Ecological Engineering 64 (2014) 250–254

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Short communication

The applicable density of sand-fixing shrub plantation in Horqin Sand Land of Northeastern China

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ARTICLE INFO

Article history:
Received 25 December 2012
Received in revised form
27 November 2013
Accepted 20 December 2013
Available online 21 January 2014

Keywords:
Horqin sandy land
Caragana microphylla
Plantation density
Soil moisture
Evapotranspiration

ABSTRACT

Caragana microphylla is the dominant perennial shrubs and widely used to stabilize shifting sand dunes in semi-arid, north China. To confirm the influence of plantations on soil water condition, we determined the soil moisture and evapotranspiration under different densities of sand-fixing *C. microphylla* shrubs during growth period. Result showed that the soil moisture under shrubs continued decreasing with the increasing of plantations densities. Soil moisture under 0.5 m × 1 m and 1 m × 2 m densities of *C. microphylla* shrubs are under wilting humidity (1.55%) level, however, soil moisture under 2 m × 2 m densities and savageness *C. microphylla* shrubs always keep above 1.6% during growth season. Evapotranspiration of all shrubs are low than rainfall and occupied above 90.3–98.5% of rainfall during growth phases, and continually increased with the increasing plant densities. The 0.5 m × 1 m density shrubs have the highest evapotranspiration, about to 298.3 mm (2009)/235.7 mm (2008) and occupied above 98.5% (2009)/94.4% (2008) of rainfall at the same time. The 2 m × 2 m density shrubs have the lowest evapotranspiration, about 283.4 mm (2009)/230.7 mm (2008), and soil moisture surplus 20.8 mm (2009)/19.0 mm (2008) at the end of growth season. According to soil moisture and evapotranspiration, the 2 m × 2 m of *C. microphylla* shrubs is applicable density in Horqin sandy land, north-east of China.

1. Introduction

Desertification is an important ecological problem in the world today. China is one of the countries facing a serious problem of desertification in the world (Wang et al., 2002). The whole national area of desert, Gobi, and the area of sandy desertification are about 1,568,000 km^2; it is about 16.3% of the national area (Wang et al., 2006). Combating desertification in China is one of great and far-reaching significance. Plantations of the tree, shrubs and grasses are the most effective measures to stabilize mobile dunes in arid, semi-arid regions where the annual precipitation varies from 200 to 400 mm (Zhang, 2000; Cui, 1998; Gao et al., 1996; Kou, 1984; Li and Liu, 1994). The soil water availability is the prime reason limiting the number and size of perennial plant species and thus is the main constraint in permanently controlling desertification (Wang et al., 2004; Li and Ma, 2001; Wainwright et al., 1999; Nish and Wierenga, 1991).

It is well known that re-vegetation is one of the most effective methods to reduce the hazards of desertification (Hu et al., 2011; Li et al., 2004; Su and Zhao, 2003). The methods that plant vegetation in straw checkerboard were initiated to stabilize sand dunes in Horqin Sandy Land (ab. HSL, abbreviation same as below) of north-east China since 1980s. *Caragana microphylla*, a dominant plant species, had been widely used in vegetation reestablishment works to stabilize shifting sand dunes (Liu et al., 2012). To improve the effects of controlling sand dunes moving, we usually plant *C. microphylla* with densities of 1 m × 1 m in practice. Over the past 30 years, it has played an important role in the restoration of the local eco-environment; therefore, it is viewed as a successful model for desertification controlling and ecological restoration in HSL. Whereas, we recently found that the soil moisture under these *C. microphylla* plantations were drop off with vegetations development, and cannot satisfied the vegetation growth needed (Alamusa et al., 2002).

The previous study showed that the soil moisture of dunes not only affected by soil structure and heterogeneity, but also affected by rainfall, plant species and planting density (Ma et al., 2011; Tian et al., 2008; Feng and Cheng, 1999). The planting density may be one of a key factor influencing the soil water balance on sandy dunes (Guo, 2011; Hu et al., 1996). The high-density of sand-binding plantations will decrease soil moisture and affect the stabilization of

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0925-8574/$ – see front matter
http://dx.doi.org/10.1016/j.ecoleng.2013.12.026

sand-fixing plantations (Singh et al., 1998; Liao and Zhang, 1996; Jiang and Cong, 1986). The low densities of plantations consumed little water, but that cannot effective reduced wind speed and stabilize dunes. In contrast, high-density plantations would do consume more soil water and restrict the growth of re-vegetations. Applicable density of sand-fixing plantations should be stressed on the basis of water balance and field tests (Li et al., 2006). However, previous studies are insufficient to guide management practice in this area. This paper determined the soil water budget of *C. microphylla* plantations according water balance theory on the process of sand dunes fixation, and discuss the relationship between soil moisture and vegetation restoration on community scale, in order to find out the suitable densities of *C. microphylla* plantations in HSL, north-east China.

2. Materials and methods

2.1. Experimental site

Research was conducted at HSL, which locate between 42°41′ and 45°15′ N latitude and 118°35′ and 123°30′ E longitude. The region has a semi-arid climate. The annual temperature is 6.2 °C, with the coldest month in January (−11.7 °C) and the warmest month in July (23.6 °C). The annual precipitation is 284.4 ± 82.4 mm (1982–2008) with about 70% of this falling in June to August. The annual potential evaporation exceeds 2300 mm. Annual wind speed averaged 4.2 m s^{-1}, with the strongest instantaneous wind speed about to 31 m s^{-1}. The dune migrates south-eastward at a speed of 4–7 m yr^{-1}. The areas have large and dense reticulate dune chains composed of loose and impoverished mobile sands with an insistent moisture content ranging from 3% to 4%. Precipitation is usually the only source of water supply, and groundwater exists at a great depth (>8 m).

2.2. Experimental treatments and design

We established the sand-binding vegetations during 1984–1988 year. The units of 1 m × 1 m straw checkerboard sand barriers had been built on shifting sand dunes surface as sand stabilization screen. *C. microphylla* were planted in sand barrier squares with different densities. Experiment plots have been located on *C. microphylla* plantations with different densities (2 m × 2 m [T_1], 1 m × 2 m [T_2] 1 m × 1 m [T_3], and 1 m × 0.5 m [T_4]), and chose the natural *C. microphylla* plantations (density of 5 tufts in 100 m^2) [*N*] and moving sand land (vegetative coverage was kept in 5–15%) [*M*] as comparison (abbreviation same as below). Soil samples were taken at 10 cm increments starting at a depth of 10 cm and going down to a depth of 200 cm with 3 repeats each depth on 3 spots under three *C. microphylla* canopies on middle part of windward slope of sand dunes. Soil moisture was measured by oven dry method, from April to October on 1st and 15th day of each month during 2009 and on 15th day of each month from April to October in 2008. Soil moisture of mobile sand dunes was measured on middle part of windward slope using the same method.

2.3. Water balance equation

Following Zhang et al. (2002), the water balance of a point can be written as:

$$P = \mathrm{ET} + R + D + \Delta S \quad (1)$$

where *P* is precipitation, ET is evapotranspiration, *R* is runoff and *D* is drainage below the root zone and ΔS is the change in soil water storage. For this exercise, we can assume *R* and *D* are zero because there are no surface runoff and drainage on sand dune plantations area. So the water excess is calculated as:

$$\Delta S = P - \mathrm{ET} \quad (2)$$

$$\Delta S_{t2-t1} = S_{t2-St1} \quad (3)$$

$$S_t = 10 \times M \times G \times H \quad (4)$$

ΔS_{t2-t1} is the soil water storage change from t_1 to t_2 time, S_{t2} and S_{t1} is the soil water storage at t_1 and t_2 time, *M* is soil moisture (%), *G* is soil bulk densities (g cm^{-3}), and *H* is soil depth of main roots distribution (cm). In this experiment we confirm the soil depth is 200 cm.

3. Results

3.1. Variation of soil moisture on different density plantations during growth phase

Soil moisture of all plots showed the same variation trend with precipitation. The peak of soil moisture coincides with the peak of precipitation, so the soil moisture of all plots has a good condition during 20-June to 29-August. At the same time, the plantations densities influenced soil moisture. There are distinctly differences of soil moisture among different densities of plantations (Fig. 1). Soil moisture continued decreasing with the increasing planting densities. The soil moisture of plots *N*, *M* and T_1 are distinctly higher than others plots, and all above wilting humidity (1.55%) of *C. microphylla* during growth season. The soil moisture of plots T_1 and *N* is higher than wilting humidity in all-time, but the soil moisture of plots T_2, T_3, and T_4 are almost under wilting humidity in whole growth phase in 2009. In 2008, the soil moisture of all plots are higher than 2009s and all above wilting humidity in whole growth season, but the soil moisture of plot T_3 and T_4 showed extremely low and under 2.5% during growth season. The soil moisture of plots T_1, T_2 and *N* are distinctly higher than T_3 and T_4.

We can compartmentalize the all plots into two groups according to soil moisture vertical section variety (Fig. 2). The group A includes plots *N*, *M* and T_1, T_2. The group B includes plots T_3 and T_4. The soil moisture of group A is high than group B in all depth of layers, and almost above wilting humidity (1.55%), except the T_2 plot on depth of below 120 cm in 2009. There are no prominent differences of soil moisture between plot *N* and T_1 in 2009 and plot *M* and T_1 in 2008. The soil moisture of group B is under wilting humidity on depth of below 70 cm, and varies between 1.0% and 1.5%. This soil water condition will restrain the plantations growth and affect the stabilization of sand-fixing plantations.

3.2. Temporal variation of evapotranspiration in growth phase

The evapotranspiration of *C. microphylla* plantations showed peak value during 21-June to 30-June (in 2009) and 15-July to 15-August (in 2008), and reach to 120.75 mm (2008) and 127.92 mm (2009), respectively. The lower point of evapotranspiration appeared during 15-April to 15-May and 15-September to 15-October. The peak of precipitation and evapotranspiration appeared at same time (Fig. 3). There is significant relationship between evapotranspiration and precipitation. The correlation coefficient of precipitation and evapotranspiration are R_N = 0.8748, R_{T2} = 0.7855, R_{T1} = 0.8693, and R_{T4} = 0.8839 ($r_{0.01}$ = 0.7079, *f* = 10).