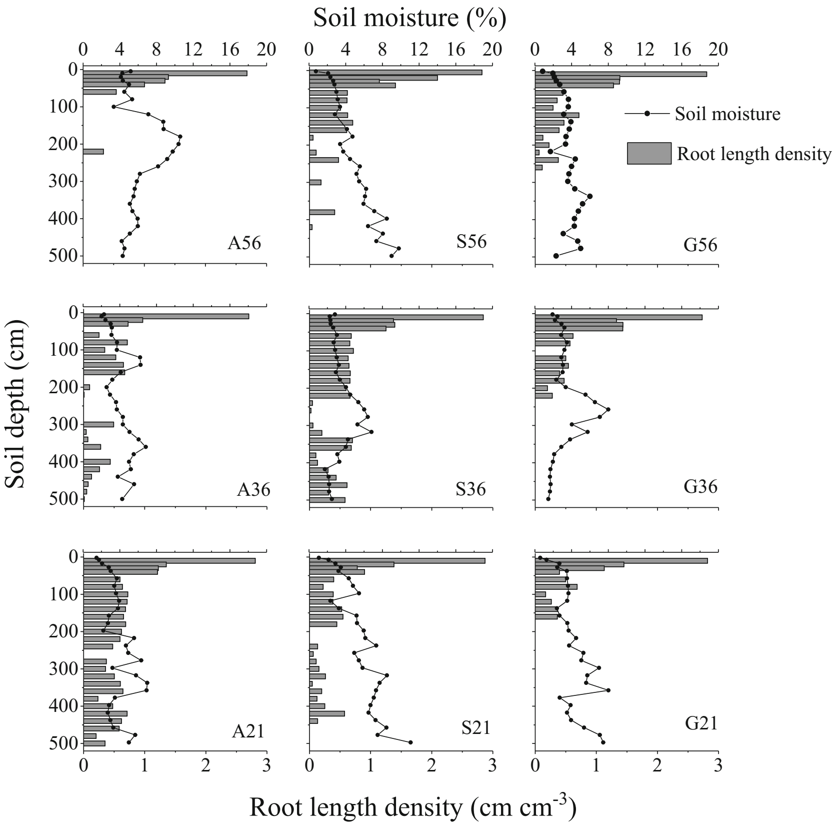

Fig. 4 Relationship between vertical distribution of soil moisture and root length density of different vegetation restored for different years. A56, A36, and A21: arbor land restored for 56, 36, and 21 years. S56, S36, and S21: shrub land restored for 56, 36, and 21 years. G56, G36, and G21: grassland restored for 56, 36, and 21 years

4 Discussion

The distribution of soil moisture is a result of interactions among many variables, such as vegetation (e.g., vegetable type, coverage, and age), climate (e.g., precipitation, evaporation, and solar radiation), topography (e.g., elevation, slope, and aspect), and soil properties (e.g., soil texture, soil bulk density, and soil hydraulic conductivity) (Yu et al. 2018; Li et al. 2015; Wang et al. 2012b). The variation of these variables makes the distribution of soil moisture highly variable in space and time (Zhang and Shao 2013). An understanding of the main factors affecting soil moisture in arid and semi-arid areas is very important for regional vegetation restoration and ecological management.

4.1 The Relationship Between Vegetation and Soil Moisture

Differences in vegetation type (arbor, shrub, grass) and restoration period lead to the difference of soil moisture under different vegetation restoration modes. Vegetation type is an important factor affecting soil moisture distribution (Jia and Shao 2014; Gao et al. 2014; Yang et al. 2014). Significant differences of soil moisture among different vegetation types we discovered are consistent with previous results from the Loess Plateau (Wang et al. 2012b), because the soil water of CK is mainly supplemented by precipitation and sandy soils in semi-arid regions also have higher water permeability. In addition, soil moisture in shifting sandy land is not affected by vegetation. Thus, soil water content increased with increasing soil depth. There is almost no grass in the arbor land, and arbor's fine roots are mainly distributed in the soil layer of 10–50 cm, so the soil moisture of 10–20 cm soil layer in arbor land is lower than that of the shifting sandy land. Soil water content in the deep layer (360–500 cm) is also significantly lower than that of CK in most of the treatments. It means that the arbors consume more water in the root distribution layers and less water can be infiltrated into the deeper soil layers. The water consumption in shallow soil layer of shrub land is also significantly larger, while water consumption in deep soil layer is smaller. The total soil water storage of the grasslands is 52.61 mm less than that of CK, which indicates that the grasslands are not good for soil moisture retention. Because the surface litter cover greatly reduces the surface soil evaporation, coupled with the preservation of water by litter, soil water contents of the shrub lands and arbor lands in the surface layer (0–5 cm) are higher than that of CK.

Soil water content of the arbor lands increased with restoration period. The main reason was that the *Pinus sylvestris* var. *mongolica* restored for 21 years are in their mature stage with strong growth and strong transpiration, so the water consumption is high, which is consistent with the results of Wang et al. (2015). *Pinus sylvestris* var. *mongolica* restored for 36 and 56 years are overmatured, and the water consumption gradually decreased (Lin et al. 2011). Because of decreased vitality and lower leaf area, the overmatured *Pinus sylvestris* var. *mongolica* have a smaller evapotranspiration than the mature ones (Liu et al., 2018c). The variation of soil water content of surface layer in the shrub lands may be related to the plant density and forest age. As the restoration period increases, the vegetation coverage increases and results in the reduction of solar radiation and soil evaporation. After the vegetation growing into a recession period, the plant density and coverage decrease gradually then, which promotes soil evaporation (Yu et al. 2017). With the increase of restoration period, the composition of plant community in the grasslands becomes more complicated, and the coverage increases. As a result, the surface soil evaporation reduces, and also the accumulation of organic matter improves the soil water retention capacity (Yu et al. 2017). Therefore, surface soil moisture of the grasslands increases with the restoration period. Average soil water content of the whole profile of the grasslands restored for different years was lower than that of CK, which indicates that the grasslands consume more soil water during the restoration process. Thus, planting grass is not recommended for vegetation restoration in the Mu Us Sandy Land.

RLD has a negative correlation with the soil water content, which is mainly caused by the water consumption of plant roots (Yu et al. 2018; Wang et al. 2012b). Conversely, the depth of root distribution is also affected by soil moisture (Copley 2000; Li et al. 2017b). The maximum RLD of all treatments in the study area appeared in the 0–60 cm soil layer. In this soil layer, plant roots make full use of the shallow soil moisture mainly supplied by precipitation, resulting in relatively lower soil water content (Li et al. 2017b). The distribution of roots in the 0–200 cm soil layer of all treatments is consistent with the results of Wang et al. (2010). The water content of the 0–200 cm soil layer was not high except for A_{56}, which further indicates that RLD is a key factor affecting the change of soil moisture, and such a result is consistent with the study of Yu et al. (2017). Soil water content in the 0–260 cm soil layer of A_{56} was relatively higher. This is because the *Pinus sylvestris* var. *mongolica* reached a period of decline and the total root content significantly reduced, which weakened the water consumption intensity, and the accumulation of precipitation infiltration increased in each soil layer (Yu et al. 2018). In addition, the soil moisture in deep soil layer showed a decreasing trend, indicating that the water supplied by precipitation mainly remained in shallow soil layer. Furthermore, the groundwater level in the study area is deep and cannot recharge the upper soil, which leads to the decrease of water content in the deep soil.

4.2 The Relationship Between Soil Texture and Moisture

Soil texture is a key factor affecting soil water distribution (Yu et al. 2018; Wang et al. 2012; Vachaud et al. 1985), and the contents of silt particles and clay particles play one key role in the process of soil moisture retention (Fu et al. 2018). Especially for deep soils with a deep groundwater burial, their moisture is mainly affected by soil texture, because there is almost no roots at the depth of 200 ~ 300 cm. There is a positive correlation between soil moisture and silt-clay content, which is consistent with previous studies (Jiao et al., 2017; Lan et al., 2017). The relationship between soil texture and water content in A_{56} showed that the silt particles are beneficial for soil moisture retention, while sand particles have higher permeability that is not conducive to soil moisture retention. This is because soil with more clay particle has higher soil water storage capacity, stronger water retention capacity, and relatively higher water content.

For another aspect, vegetation restoration would influence precipitation infiltration. Previous study indicated that the main water sources for vegetations were precipitation-derived shallow soil water in the Mu Us Sandy Land and the contribution proportion decreased with increasing forest age (Zhou et al., 2019). Because partial precipitation is intercepted by the canopy that cannot enter into the soil, and most precipitation infiltrated into the soil is consumed by plant transpiration, deep soil moisture is difficult to be recharged by precipitation in the restored forest lands. However, low coverage leads to a lower water consumption by plants and leads to a much higher soil evaporation in shifting sandy land (Qubaja et al., 2020).

Thus, soil water status is controlled by multiple comprehensive factors. From the perspective of increasing soil moisture and sustainable development of vegetation, planting arbors and bushes is a preferred vegetation restoration method in the semi-arid northwest of China. Certainly, some water-saving measures should be considered for vegetation restoration, such as precipitation collection with fish-scale pits and gravel mulching (Zheng et al. 2019). Furthermore, soil compaction caused by machines is one common problem (Varol et al. 2020), which may also affect the soil moisture status. That is what we should pay attention in the near future.

5 Conclusions

Vegetation restoration is beneficial for improving the ecology and environment, especially in the arid and semi-arid regions. Based on the study of soil moisture status after the restoration of different vegetation types for a 56-year sequence, we found that after long-term vegetation restoration in the Mu Us Sandy Land, soil moisture of the 5 m profiles is significantly influenced by vegetation type, restoration period, root length density, and soil particle composition. The soil water storages of the arbor land and shrub land were higher, but the soil water storages of grassland were lower than those of the shifting sandy land. The average soil moisture of the arbor lands increased, and the shrub lands and grasslands decreased firstly and then increased with the restoration period. Soil moisture decreased with increasing root length density. Soil texture had a certain degree of influence on soil water content, and the higher clay and silt content, the higher water content. Thus, we concluded that planting arbors and bushes, instead of grass, is a preferred vegetation restoration method in the semi-arid northwest of China. Our foundlings are helpful for vegetation construction in semi-arid sandy lands, which can be also referred in the areas with similar natural environmental conditions of the world.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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