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Short communication

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

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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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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:

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

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:

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

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

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

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).

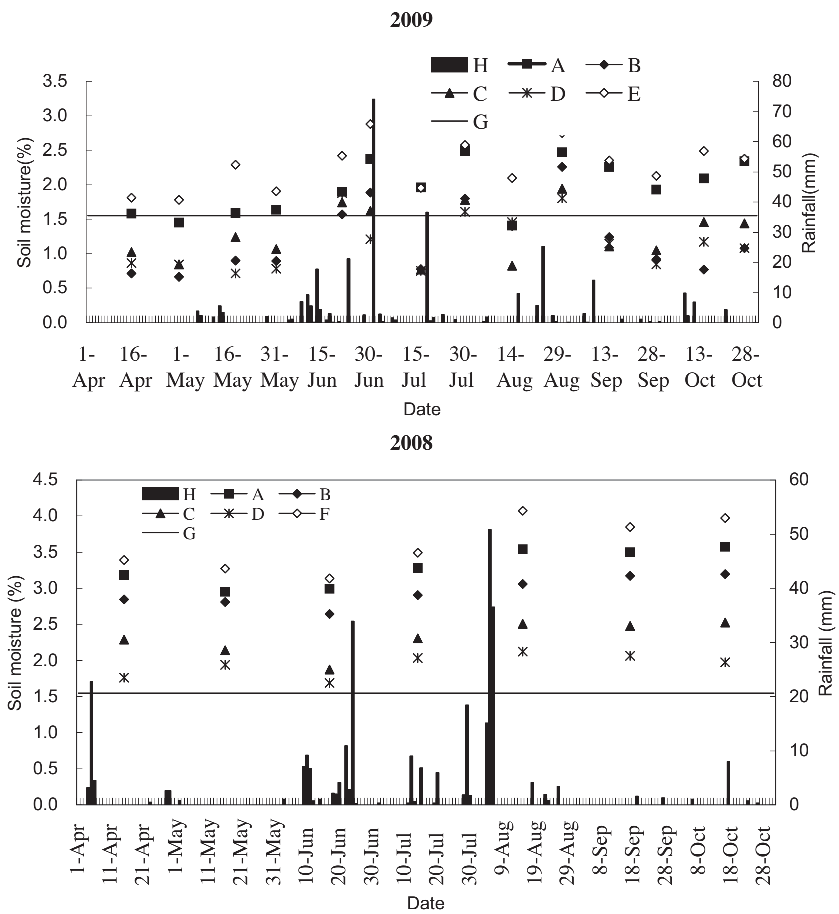

Fig. 1. Soil moisture under different densities of *C. microphylla* plantations during growth phase (April–October) in 2008 and 2009. Different densities of plantations: A: 2 m × 2 m [T_1]; B: 2 m × 1 m [T_2]; C: 1 m × 1 m [T_3]; D: 1 m × 0.5 m [T_4]; E: nature *C. microphylla* plantations [*N*]; F: moving sand dunes [*M*]; G: wilting humidity; H: rainfall.

3.3. Comparing evapotranspiration under different density of C. microphylla shrubs

The evapotranspiration of *C. microphylla* of different densities shrubs showed gradually increscent trend with the planting densities increased. Evapotranspiration of all plots are low than precipitation and occupied above 90.3–98.5% of precipitation during growth phase. Evapotranspiration is lowest in *M* plot and highest in T_4 plot in 2008 and 2009 (Fig. 4). During the growth phase in 2009, precipitation is 304.2 mm, the evapotranspiration of T_4 plot have the highest evapotranspiration, about 298.3 mm and occupied above 98.5% of rainfall at the same time. The T_1 plot has the lowest

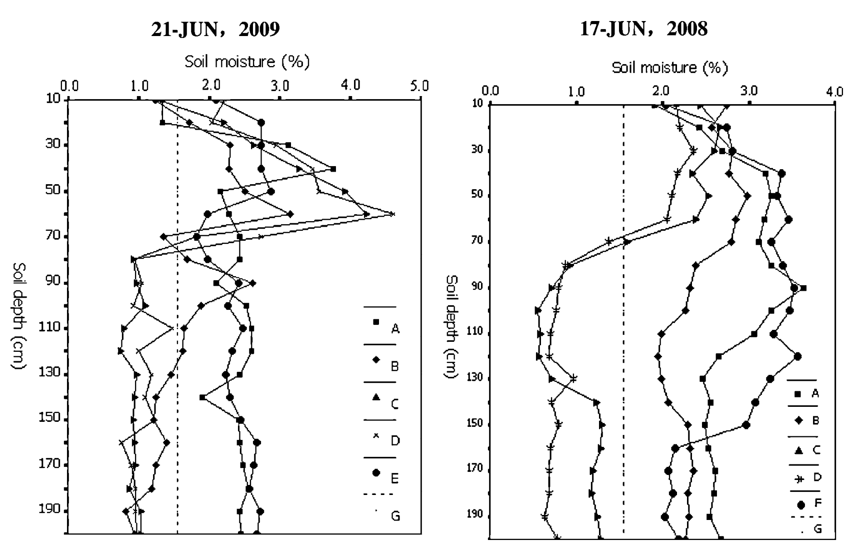

Fig. 2. Vertical variety of soil moisture under different planting densities of *C. microphylla* plantations in JUN of 2008 and 2009. A: 2 m × 2 m [T_1]; B: 2 m × 1 m [T_2]; C: 1 m × 1 m [T_3]; D: 1 m × 0.5 m [T_4]; E: nature *C. microphylla* plantations [*N*]; F: moving sand dunes [*M*]; G: wilting humidity.

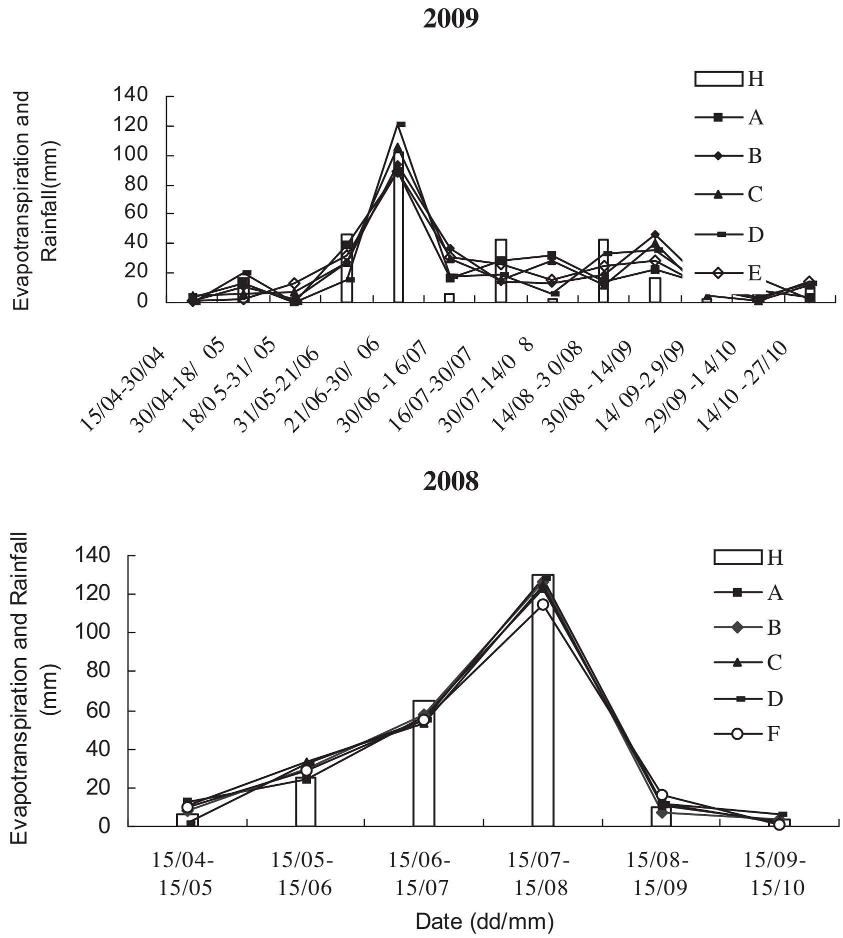

Fig. 3. Temporal variation of evapotranspiration of different densities *C. microphylla* plantations during growth phase in 2008 and 2009. A: 2 m × 2 m [T_1]; B: 2 m × 1 m [T_2]; C: 1 m × 1 m [T_3]; D: 1 m × 0.5 m [T_4]; E: nature *C. microphylla* plantations [*N*]; F: moving sand dunes [*M*]; H: rainfall.

evapotranspiration, about 283.4 mm, and has soil moisture surplus 20.8 mm at the end of growth phase. During the growth phase in 2008, precipitation is 249.7 mm, the evapotranspiration of T_4 plot have the highest evapotranspiration, about 235.7 mm and occupied above 94.4% of rainfall at the same time. The *M* plot has the lowest evapotranspiration, about 225.6 mm, and has soil moisture surplus 24.1 mm at the end of growth phase.

4. Discussion

In this study, we found that the planting densities of plantations affected soil moisture on sandy dunes, and the soil water depressed with the densities increasing. The results indicate the density of 2 m × 2 m *C. microphylla* has a good soil water condition, and the soil moisture all the time was above the wilting humidity during growth season. In contrast, the soil moisture of 1 m × 1 m and 1 m × 0.5 m *C. microphylla* was obviously lower than 2 m × 2 m densities and usually under the wilting humidity during growth season. This predicated that plantations will incept more deep soil water, and result in soil water storage decrease. The higher density of plantations is the principal reason caused soil water depressing in sandy land. According to soil water balance calculation, the suitable densities of *C. microphylla* are 2 m × 2 m, 2500 every ha^2 in this area. Compare of this plantation with the savageness *C. microphylla* vegetations, we found the savageness *C. microphylla* can keep the soil water balance, and there is 4–10 m^2 space for per individual. About the relationship of planting densities and soil moisture on sandy land, the previous investigators had researched the soil moisture on different densities of variety species on sand dunes. They found the suitable density of *Caragana korshinskii* is 8115 cluster per ha^2 in Loess Plateau (Guo, 2011; Xia and Shao, 2008). In Shapotou Region in the Tengger Desert, Northern China, investigators studied the different plantations on sand dunes during 1950–1990s and find the soil moisture depress with the age and the vegetative coverage increase, and the more above ground biomass, the less soil moisture (Wang et al., 2006; Li et al., 2004). Bi et al. (2007) showed the suitable coverage of *Pinus tabulaeformis and Robina perseudoacacia* was 53.82% and 51.30%, respectively. Tian et al. (2008) found out the suitable density of plantations on sandy land with the leaf area index. It was concluded the leaf area index of the vegetation was 1.7 m^2 m^{-2} in the North-east of Ulan Buh Desert, China. All of these results are same as we found about *C. microphylla* sand-fixing plantations in HSL, the density of plantations is a key factor to keep the soil water balance.

According to this study, the soil water balance becomes the significant influence factor on plantations' living on the sandy dune area. The water needed of plantations should keep balance with the soil water supply capacity. The feasible method of keeping soil water balance on sand dune area is to choose suitable species of which need little water or adjust densities of plantations. When we ascertain the suitable densities of plantations, we should consider some factors as below. (1) We should keep the suitable plantations densities, and ensure the soil water keeping balance, and the plantations can keep growth for a long-time. (2) The sand dune fixation

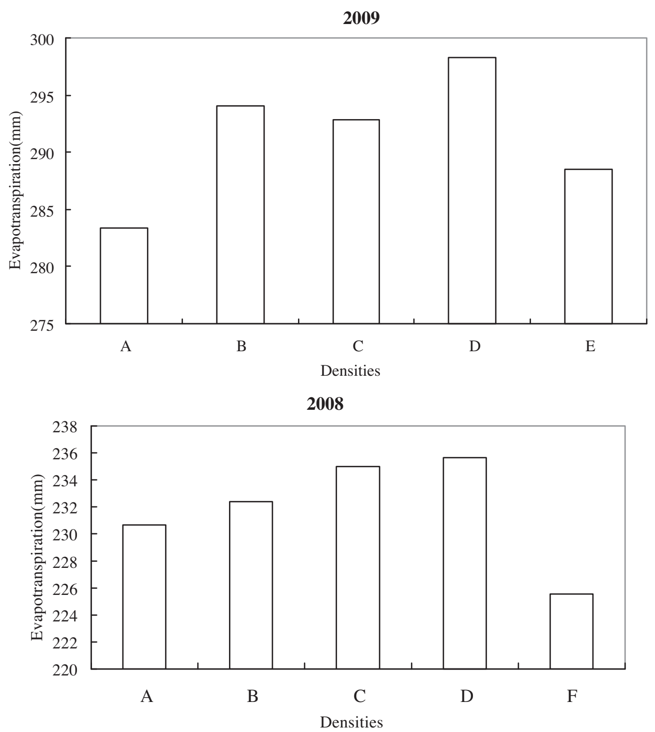

Fig. 4. The accumulative evapotranspiration of different densities *C. microphylla* plantations during growth phase in 2008 and 2009. A: 2 m × 2 m [T_1]; B: 2 m × 1 m [T_2]; C: 1 m × 1 m [T_3]; D: 1 m × 0.5 m [T_4]; E: nature *C. microphylla* plantations [*N*]; F: moving sand dunes [*M*].

plantations should keep suitable vegetative coverage to take on fixation sand dune effect.

5. Conclusions

1. The soil moisture of *C. microphylla* shrubs continued decreasing with the increasing of plantations densities. The 2 m × 2 m densities of *C. microphylla* shrubs, same as natural vegetations, can keep soil moisture above wilting humidity during growth phase, and the rainfall can reinforce the soil water content. The soil moisture under 1 m × 1 m densities of *C. microphylla* shrubs are almost lower than wilting humidity during growth season, and the shrubs loss more water by evapotranspiration.
2. The evapotranspiration of *C. microphylla* shrubs continued increasing with the increasing of plantation densities, and occupied above 90.3–98.5% of the precipitation. The evapotranspiration of 2 m × 2 m densities is lowest among all plots and surplus 20.8–19.0 mm soil water storage at end time of growth season.
3. Under the condition of Horqin Sandy land, the suitable density of *C. microphylla* plantation is 2 m × 2 m, and the soil moisture can keep high-level and have preferably effect on windbreak and dune fixation.

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