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The differences of water balance components of *Caragana korshinkii* grown in homogeneous and layered soils in the desert–Loess Plateau transition zone

Xiangrong Cheng [a,b], Mingbin Huang [b,*], Bing Cheng Si [c], Mukui Yu [a], Mingan Shao [b]

[a] Institute of Subtropical Forestry, CAF, Fuyang, Zhejiang 311400, China
[b] The State Key Laboratory of Soil Erosion and Dryland Farming of the Loess Plateau, Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Shaanxi 712100, China
[c] Department of Soil Science, University of Saskatchewan, Saskatoon, SK S7N 5A9, Canada

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ABSTRACT

Soil texture greatly influences soil water movement, thus may affect the water balance and vegetation growth in the desert–Loess Plateau transition zone. This study is to determine if the water balance differs in homogeneous and layered soils with *Caragana korshinkii* stands in semiarid region. Soil water measurements up to 500-cm depth were taken in 2006 and 2007 on homogeneous sandy soil, homogeneous silt loam soil, and layered soil with sand overlying silt loam. HYDRUS-1D was used to simulate the soil water balance. The results indicated the annual water balance components were greatly affected by soil layering. The ratio of average actual evapotranspiration (ET_a) to precipitation (P) during the two years in the layered soil was slightly lower than that in homogeneous soils. The ratios of annual actual transpiration (T_r) to evapotranspiration were 50.9%, 41.2% and 30.6% in layered soil, homogeneous sandy soil, and homogeneous silt loam soil, respectively. *C. korshinkii* grown in layered soil had deeper soil water recharge and higher T_r/ET_a ratio, thus had more available water for transpiration than that in homogeneous soils. This study suggested the layered soil with sand overlying silt loam is more favorable to *C. korshinkii* growth in terms of water use than homogeneous soils in the desert–Loess Plateau transition zone.

1. Introduction

Water is a key limiting factor for plant growth in arid and semiarid regions (Duniway et al., 2010; Kemp et al., 1997; Sala and Lauenroth, 1982; Smith et al., 1997). Thus, any control on soil water could affect plant community composition and its function (Loik et al., 2004). Soil water movement was affected by soil physical characteristics, such as particle size distribution, bulk density and hydraulic conductivity (Jury and Horton, 2004; Zhao et al., 2011). These properties influence not only the amount of rainfall entering soil through infiltration, but also the available water storage of the soil after infiltration. Vertical heterogeneity such as layers in soil also affects water flow in soil. A number of laboratory and simulation studies on evaporation and water redistribution in layered soils have been conducted over the years (Huang et al., 2011; Willis, 1960; Wilson, 1990; Wilson et al., 1997). However, little is known on the interaction between the layered soil and vegetation and consequently on water balance in the layer soils in arid and semiarid regions. The poor understanding led to insufficient understanding of regional water balance.

In the Loess Plateau of China, water erosion is very serious, and the soils in the region are among the most erodible in the world. The average annual soil loss resulting from both wind and water erosion is as much as 15 000 t km^{-2} (Yang et al., 2010). Approximately 18.8% of this area has been desertified (Chang et al., 2005). For example, the desert has advanced 3–10 km from the northwest to the southeast during the past 20 years (Tang et al., 1993). As a result, soil textures are modified by the serious desertification. Silt loam soil (one of the main soil types on the Loess Plateau), sandy soil and layered soil (sand overlying silt loam soil) are distributed in a fragmented mosaic pattern, in the transition zone from the fertile loess hills to the desert on the Northern Loess Plateau.

In order to reduce soil erosion, control land desertification, and improve environmental quality on the Loess Plateau, a series of soil conservation practices are being implemented to increase vegetative recovery. *Caragana korshinkii* Kom, a drought-tolerant mesquite

* Corresponding author. Tel.: +86 29 87019071; fax: +86 29 87012210.
E-mail address: hmingbin@yahoo.com (M. Huang).

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that can grow with precipitation from 100 mm to 550 mm, is widely planted in the Loess Plateau. *C. korshinkii* is known to conserve water and soil, and to control land desertification (Yang, 2001; Yang et al., 2006). However, little is known about the difference in water consumption by *C. korshinkii* grown in homogeneous soil (silt loam or sandy soil) and layered soils (sand overlying silt loam) in this region. Therefore, it is important to understand the water balance of *C. korshinkii* growing in different soil profile in order to better manage and expand the planted areas and thus to improve vegetation restoration in the transition zone.

The objectives of this study were: (1) to simulate soil water dynamics in homogeneous and layered soils under *C. korshinkii* stands using HYDRUS-1D; (2) to determine the actual transpiration characteristics in different soils; and (3) to compare the water balance components in homogeneous and layered soils in the transition zone on the Loess Plateau. HYDRUS-1D model (Simunek et al., 2008) was used to simulate water flow of the unsaturated zone in layered soils. This model has been used for a number of hydrological studies under different climatic and vegetation conditions (Gutierrez-Jurado et al., 2006; Hernandez, 2001; Meiwirth and Mermoud, 2004; Sommer et al., 2003).

2. Materials and methods

2.1. Site description

This study was conducted during 2006–2007 at the Liudaogou watershed in Shenmu County (110°22′ E, 38°48′ N; mean altitude 1163 m), Shaanxi province, China. The area of Liudaogou watershed is around 6.89 km^2, located in the transition zone from desert to the fertile loess hills, in the semiarid region of the Northern Loess Plateau. The mean annual temperature is 8.4 °C, and the frost-free period is 135 days. The long-term average annual precipitation is 430 mm, 77% of which falls from June to September. The growing season precipitation (April–October) was 367.8 mm in 2006 (which was 16% lower than the long-term average) and 435.7 mm in 2007 (close to average) (Fig. 1). Drainage is negligible in the study area, and the observed maximum infiltration depth of rainfall in sand is about 3 m (Li, 2001). The groundwater level is about 30–100 m below the soil surface, therefore, groundwater has negligible influence on the soil water balance (Li, 2001).

2.2. Experimental plots

Because the Liudaogou watershed is located in the transition zone from desert to the fertile loess hills, the soil texture profile is different from location to location in the watershed. According to

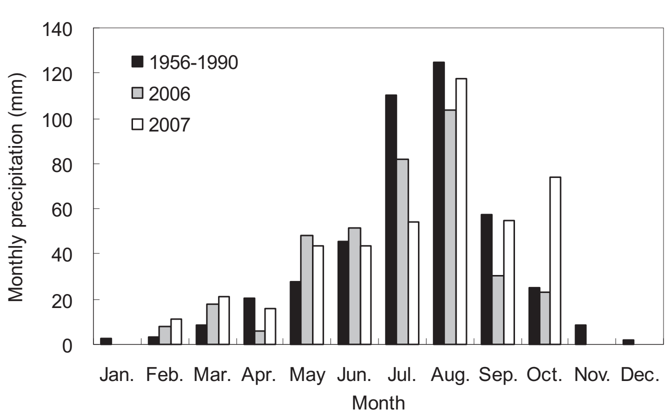

Fig. 1. Monthly precipitation of the study area in 2006 and 2007 and the long-term normal (1956–2007).

soil survey done by Tang et al. (1993), the main soil texture profiles include homogeneous sand, homogeneous silt loam, and partly sand overlying silt loam. Experimental plots were selected based on soil profile information and vegetative information. When the experimental plots were primarily selected, soil profile (to a depth of 500 cm) was dug in each soil type. Soil samples were collected at 0.1 m increments between 0 and 1 m soil depth, and at 0.2 m increments below 1 m depth, to determine soil physical properties. Soil mechanical composition was measured using a laser particle-size analyzer (Master Sizer 2000, Malvern, UK). Bulk density with soil volume measured on oven-dried natural clods. Selected soil physical properties of these soils are shown in Table 1. Two plots of 4×15 m^2 were established on slopes for *C. korshinkii* grown in each of the three soil profiles. The slopes of plot were 14%, 13% and 7% for the homogeneous sand plots, homogeneous silt loam plots, and layered soil plots, respectively. All plots had a southeastern aspect and their distance apart was within 1.5 km. Each plot was bordered with iron sheeting that was 15 m in length, 4 m in width, and 0.2 m in height. At the lower end of the plot, the sheeting funneled runoff water into two barrels (Fig. 2).

2.3. Plant characteristics measurements

The *C. korshinkii* is a deciduous mesquite shrub, with growing season from the beginning of April until late October. The *C. korshinkii* grown in these plots had been planted in 1984. Shrub height in each plot was measured with a tape measure, 6–8 samples (selected according to average height, limb and crown width) outside the plot were harvested to estimate aboveground biomass (kg ha^{-1}). Plant density was estimated by the number of shrub in the plot. Plant cover was calculated by shrub crown width divided plot area. LAI was measured by LAI-2000 plant canopy analyzer (LI-COR Inc, Lincoln, Nebraska, USA). Characteristics of the plants on the three soils are shown in Table 2. There were a few grasses, mainly *Stipa breviflora* Griseb, growing under the shrubs; otherwise the ground surface was bare. Generally, C. *korshinkii* grown in homogeneous sand and layered soil profiles had larger biomass than homogeneous silt loam profile (Table 2).

2.4. Soil water measurements

In each plot, three 530 cm long neutron access tubes were installed to measure soil water, at 10 cm increments between 20 and 100 cm soil depth, and at 20 cm increments below 100 cm depth using a CNC-503B(DR) neutron probe (Beijing ST Ltd., China). Neutron probe measurements were calibrated by the gravimetric method and the neutron count ratio was subsequently converted to volumetric water content. Soil water content of 0–10 cm and 10–20 cm soil layers were measured by the gravimetric method. Measurements of volumetric water content were made at approximately two week intervals during the period of May–October, 2006, and April–September, 2007.

2.5. Fine roots measurements

The vertical fine root distributions of *C. korshinkii* in the three soil profiles were investigated using the trench-profile method (Böhm, 1979). One soil pit ($1 \times 2.5 \times 3$ m) was dug to expose the vertical section in each plot under the *C. korshinkii* canopy. Roots were selected from a 40×40 cm^2 grid at 10 cm increments in the soil pit, and were stored in polythene plastic bags for later surface area measurement. A total of 64 fine root samples were collected from the homogeneous sand profile, 108 samples from the silt loam profile, and 80 samples from sand overlying silt loam profile. Root surface area and diameter were measured using a WinRHIZO that