Microclimate Effect of Artificial *Caragana microphylla* Communities in Horqin Sandy Land

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Abstract *Caragana microphylla* is one of the key species for vegetation restoration in Horqin Sandy Land. Adopting field investigation and outdoor experiments, the microclimate effect of artificial C. microphylla communities with different restoration years were studied by observing wind velocity, air temperature, relative humidity and soil temperature. The results show that: (1) *Caragana microphylla* community has an obvious wind-breaking effect near ground surface. Compared with shifting dunes, the wind velocity in the 6-year-old and 11-year-old C. microphylla shrubs at the height of 30 cm separately decreases by 71.9% and 76.0%. (2) Mean daily temperature in the 6-year-old and 11-year-old C. microphylla communities is 3.7 ℃ and 4.9 ℃ lower than in shifting dunes, respectively. (3) The relative humidity of air in the *Caragana microphylla* shrubs is higher than in shifting dunes. (4) Soil temperature in *C. microphylla* plantation is lower than in shifting dunes. These results are significant in further exploring material and energy exchange near surface layer of artificial vegetation in the extremely arid condition.

Key words *Caragana microphylla*, Microclimate effect, Wind – breaking effect, Relative humidity, Soil temperature

The microclimate refers to any climatic condition in a relatively small area, within a few meters of or less above and below the Earth's surface and within canopies of vegetation. The microclimate is an essential environmental factor for growth and development of organisms, and reflects slight changes of ecosystem functions and landscape structure to a certain extent[1]. Different plant communities create different microclimates, while different microclimates make up different biological communities[2]. On the one hand, growth, photosynthesis and transpiration physiological activities of plant tissues are limited by micro-meteorological factor of habitat. On the other hand, vegetation reflects local characteristics of underlying surface, influences microclimate characteristics of near-surface layer through radiation, transpiration and barrier effect, and adjusts water and heat microclimate within the system, leading to difference in heat and water balance[3]. Researches have shown that development of shrubs can reduce speed in forest, change soil and air temperature and soil humidity condition, greatly improve forest microclimate, and create favorable environment for settlement and growth of organisms[4]. Therefore, the formation of community microclimate is the result of vegetation and environment, comprehensive reflection of community quality, and an essential indicator for evaluating restoration and reconstruction of degraded vegetation[5]. To coordinate the relationship between organism and environment, the study on microclimate is necessary[6-7].

Horqin Sandy Land, situated in northern farming-pastoral area, is an environment vulnerable area in Chinese ecosystem. In recent years, many scholars have made extensive researches on plant community structure, population composition, and construction of artificial ecosystem in this area[8-10]. *Caragana microphylla* (Little-leaf Pea Shrub) is a medium sized fully hardy perennial deciduous tree. It features cold-resistance, drought and barren tolerance, and high-temperature resistance, so it is widely used in restoration of vegetation in Horqin Sandy Land[11-17]. In the past, researches on *Caragana microphylla* were mainly concentrated in sand-fixation effect[11,12], soil environment and water[13-15], but there are still no reports about microclimate of artificial communities. Using wind velocity, air temperature, relative humidity, and soil temperature, we analyzed characteristics of microclimate in Horqin shifting dunes and artificial *Caragana microphylla* communities with different restoration years, in the hope of setting up improvement function of artificial vegetation. Besides, we also discussed the relationship between microclimate factor and restoration and reconstruction of vegetation, in order to provide theoretical basis and practical reference for ecological restoration and effect evaluation of vegetation in northern desertification areas.

1 Overview of the study area

The study area is situated in Uranaodu area in western Horqin Sandy Land. This area has typical semi-arid sandy climate, with annual average temperature of 5.8 – 6.4 ℃, mean annual precipitation of 330 – 340 mm, and annual evaporation of 2 000 – 2 500 mm. Sandstorm is strong and frequent, with annual average wind velocity up to 4.5 m/s and more than 75.3 days with wind scale above 8. Fluctuant dunes and heaps are distributed alternately, forming broad sand landscape. Major habitat types include drifting and semi-drifting dunes, fixed dunes, sandy land, interdune depression, and sand dunes. Soil types mainly include sandy soil, meadow soil, and saline-alkali soil. Its native vegetation belongs

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to transitional type from forest to grassland. Native vegetation has been destroyed almost totally. At present, vegetation shows strong secondary characteristic and most have evolved into psammophytic vegetation and meadow vegetation[18]. As for flora distribution, it belongs to Mongolian flora, North China flora, and Changbai flora, and Mongolian flora has the widest distribution and most types.

2 Materials and methods

2.1 Sample plot setting We selected sample plots in shifting dunes and artificial *Caragana microphylla* communities with different planting years. Initial planting density of artificial *Caragana microphylla* is 1 m × 1 m, and planting years are 6 years and 11 years respectively. Our survey in sample plots indicates that with increase in restoration years, species in *Caragana microphylla* shrubs gradually become rich, and the quantity becomes more, gradually forming a relatively stable community[19]. Basic conditions of sample plots are listed in Table 1.

2.2 Study methods

2.2.1 Measurement of wind velocity. Wind velocity was measured on spring days with average daily wind speed not less than 8.0 m/s by AVM-03 Wind Wheel Anemometer at the height of 200 cm, 80 cm, and 30 cm. One time was measured every half minute and a total of 30 times was measured in each height. All observation points of wind velocity in *Caragana microphylla* communities are situated in downwind direction of shifting dunes (about 50 cm from edges of shifting dunes).

Table 1 Basic conditions of sample plots

Items	Shifting dune sample plot (A)	6-year-old Caragana microphylla sample plot (B)	11-year-old Caragana microphylla sample plot (C)
Geographical coordinate	42°59′28″N 119°39′39″E	42°59′29″N 119°39′37″E	42°59′29″N 119°39′36″E
Total coverage of vegetation[13, 19]	<5%	50%	70%
Density of *Caragana microphylla* // grove/hm^2	0	6 438	7 625
Average height and crown diameter of *Caragana microphylla* // cm	0	81	97
		99 × 82	106 × 96
Major associated species	Artemisia wudanica and Agriophyllum arenarium	Artemisia halodendron, Corispermum candelabrum, Setaria viridis, and Cynanachum sihiricum	Artemisia halodendron, Corispermum candelabrum, Setaria viridis, Cynanachum sihiricum, and Salsola ruhtenica

2.2.2 Measurement of air temperature. Air temperature was measured on summer typical days (fine days with average daily temperature ≥ 25 ℃) by mercurial thermometer at different heights (0 cm and 30 cm) in the sample plots. The observation time was 8:00, 14:00, and 20:00, and each height was measured 3 times.

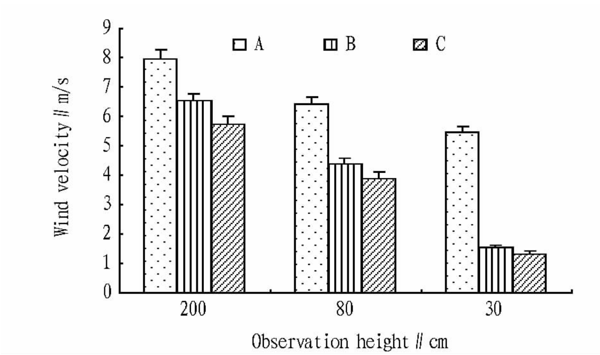
2.2.3 Measurement of relative humidity. Relative humidity was measured by wet-bulb thermometer (calibrated by Assmann psychrometer) at different heights (0 cm and 30 cm). The observation time was 8:00, 14:00, and 20:00, and each height was measured 3 times.

2.2.4 Measurement of soil temperature. Soil temperature was measured by bent stem earth thermometer at different depths (0 cm, 5 cm, and 10 cm). The observation time was 8:00, 14:00, and 20:00, and each depth was measured 3 times.

To avoid influence of rainfall on observation indicators, all indicators were measured 5 days after rainfall. We made statistical analysis on all data with the aid of SPSS19.0 software.

3 Results and analyses

3.1 Changes of wind velocity As shown in Fig. 1, changes in wind velocity during observation are consistent with changes of height, namely, wind velocity of shifting dunes > wind velocity of 6-year-old *Caragana microphylla* communities > wind velocity of 11-year-old *Caragana microphylla* communities. It clearly reflects that *Caragana microphylla* communities have great wind-breaking function on near-surface wind velocity. Also, with the reduction of height, the wind-breaking function becomes more and more obvious. This is because the artificial vegetation increases surface roughness. When wind blows across woods, wind velocity will be reduced due to friction and obstruction of tree trunk, branches and leaves. Besides, large air flow will be reduced to small air flow with different strengths and directions. As a result, kinetic energy of air flow is gradually depleted, and wind velocity decreases accordingly. At 200 cm, 80 cm, and 30 cm heights, compared with shifting dunes, the wind velocity of 6-year-old *Caragana microphylla* shrubs and 11-year-old *Caragana microphylla* shrubs drops 17.9%, 31.6%, 71.9% and 27.9%, 39.7%, and 76.0% respectively. 11-year-old *Caragana microphylla* communities have higher density, height and crown diameter, and better total coverage, so its wind-breaking effect is better than 6-year-old *Caragana microphylla* communities.



Note: A – sample plot of shifting dunes; B – sample plot of 6-year-old *Caragana microphylla* communities; C – sample plot of 11-year-old *Caragana microphylla* communities; for the same height, significance test was carried out in different sample plots; the same letter means not significant difference, and different letters means significant difference ($P<0.05$).

Fig. 1 Changes of wind velocity in sample plots

3.2 Changes of air temperature The observation of shifting dunes and *Caragana microphylla* communities in the same period (as listed in Table 2) indicates that the daily changes of air temperature are basically consistent, but the air temperature of *Caragana microphylla* communities is significantly lower than shifting dunes in different times and heights. This is possibly because crown cover has absorption and reflection functions to solar radiation, which greatly reduces solar radiation transmitted through woods, consequently leading to lower surface and near-surface air temperature. At 0 cm and 3 cm heights, the daily average air temperature of shifting dunes is 4.5 ℃ and 3.0 ℃ higher than 6-year-old *Caragana microphylla* communities respectively, and 5.9 ℃ and 3.9℃ higher than 11-year-old *Caragana microphylla* communities, indicating that *Caragana microphylla* shrubs can effectively reduce summer air temperature in woods.

3.3 Changes in relative humidity of air The relative humidity of air is a comprehensive manifestation of microclimate. Barrier of woods and friction of braches and leaves reduce wind velocity and cause water evaporated from ground surface and plants in the woods to stay for a long time. In addition, air temperature in woods is significantly lower than shifting dunes, so the relative humidity of air is higher. From Table 3, it can found that daily changes of relative humidity of air are basically consistent in three sample plots. The relative humidity of air in 6-year-old *Caragana microphylla* communities and 11-year-old *Caragana microphylla* communities is obviously higher than that in shifting dunes in all times, particularly in 8:00 and 20:00. The relative humidity of air in 6-year-old *Caragana microphylla* communities and 11-year-old *Caragana microphylla* communities is 13.7% and 21.2% higher than shifting dunes respectively. It proves that vegetation significantly increases relative humidity of surrounding air.

3.4 Changes in temperature of surface soil From Table 4, we can know that there are considerable differences in surface soil between vegetation area and shifting dunes. At each soil depth, the maximum temperature of soil in *Caragana microphylla* shrubs (14:00) is significantly lower than shifting dunes, while the minimum temperature (8:00) is slightly higher than shifting dunes. In general, daily changes in soil temperature in 6-year-old *Caragana microphylla* shrubs and 11-year-old *Caragana microphylla* shrubs are lower than shifting dunes. In other words, temperature changes are gentle, which is very favorable for settlement and growth of plants in the woods. Regulating function of vegetation on temperature of surface soil mainly gives the credit to the fact that the setup of artificial vegetation greatly increases surface roughness. Also, in the action of vegetation, drifting sands gradually become stable and form a layer of gray scale, soil volume-weight and volumetric heat capacity drop accordingly, which directly affects heat conductivity of soil.

Table 2 Changes of air temperature in sample plots ℃

Sample plot	8:00		14:00		20:00	
	0 cm	30 cm	0 cm	30 cm	0 cm	30 cm
A	33.1 a	29.8 a	39.8 a	38.0 a	28.1 a	27.9 a
B	26.2 b	27.6 b	35.6 b	33.9 c	25.8 b	25.3 b
C	22.9 c	25.7 c	34.7 c	35.5 b	25.7 b	22.8 c

Note: for the same time and height, significance test for air temperature was carried out in different sample plots; the same letter means not significant difference, and different letters means significant difference ($P<0.05$)

Table 3 Changes in relative humidity of air in sample plots %

Sample plot	8:00		14:00		20:00	
	0 cm	30 cm	0 cm	30 cm	0 cm	30 cm
A	24 c	25 c	20 c	15 b	29 b	26 c
B	42 b	43 b	29 b	26 a	43 a	38 b
C	55 a	51 a	35 a	29 a	42 a	54 a

Note: for the same time and height, significance test for relative humidity of air was carried out in different sample plots; the same letter means not significant difference, and different letters means significant difference ($P<0.05$)

Table 4 Changes in temperature of surface soil in sample plots ℃

Sample plot	8:00			14:00			20:00		
	0 cm	5 cm	10 cm	0 cm	5 cm	10 cm	0 cm	5 cm	10 cm
A	27.5 a	19.1 b	19.0 c	43.2 a	33.0 a	31.2 a	30.1 a	30.8 a	29.0 a
B	21.8 b	20.2 a	19.7 a	41.6 b	32.8 a	29.4 b	28.7 b	28.8 b	28.2 b
C	21.3 c	20.0 a	19.5 b	36.5 c	28.4 b	26.7 c	27.3 c	27.3 c	27.0 c

Note: for the same time and height, significance test for temperature of surface soil was carried out in different sample plots; the same letter means not significant difference, and different letters means significant difference ($P<0.05$).

4 Conclusions

Through the above analyses, we arrive at conclusions that there are distinct difference in microclimate factors such as wind velocity, air temperature, relative humidity, and soil temperature due to difference in underlying features between shifting dunes and *Caragana microphylla* communities with different restoration years. In general, (1) *Caragana microphylla* community has an obvious wind-breaking effect near ground surface. Compared with shifting dunes, the wind velocity in the 6-year-old and 11-year-old C. microphylla shrubs at the height of 30 cm separately decreases by 71.86% and 75.96%. (2) After restoration of artificial vegetation, the mean daily temperature in the 6-year-old and 11-year-old C. microphylla communities is significantly lower than in shifting dunes, the relative humidity of air is significantly increased, while daily changes of temperature of surface soil decrease.

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4.3 Strict enforcement of control standards for agricultural utilization of solid wastes As mentioned, agricultural utilization of solid wastes is one of the effective ways of recycling. For example, steel slag can be processed into silicon fertilizer, and coal ash can be processed into silicon-calcium fertilizer. In addition, many industrial residues can be applied directly in farmland soil as soil improvement agent. For instance, the by-product of phosphate fertilizer production is phosphogypsum, which can be used for improving alkaline soil. After appropriate crushing process, blast furnace slag can be used as soil improvement agent to improve the soil with heavy texture and poor permeability. Improper use of these solid wastes will result in serious consequences including soil contamination and land degradation *etc*. After soaking into the soil, heavy metals and the poisonous and harmful organic compounds will affect crop growth and will enter the food chain after being absorbed by crops. Ultimately, human health will suffer serious hazards. Excessive application of solid wastes could also result in secondary salinization, acidification or alkalinization of soil as well as soil texture deterioration due to the mixing of impurities including glass fragments. And of course, those heavy metals and organic pollutants soaking into the soil will continue to move in the soil mass and even reach the underground water under the action of rainfall or irrigation water. In this way, a greater range of environmental pollution will be caused. Therefore, the agricultural utilization of solid wastes should be conducted very carefully in strict accordance with national control standards on agricultural utilization of solid wastes. Besides, through discussion and demonstration should be carried out. When necessary, field trial can be performed on a small scale. And then extend the scope of application with reliable data obtained[4].

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