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Soil water depletion patterns of artificial forest species and ages on the Loess Plateau (China)

Yu Liu[a,c,1], Hai-Tao Miao[a,c,1], Ze Huang[a,b,1], Zeng Cui[b], Honghua He[a,b], Jiyong Zheng[a,b], Fengpeng Han[a,b], Xiaofeng Chang[a,b], Gao-Lin Wu[a,b,*]

[a] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resource, Yangling, Shaanxi 712100, China

[b] Institute of Soil and Water Conservation of Northwest A & F University, Yangling, Shaanxi 712100, China

[c] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

Afforestation as an effective measure to control soil erosion has achieved remarkable effects in northern China. However, large scale of artificial afforestation can increase soil water consumption and induce soil desiccation in arid and semi-arid areas. This study analyzed the variations of soil water storage following the conversion of croplands into forests with different species and stand ages on the Loess Plateau. Three most common artificial forests dominated by *Salix matsudana*, *Populus cathayana*, and *Sophora japonica* with stand ages of 5, 10, and 15 years were investigated to determine the variations in soil water storage. The results showed that soil water storage decreased with increasing afforestation ages and soil depth. *Salix matsudana* mainly consumed shallow soil water (0–100 cm), *P. cathayana* mainly consumed deep soil water (100–150 cm), while *S. japonica* had relatively lower water consumption than the other two species. Converting cropland into forest resulted in a significant water deficit. Soil water deficit in the 0–100 cm soil profiles was significantly higher under *S. matsudana* than under the other two artificial forests. Severe soil water depletion and obvious soil desiccation occurred after 12 years of afforestation. Therefore, artificial forests with less water consumption, e.g. *S. japonica*, should be given priority in future afforestation practice. To maintain the sustainability of vegetation, changes in land-use patterns should be considered after 12 years of afforestation.

1. Introduction

Afforestation has been implemented worldwide (IPCC, 2014) and received increasing attention because of its numerous benefits to ecosystems, such as carbon sequestration (Richter et al., 1999; Fang et al., 2001), desertification prevention (Wang et al., 2010), soil erosion and water loss control (Chirino et al., 2006; Fu et al., 2011), and biodiversity conservation (Elbakidze et al., 2011). However, large scale of artificial afforestation can increase soil water consumption, thus inducing soil desiccation in arid and semi-arid areas (Deng et al., 2016; Jia et al., 2017a).

Soil water is a crucial component of the hydrological process (Jia et al., 2017b). Biosphere-atmosphere interrelationships are mediated by soil water conditions in each ecosystem (Vivoni et al., 2008). To determine the distribution of soil water across global storage is one of the most essential tasks of hydrological sciences (McColl et al., 2017). Soil water plays an essential role in processes such as soil microbial respiration (Yuste et al., 2007), streamflow (Koster et al., 2010), and biogeochemical cycles (Falloon et al., 2011). Characterizing the magnitude and dynamics of soil water across a range of spatial and temporal scales has important applications in both theory and practice, and can provide a fundamental guideline for optimal allocation of space for restoring lost vegetation (Deng et al., 2016). The temporal and spatial variations of soil water are influenced by many factors such as soil properties (Gwak and Kim, 2017), topography (Qiu et al., 2001), climate (D'Odorico and Porporato, 2004), and vegetation types (Zheng et al., 2015; Deng et al., 2016). Vegetation has an important influence on soil water content in arid and semi-arid regions (Chen et al., 2007). Vegetation can intercept precipitation and change its spatial distribution, thus mediating soil water (Vivoni et al., 2008). Such influence also varies with plant species and results in temporal variations in soil water. Therefore, quantifying the soil water content under different species across the temporal scale is important as it serves as a driver for many ecohydrological processes in arid and semi-arid regions.

* Corresponding author at: Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, 26 Xinong Road, Yangling, Shaanxi 712100, China.
E-mail addresses: gaolinwu@gmail.com, wugaolin@nwsuaf.edu.cn (G.-L. Wu).

[1] These authors contributed equally to this work.

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The Loess Plateau has experienced the most severe soil and water loss in the world, where serious soil erosion has aggravated the fragility of the ecosystem. In 1999, th0065 Chinese government started to implement the "Grain-for-Green" program, which is a crucial countermeasure to reduce soil and water loss and increase vegetation coverage by converting croplands into forests or grasslands. The program has increased the vegetation cover from 31.6% in 1999 to 59.6% in 2013 on the Loess Plateau (Chen et al., 2015). Precipitation is the only water source to supplement soil water on the Loess Plateau. However, previous studies have shown that forests consume more water by evapotranspiration than other vegetation types, and the replenishment from precipitation is insufficient and soil water deficits frequently occur in the forests on the Loess Plateau (Jian et al., 2015; Deng et al., 2016; Jia et al., 2017a,b), indicating that converting croplands into forests can influence soil water content by increasing soil water consumption.

Forests can influence the water balances in ecosystems by their capacity to access, transport and transpire soil water, and the most direct way is by increasing leaf interception and root water uptake (Jian et al., 2015). It has been well demonstrated that soils become extremely dry in both the deep and shallow soil layers after afforestation in arid and semi-arid regions (Jia and Shao, 2014). Therefore, soil water availability is a key factor determining the success of large-scale afforestation in arid and semi-arid regions (Jiménez et al., 2017). Deng et al. (2016) found that afforestation resulted in severe depletion in soil water levels (as low as 9%) in the 0–100 cm soil profile, and the degree of depletion was mainly influenced by plant species. Jia et al. (2017a) analyzed the changes in soil water content after converting croplands into forests on the Loess Plateau, the results showed that soil water content in the 0–400 cm soil layer declined at a rate of 0.008 to 0.016 $cm^3\,cm^{-3}\,yr^{-1}$ under *Caragana korshinskii* plantation. Chen et al. (2008) reported that severe depletion of deep soil water by afforestation and long-term shortage of precipitation triggered soil desiccation and ecological degradation in semi-arid regions. Although recent researches have reported that extensive afforestation has deteriorated water scarcity (Jia and Shao, 2014; Jian et al., 2015; Jia et al., 2017a), the characteristics of water consumption by several common species on the temporal scale remain poorly understood.

Historically, species such as willow (*Salix matsudana*), poplars (*Populus cathayana*) and locust (*Sophora japonica*), which grows fast, propagates and establishes easily, were used as the major plant species for afforestation and have been planted in large-scale afforestation on the Loess Plateau (Chen et al., 2015). Leaf area characteristics have significant effects on rainfall interception, and root characteristics determine the uptake of water by roots. The effects of these variations are mainly determined by plant species, and selection of suitable artificial forest species may reduce water consumption to acceptable levels. Thus, the specific objectives of this study were: (1) to quantify the soil water content under different species in arid and semi-arid regions, (2) to determine the post-planting temporal variations in soil water storage with stand age, and (3) to select optimal plant species for local soil water conditions in arid and semi-arid regions.

2. Materials and methods

2.1. Study site

The experiment was conducted in the Xiaqu town of Wenshui Country (37°15″–37°35′9″ N, 111°29′47″–112°19′15″ E) in Shanxi Province, China. The study region is a typical area with loess geomorphology located in the eastern part of the Loess Plateau. It has a semi-arid temperate continental climate, and the altitude ranges from 739 m to 2169 m asl. The mean annual temperature is 10.1 °C and the mean annual precipitation is approximately 457 mm, of which more than 60% occurs in July and August (Chang et al., 2016). The climate is characterized by a cold and dry winter and spring, and a rainy and hot summer. The soils in the study area are Loessial and Castanozems. The annual maize or sorghum monoculture is the main cropping pattern (Pan et al., 2016). Dominant artificial forest species in this area include *Salix matsudana*, *Populus cathayana*, and *Sophora japonica*.

2.2. Experimental design and sampling

Three artificial forest species, i.e. *S. matsudana*, *P. cathayana*, and *S. japonica*, were planted on 2002, 2007, and 2012, respectively. Therefore, all forest sites were divided into nine treatments according to the differences in species and ages (5yr, 10 yr, and 15 yr) of the artificial forests. Three plots (50 m × 20 m) were established in each site selected, and three quadrats (10 m × 10 m) were chosen in each plot. In each quadrat, stand density (number of plants ha^{-1}) and breast-height diameter (cm) were measured. The cropland near the woodland was selected for study. The plots set for the cropland were 10 m × 5 m, and five quadrats (1 m × 1 m) were randomly placed in each plot.

Soil water contents of the 0–400 cm soil profiles in each quadrat were measured at 10-cm intervals in September during the growing season in 2017. Gravimetric soil water content (SWC, %) was measured by taking soil samples with an auger of 40-mm internal diameter, with three sites randomly chosen for sampling at each quadrat. All samples were weighed in aluminum boxes and then oven-dried at 105 °C to constant weight. Soil water content was calculated as the proportion of mass loss during oven-drying to the constant weight after drying. Soil bulk density of the 0–100 cm profiles was measured at 10-cm intervals using a cutting-ring of 5-cm diameter and 5-cm height. Three replicate samples were taken to estimate the average values. Field capacity (Fc, %) of the 0–100 cm soil profiles was measured by the cutting-ring method and calculated according to the following formula for soil water storage (SWS) for converting the unit from percentage to mm. Soil bulk density and field capacity of the 100–400 cm soil profiles were represented by the average values of the 50–100 cm soil profiles.

Soil water storage (SWS) was calculated as follows (Gao et al., 2014):

$$SWS = \sum_{i=10}^{n} D_i \times B_i \times SWC_i \times 10^{-1} \qquad i = 10,20,30,\ldots,400$$

where SWS is the soil water storage of the 0-i cm soil procfile (mm), D_i is the soil depth (cm), B_i is the soil bulk density ($g\,cm^{-3}$), and SWC_i is the gravimetric soil water content (%). Changes in soil water storage were expressed in terms of the differences between the cropland and woodland.

Soil water storage deficit degree ($SWSD$) was calculated as follows (Wang et al., 2004):

$$SWSD = \sum_{i=1}^{n} \frac{SWs_i - Fc_i}{Fc_i} \times 100\% \qquad i = 10,20,\ldots,400$$

where SWS_i is the soil water storage of the 0-i cm soil profile (mm), Fc_i is the field capacity (mm), and SWS for the depth of 0–400 cm were used in this study. The average SWS of each plot at time t and depth h, i.e. $\overline{SWS_{t,h}}$, was calculated as follows (Jia and Shao, 2014):

$$\overline{SWS_{t,h}} = \frac{1}{N_i} \sum_{i=1}^{N_i} SES_{i,t,h}$$

where $SWS_{i,t,h}$ is the soil water storage at plot i, depth h, and time t, and N_i is the number of measurements at each plot.

2.3. Statistical analyses

Two-way ANOVA followed by the Tukey's HSD test was used to analyze the differences in the changes of water storage and SWSD among different species. Linear regression analysis was performed to determine the relationships between soil water storage and stand age. Significant differences were evaluated at the 0.05 probability level. All data are presented as means ± standard errors of means. All statistical

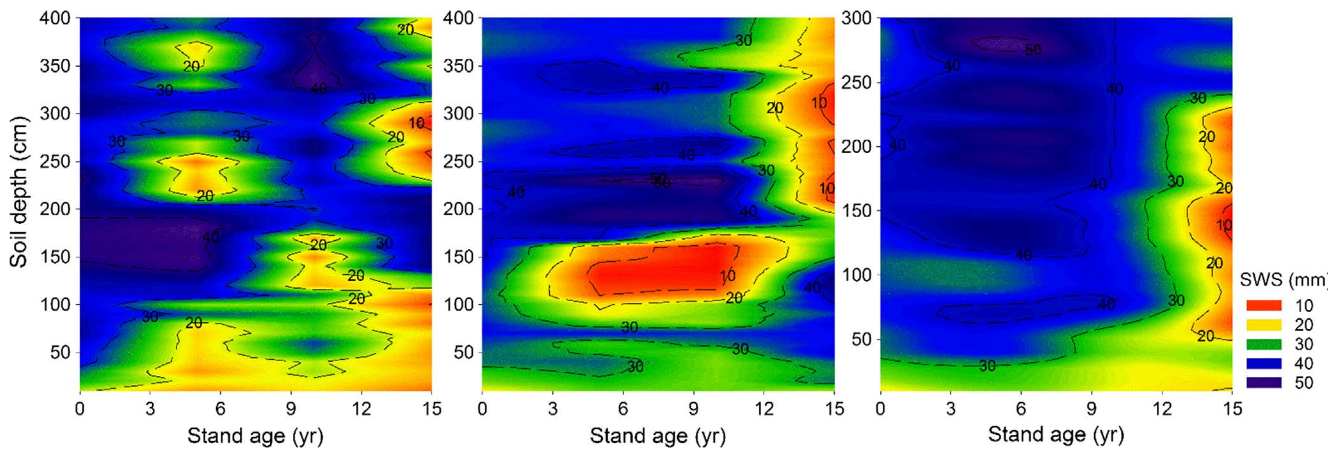

Fig. 1. Vertical distribution and temporal dynamics of soil water storage (SWS) in plots under different artificial forest species. *Salix matsudana* (left), *Populus cathayana* (middle), and *Sophora japonica* (right). Soil water storage (SWS) is labelled with Arabic numers on the soothing contours line.

analyses were performed using the IBM SPSS Statistics 20.0 software package (IBM, Montauk, New York, USA).

3. Results

3.1. Distribution of SWS with afforestation age under different artificial forest species

SWS under all three species decreased with increasing afforestation age and soil depth (Fig. 1). SWS was < 20 mm in the shallow soil layer (0–100 cm) across the entire period under the *S. matsudana* plantation. SWS in the 250–400 cm soil profile decreased in the intermediate stage (3–9 yr) and the later stage (12–15 yr), but showed a remarkable recovery in the 9–12 yr under the *S. matsudana* plantation. Desiccation (SWS < 17 mm) occurred at the depth of 100–150 cm during the middle stage (3–12 yr) and in the deep soil layer (< 200 cm) in the later stage (12–15 yr) under the *P. cathayana* plantation. Similar to the SWS change under the *P. cathayana* plantation, mild water consumption (< 30 mm) was observed in the topsoil profile (0–30 cm) across the period and obvious soil desiccation occurred in the later stage (> 14 yr) under the *S. japonica* plantation.

SWS of the soil profiles was calculated at 100-cm intervals and was depicted in Fig. 2. SWS in each soil profile under all three species gradually decreased with increasing stand age, albeit with fluctuations. To identify the variations in SWS distribution with afforestation age among different species, the stand age vs. SWS were fitted with different functions (Fig. 3). SWS in different soil profiles significantly decreased with the increase of stand age under the plantations of *S. matsudana* and *S. japonica*. SWS under the *S. japonica* plantation showed a strong unimodal trend with the increase of stand age in the 0–100 cm, 0–200 cm, and 0–400 cm soil profile, and showed a significant negative correlation with the increase of stand age in the 0–300 cm soil profile (Fig. 3C).

3.2. Changes of SWS with afforestation age under different artificial forest species

The changes of SWS obviously increased along with the years of afforestation (Fig. 4). Compared with the croplands, the reduction of SWS in the 0–100 cm soil profile was significantly higher under *S. matsudana* than under *P. cathayana* and *S. japonica* across the chronosequence (Fig. 4A). The reduction of SWS in the 100–200 cm soil profile was higher under *S. matsudana* and *P. cathayana* than under *S. japonica* in the 5th and 10th year, but a contrary trend was shown in the 15th year. SWS in the 200–300 cm and 300–400 cm soil profile under *P. cathayana* increased to 41.87 mm and 32.14 mm in the 5th year, but decreased to 139.07 mm and 198.04 mm in the 15th year. SWS in the 0–400 cm soil profile under all three species decreased in the 15th year (Fig. 4C). SWS in the 0–400 cm soil profile was in a consumption state under *P. cathayana* and *S. japonica* across 30 years of afforestation.

The average rates of SWS changes in the 0–200 cm soil profile under *S. japonica* were $-0.52\ \mathrm{mm\ yr^{-1}}$, $-0.50\ \mathrm{mm\ yr^{-1}}$, and $-1.58\ \mathrm{mm\ yr^{-1}}$ in the 5th, 10th, and 15th years, respectively (Fig. 5). The rate of SWS change under *P. cathayana* decreased over soil depth with an average rate of $-3.31\ \mathrm{mm\ yr^{-1}}$ in the 50–170 cm soil profile, but it increased and almost remained stable in the 200–400 cm soil profile in the 5th year (Fig. 5A). The average rate of SWS change in the 200–400 cm soil profile was $-3.49\ \mathrm{mm\ yr^{-1}}$ under *S. matsudana*, being obvious lower than under *P. cathayana* and *S. japonica* in the 5th year. The rates of SWS changes under *P. cathayana* and *S. matsudana* obviously decreased in the 50–170 cm soil profile and almost remained stable in the 200–400 cm soil profile in the 10th year (Fig. 5B). The rates of SWS changes under all three species were stable in the 15th year, but the rate under *S. japonica* was lower than those under *S. matsudana* and *P. cathayana* (Fig. 5C).

3.3. SWSD variation in soil profile under different artificial forest species

SWSD under *S. matsudana* mainly occurred in the 0–100 cm soil profile (−37.28%, −20.14%, and −51.96% in the 5th, 10th, and 15th year, respectively), and were significantly higher than under the other two species across the chronosequence (Fig. 6). SWSD under *P. cathayana* mainly occurred in the 0–100 cm and 100–200 cm soil profiles in the 5th and 10th year, respectively, but they were compensated in the 15th year (Fig. 6C). The lowest SWSD under *P. cathayana* was −36.53% in the 100–200 cm soil layer in the 10th year. SWS under *S. japonica* in each soil layer (0–300 cm) was compensated in the 5th and 10th year, but SWSD occurred in the 15th year. There was no SWSD in the cropland throughout the whole 0–400 cm soil profile (Fig. 6D). The highest soil water compensation was 29.01% in the 100–200 cm soil profile, and the lowest soil water compensation was 12.89% in the 300–400 cm soil profile.

4. Discussion

4.1. Response of SWS dynamics to afforestation

Afforestation has been implemented to control soil erosion and other environmental degradation issues in arid and semi-arid regions in China. In the past few decades, afforestation has made great achievements and the landscape has changed dramatically in China (Chen et al., 2015). Although the positive effects of afforestation have been

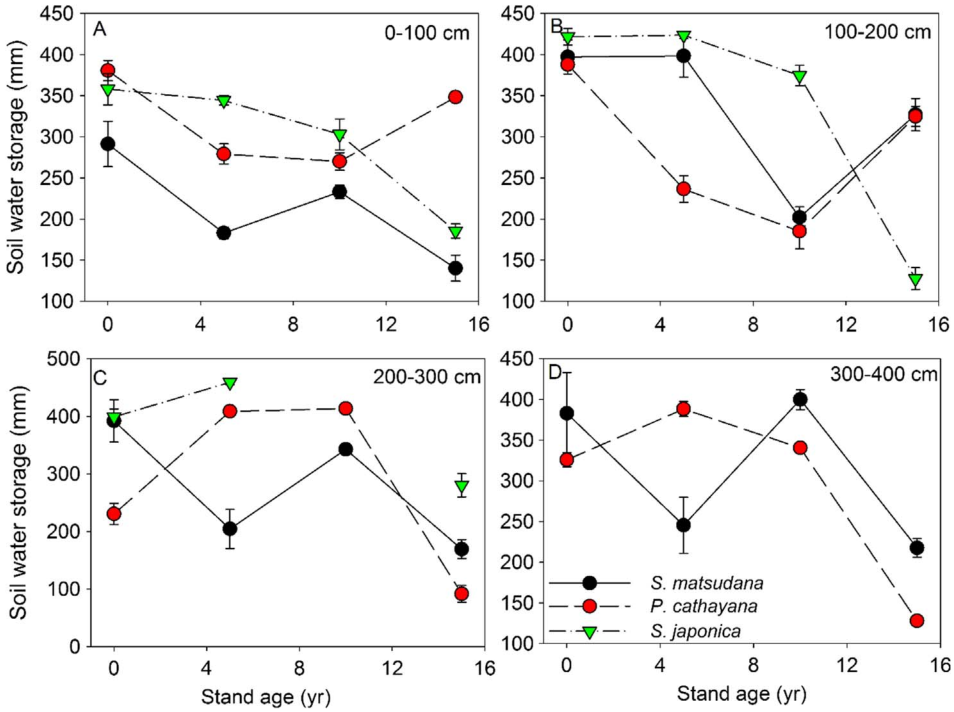

Fig. 2. Changes of soil water storage under different artificial forest species over the stand age in different soil layers (A for the 0–100 cm soil layer, B for the 100–200 cm soil layer, C for the 200–300 cm soil layer, and D for the 300–400 cm soil layer). Note: All data are presented as means ± standard errors of means. There was too high water content below the depth of 300 cm to sample with soil drilling sampler under the *Salix japonica* plantations, so the data were not displayed in the figure.

well investigated in recent years (Fu et al., 2011; Feng et al., 2012; Jian et al., 2015), the negative effects of afforestation on soil water have gradually received increasing attention (Cao et al., 2011, Jia et al., 2017a). The effects of afforestation on soil water storage levels primarily depend on the water consumption characteristics of plant species. Water yields have decreased by 30–50% on the Loess Plateau, due to water consumption by forest plantation (Sun et al., 2006). In the present study, SWS decreased with stand age and soil depth. Earlier studies showed that the effects of artificial forests on SWS in the topsoil (< 20 cm) could be positive (Joffre and Rambal, 1998), negative (Deng et al., 2016), or negligible (Maestre et al., 2001). We found that SWS was consumed slightly in the shallow soil layer (0–50 cm) across the entire period under all three plant species, consistent with the results of Deng et al. (2016), possibly because that the initial soil water could maintain the growth of artificial forests well and rainfall could supplement shallow soil water during the early stage of afforestation.

Afforestation influenced SWS not only by plant physiologic characteristics such as leaf area, sapwood area, and root system, but also by the succession stages. In general, it takes many years for forest land to develop into well-functioning forests in the temperate and boreal regions (Sun et al., 2006). The influence of forests on SWS is difficult to calculable during the whole process because there are various factors cannot be determined and accurately quantified. Yang et al. (2014) and Deng et al. (2016) found that soil water had no obvious temporal changes in the sub-surface soil layer on the Loess Plateau. However, SWS continued to be consumed apparently over time in deep soil layers,

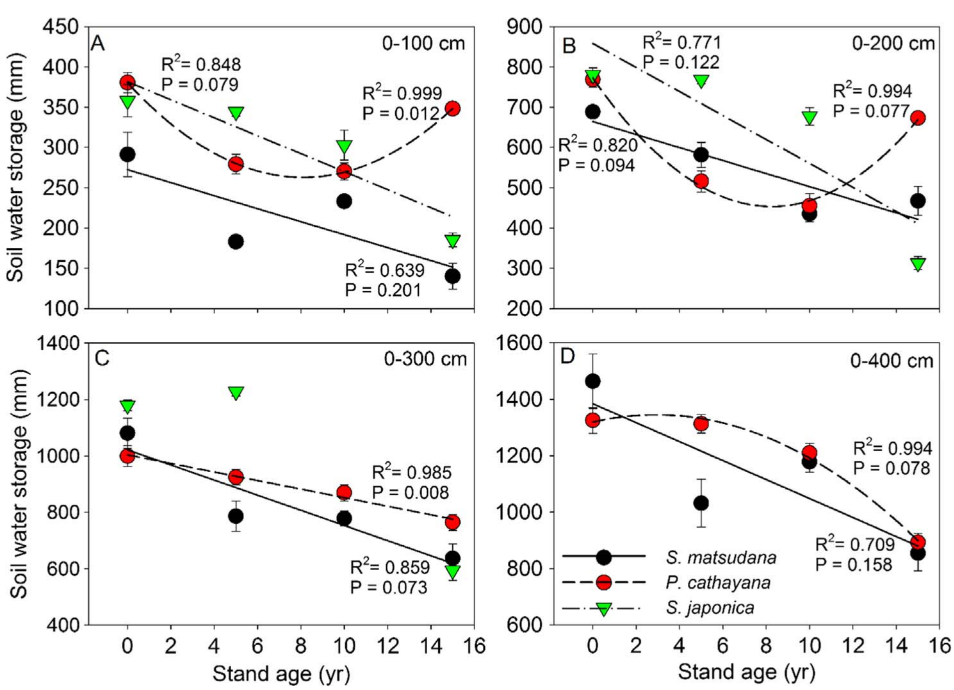

Fig. 3. The relationships between soil water storage under different artificial forest species and stand age in different soil layers (A for the 0–100 cm soil layer, B for the 0–200 cm soil layer, C for the 0–300 cm soil layer, and D for the 0–400 cm soil layer). Note: All data are presented as means ± standard errors of means. There was too high water content below the depth of 300 cm to sample with soil drilling sampler under *Salix japonica* plantations, so the data were not displayed in the figure.

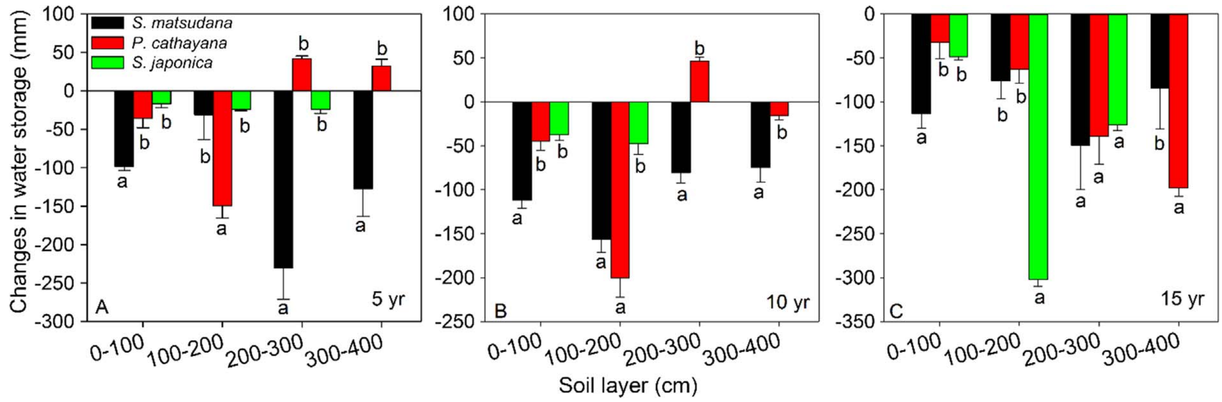

Fig. 4. Variations of soil water storage in different soil layers under different artificial forest species over stand age (A for 5 years, B for 10 years, and C for 15 years). Note: All data are presented as means ± standard errors of means; the different lowercase letters indicate significant differences among different species at 0.05 level.

as a result of the increasing transpiration as the plants grew larger (Chen et al., 2007). The wood grows well at the beginning, but often degrade when the initial water supply has been exhausted. Our findings showed a near-continuous decrease in SWS after 12 years, which resulted in severe drying of the deep soil. Artificial forests need more water to sustain their rapid growth after maturity once the supply of soil water is insufficient in the shallow layer (0–100 cm), they gradually tap into the water resources in the deeper soil layer and then release the absorbed water into the shallow soil layer (Deng et al., 2016). The amount of water consumed by plants was significantly larger than the amount of water replenished from deeper soil layers, thus, the shallow soil water showed a decreasing trend with the increase of afforestation age.

In the present study, SWS under all three plant species decreased in the 0–200 soil layer across the chronosequence (Fig. 4). SWS was consumed in the shallow soil layer under the *S. matsudana* plantation, but it was consumed in the sub-surface soil layer under the *P. cathayana* plantation in the early stage of afforestation (0–12 yr). The distinctions can be attributed to the different characteristics of water uptake caused by root distribution (Deng et al., 2016). *Salix matsudana* and *S. japonica* are shallow-rooted species, although their roots can reach as deep as 200 cm, their effective roots are mainly distributed in the 0–60 cm soil layer (Cao et al., 2006; Zhu and Xue, 2016). Therefore, the reduction of SWS in the 0–100 cm soil profile was significantly higher under *S. matsudana* than under *P. cathayana* and *S. japonica* across the chronosequence. *Populus cathayana* has a shallow root system, but it has a strong growing capacity, that the direct effect on soil water can reach to 240 cm soil layer (Dong et al., 2014).

4.2. SWSD variations with afforestation age under different species

Because of the strong interception of rainfall by leaves, massive root take uptake, and substantial loss by evapotranspiration (Yang et al., 2014; Jian et al., 2015; Jiménez et al., 2017), afforestation can reduce SWS when compared to the levels before afforestation, especially the previous land use is cropland. When croplands are converted into forests, large amounts of soil water are lost via transpiration through the deep root systems of woody vegetation. Deng et al. (2016) analyzed

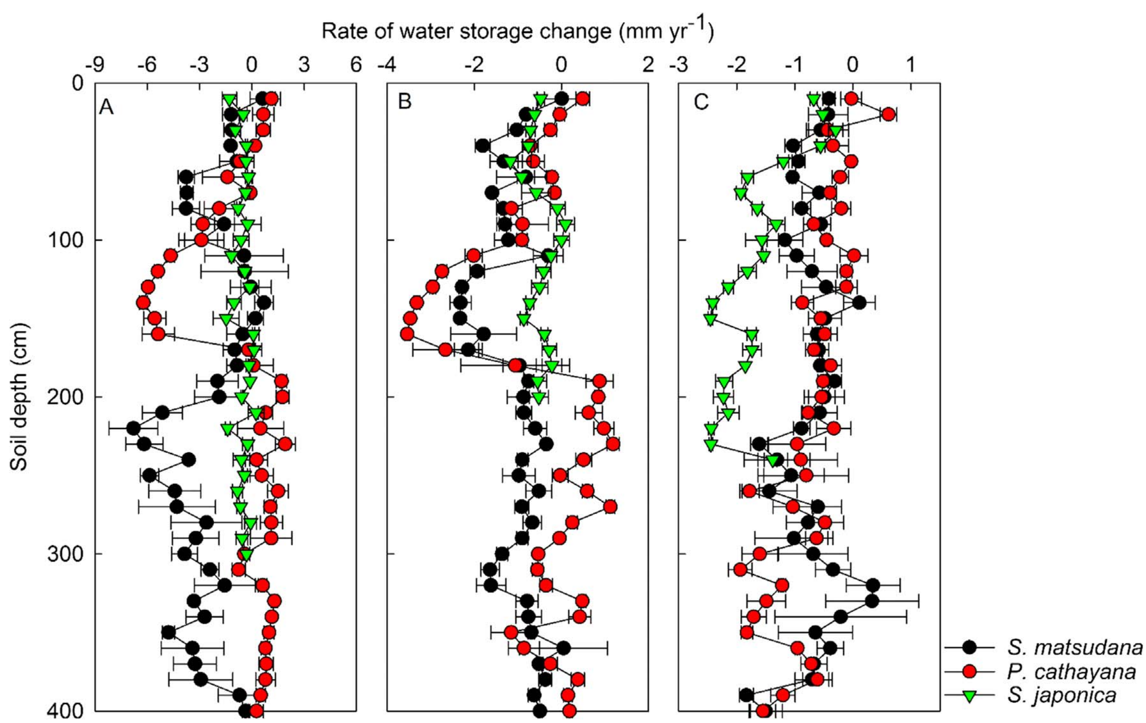

Fig. 5. Rates of soil water storage changes under different artificial forest species along the stand age (A for 5 years, B for 10 years, and C for 15 years). Note: All data are presented as means ± standard errors of means.

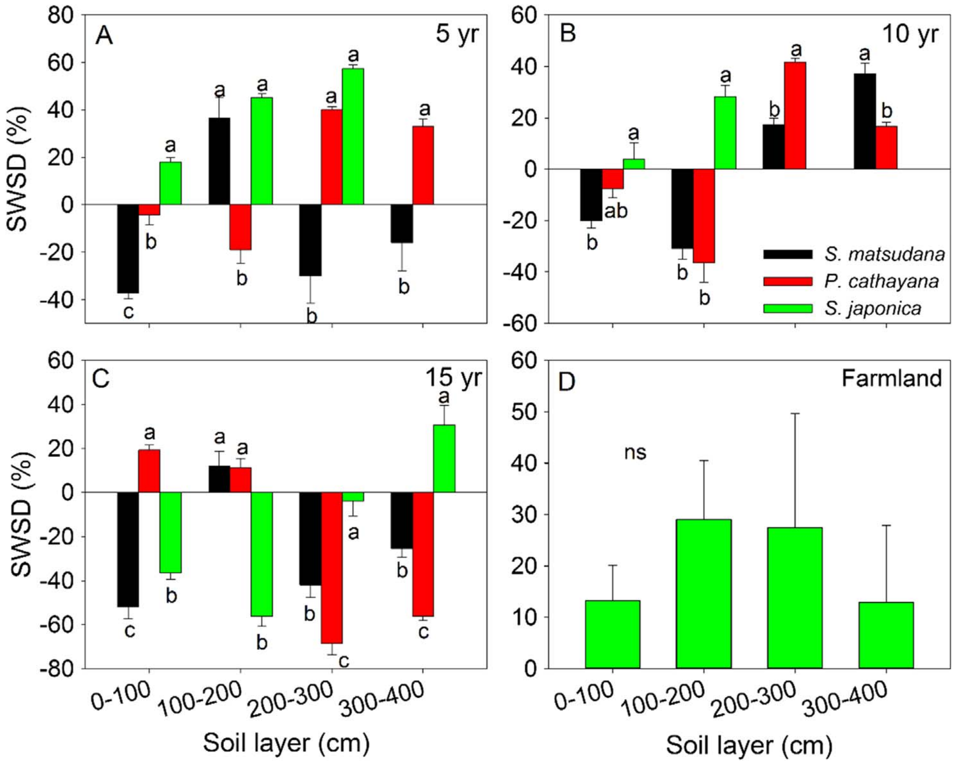

Fig. 6. Variations of soil water storage deficit degree (SWSD) in different soil layers over stand age (A for 5 years, B for 10 years, C for 15 years, and D for the cropland). Note: All data are presented as means ± standard errors of means. The error bars indicates standard errors; the different lowercase letters indicate significant differences among different artificial forest species at 0.05 level; ns indicate non-significant difference at 0.05 level among different soil layers in the cropland.

1740 observations and showed that soil water decreased by 20% after converting croplands into forests in northern China. The limited rainfall is the only source of water supplement for SWS due to the groundwater levels on the Loess Plateau are generally deep, being 30–100 m below the land surface (Jia et al., 2017a). In our study, *S. matsudana* was in a state of deficit in the 0–100 cm soil layer due to its strong water consumption capacity. The initial soil water and rainfall supplement in the surface soil were not enough for the growth of *S. matsudana*. However, the shallow SWS could meet the water demand for the growth of *S. japonica*, so there was no water deficiency under *S. japonica* in the first 10 years of afforestation, but the shallow soil water was depleted and water deficit occurred over time. Moreover, shallow soil water can fully sustain the water demands of farmland crops. Our findings showed that there was no water deficit in the cropland in the 0–400 cm soil profile (Fig. 6). Although afforestation increased water infiltration, decreased surface runoff, and improved soil water-holding capacity, the water from these supplements is unevenly distributed, discontinuous, and irregular for the continual growth of plants. Although these replenishes play a crucial role in soil water maintenance, it is still not enough to replenish severe soil water loss via long-term transpiration of plants. Such discrepancy leads to an imbalance in soil water availability and utilization by artificial forests. With increasing afforestation age, the imbalance eventually caused water deficit and soil desiccation. In turn, water deficit affects plant growth and results in vegetation degradation. The whole process forms a vicious circle, and the "small old trees" caused by soil desiccation on the Loess Plateau provide good examples.

4.3. Implications for afforestation management

Afforestation as an effective measure to control soil erosion has achieved remarkable effects in northern China. Large-scale afforestation has also posed a severe test to soil water. Water availability is a crucial decisive factor for successful afforestation in arid and semi-arid regions (Cao et al., 2011). Unsuitable artificial forest species and overly high planting density can result in severe water depletion (Deng et al., 2016). Moreover, the potential for soil water recovery is difficult to quantify (Jia et al., 2017a). Therefore, to restore vegetation or artificially construct vegetation, the past, present, and future situations in the region should be taken into account in a comprehensive manner.

Vegetation construction or restoration should be adapted to local conditions, and suitable vegetation types should be selected, rather than put too much emphasis on afforestation. Precipitation should be used as the main reference for afforestation in arid and semi-arid regions. Afforestation may have negative effects on soil water in areas with a mean annual precipitation of < 600 mm (Deng et al., 2016). Many studies have shown that converting croplands to grasslands has many environmental benefits (Breuer, et al., 2006; Qiu et al., 2011; Liu et al., 2017), and may be the best option for rehabilitation of vegetation in areas with a mean annual precipitation of 510 mm on the Loess Plateau (Xiao et al., 2011). For the choice of species, exotic species usually have greater water demands than native species, and soil water in arid and semi-arid regions cannot meet the water demands of exotic species. There is also a great difference in the water consumption characteristics among plant species. In our study, *S. matsudana* mainly consumed shallow soil water, *P. cathayana* mainly consumed deep soil water, and *S. japonica* had a relatively less water consumption. Unsuitable artificial forest species and management can intensify soil water depletion in arid and semi-arid regions. After 12 years of afforestation, due to a large amount of water consumption and obvious soil desiccation, changes in land-use patterns can be considered. To better maintain the sustainability of vegetation, bioengineering techniques should also be implemented properly. For example, 'fish scale pits' can be used to increase soil surface roughness, decrease surface runoff, promote soil infiltration, and increase water storage on eroded hillslopes.

5. Conclusions

Afforestation is an effective soil erosion control measure on the Loess Plateau, China. However, compared with croplands, three afforestation species caused severe water consumption. Soil water storage decreased with the increase of afforestation age and soil depth. *Salix matsudana* mainly consumed shallow soil water (0–100 cm), *P. cathayana* mainly consumed deep soil water (100–150 cm), and *S. japonica* has a relatively lower water consumption than the other two species. Converting croplands into forests resulted in a significant water deficit. Soil water deficit in 0–100 cm soil profiles was significantly higher under *S. matsudana* than under the other two artificial forest species. Soil water was severely depleted and obvious soil desiccation occurred after 12 years of afforestation. Therefore, artificial forest species such as *S. japonica*, which had a less water consumption should be considered in future afforestation practice. To maintain the sustainability of vegetation, changes in land-use patterns can be considered for change after 12 years of afforestation.

Acknowledgements

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