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Full Length Article

Study of Drought Resistance of Thirteen Sand-Fixing Plants in Horqin Sand Land, China

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Abstract

The Horqin Sand Land is characterized by a continental semi-arid monsoon climate. Water is a key limiting factor for the restoration of vegetation and ecological construction in this area. Selecting species with high levels of drought resistance for the restoration of vegetation in this area is important. Thirteen sand-fixation plants species in this region (*Caragana korshinskii*, *C. microphylla*, *Elaeagnus angustifolia*, *Euonymus bungeanus*, *Hedysarum fruticosum*, *Hippophae rhamnoides*, *Picea mongolica*, *Pinus sylvestris* var. *mongolica*, *Sabina vulgaris*, *Salix gordejevii*, *S. matsudana*, *Ulmus pumila*, and *Xanthoceras sorbifolia*) were selected and seven drought resistance indexes (water saturation deficit, specific leaf area, leaf water-retaining capacity, chlorophyll content, foliar δ^{13}C value, leaf water potential, and leaf transpiration rate) were measured. The comprehensive evaluation of the thirteen species generated the following rank order as *S. vulgaris*>*P. mongolica*>*P. sylvestris* var. *mongolica*>*H. rhamnoides*>*E. angustifolia*>*C. microphylla*>*S. gordejevii*>*X. sorbifolia*>*C. korshinskii*>*S. matsudana*> *E. bungeanus*>*U. pumila*> *H. fruticosum* in terms of drought resistance through subordinate function values analysis. Using the group mean cluster analysis method, the thirteen plant species fall into three groups and the rank order of the capacity for drought resistance from the highest to the lowest was as follows: (1) *S. vulgaris*, *P. mongolica*, and *P. sylvestris*; (2) *H. rhamnoides*, *E. angustifolia*, *C. microphylla*, *S. gordejevii*, *X. sorbifolia*, *C. korshinskii*, *S. matsudana*, *E. bungeanus*, and *U. pumila*; and (3) *H. fruticosum*. Among the seven drought resistance indexes, specific leaf area was the most effective. The results have important implications for the establishment of artificial plantations in Horqin sand land and other semi-arid sand land areas in China.

Keywords: Semi-arid area; Grey correlation analysis; Subordinate function values; Comprehensive evaluation

Introduction

The Horqin sand land is situated in the eastern portion of the Inner Mongolia desert of Northeast China (42°41'–45°15'N, 118°35'–123°30'E, 180–650 m asl) and has experienced serious desertification, primarily from overgrazing, excessive farming and vegetation deterioration (Liu and Zhao, 1993). Revegetation has been widely accepted to be the most effective method for preventing desertification. Water is the key factor for vegetation restoration and ecological construction in sandy areas. In desertified areas, sand-fixing plants grow and develop rapidly at first, but their growth rate declines once the original soil water has been depleted (Guo *et al*., 2000; Jiang *et al*., 2004; Lei *et al*., 2010). Research on the drought resistance capacity of sand-fixing plant species is important for plant survival and sustainable development in Horqin sand land.

Researchers have linked various characteristics of plants with their drought resistance mechanisms, such as relative water content, transpiration rate, electrical conductivity, specific leaf area, root-shoot ratio, chlorophyll content, water-use efficiency and water potential etc. (Li *et al*., 2006; Li *et al*., 2009; Yang *et al*., 2009). Based on analysis of previous studies, there are four types of indices of drought resistance: morphological, growth, physiological, and biochemical (Ji *et al*., 2006). In recent years, several researchers have evaluated plant drought resistance through examination of the anatomical structure of leaves (Han *et al*., 2006; Zhu *et al*., 2007). Growth indices, such as plant height, leaf area, expansion rate of leaves, dry weight, etc., can be used to assess the drought resistance of plants under dry conditions (Zhou and Li, 2002). Physiological and ecological characters, such as net photosynthetic rate, evaporation intensity, water-use efficiency, water saturated deficit, water potential etc., have a close association with drought-resistance in plants (Zgallai *et al*., 2006). Biochemical indices of drought resistance include POD, SOD, CAT, NRA, chlorophyll content, etc. (Hu *et al*., 1999). These characteristics include morphological and anatomical structure, water physiological and ecological characteristics, physiological and biochemical reactions and the features of tissue cells, photosynthetic organs and

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bioplasm (Li *et al*., 1996, 2007). In order to evaluate the drought resistance of different plants comprehensively and objectively, it is necessary to make a comprehensive quantitative evaluation using several indices related to drought resistance. Robust results can only be obtained through comprehensive research of drought resistance.

Plant species with high performance—plants that grow rapidly, are high quality, are adaptable and resistant to drought have been widely used for wind break and fixation sand in Horqin sand land. Drought resistance of common species employed in vegetation restoration has been studied in Horqin sand land (Jiang *et al*., 2013). Most research concerning the drought resistance of plants has been conducted on only a few plant species. Research that has compared the drought resistance of several different woody plants for revegetation in Horqin sand land is also scarce. A comprehensive survey of the drought resistance of common sand-fixing tree species is urgently needed. In this study, based on a field survey in Horqin sand land, the values of seven drought resistance indexes of thirteen afforesting tree and shrub species were measured. A comprehensive evaluation of the drought resistance of the thirteen species was systematically conducted using the fuzzy function method (Yang *et al*., 2009) and grey correlative analysis (Li *et al*., 2006). The major objective was to compare the drought resistance of the most common afforestation tree species in Horqin sand land and to develop a proper approach for vegetation restoration and reconstruction in Horqin sand land.

Materials and Methods

Study Area

The study was conducted at Wulanaodu village (43°02'N，119°39'E；480 m asl) in the southwestern portion of Horqin Sand Land, Inner Mongolia Autonomous Region, China. The study area has a continental semi-arid monsoon climate. The average annual temperature is 6.3°C, ranging from -14°C (January) to 23°C (July). Annual precipitation is 340 mm; 70% of the precipitation falls between May and September. The mean annual pan-evaporation is approximately 2,300 mm: six times the annual precipitation. The mean annual wind velocity is 4.4 m/s and the number of gale days (>16 m/s) varies between 21 and 80, with the windy season occurring from March to May. The growing season is generally from April to September (Yan *et al*., 2005).

Plant Material and Field Site

In this study, seven drought resistance indexes (water saturation deficit, specific leaf area, leaf water-retaining capacity, chlorophyll content, leaf water potential, leaf transpiration rate and foliar $\delta^{13}C$ values) in thirteen afforesting tree and shrub species (*Caragana korshinskii*, *C. microphylla*, *Elaeagnus angustifolia*, *Euonymus bungeanus*, *Hedysarum fruticosum*, *Hippophae rhamnoides*, *Picea mongolica*, *Pinus sylvestris* var. *mongolica*, *Sabina vulgaris*, *Salix gordejevii*, *S. matsudana*, *Ulmus pumila*, and *Xanthoceras sorbifolia*) in Horqin sand land were studied. General descriptions of the thirteen sand-fixing species and seven drought resistance indexes are provided in Table 1 and Table 2, respectively.

The experiments were conducted at the Wulanaodu Experimental Station of Desertification, Chinese Academy of Sciences. The thirteen species were all planted in the yard of the station in 2008, and characteristics of the plant species measured at the end of August 2012 are shown in Table 3. Soil water is a fundamental parameter of hydrological status. The mean soil water content for the plant community was 3.1 ~ 5.0% during the experimental period, which is capable of meeting the demands of plant growth.

Sampling Design and Index Measurements

During the growing period, three plants of each species in the experimental field were selected as sampling trees. The leaf traits of water saturation deficit (WSD), specific leaf area (SLA), leaf water-retaining capacity, and chlorophyll content were measured in August 2013.

Water saturation deficit was measured using the method of Yang *et al.* (2009). Leaves were cut from the plants, weighed and saturated in distilled water for about two hours until the weight did not change. The turgid weight was then obtained, and after drying for 24 h at 85°C, the dry weight was determined. The water saturation deficit was calculated using the formula [(HydW-FW)/(HydW-DW) *100], where FW, HydW and DW are the leaf fresh weight, hydrated (full turgor) and dry weights, respectively (Yang *et al*., 2009).

Specific leaf area was calculated using the formula [SLA = LA/LDW], where LA is leaf area, and LDW is leaf dry weight (Bai *et al*., 2008). Leaves were cut from the plants and then measured. Leaf area was measured using portable leaf area meter and leaf area image processing soft. The leaf areas of evergreen species were calculated using the method of Wu *et al.* (1995).

Leaf water-retaining capacity was measured using a natural drying method. Fresh leaves were hung indoors. The leaves were weighed every two hours and the percentage of water loss in the fresh leaves at every moment was calculated (Bai *et al*., 2008).

Chlorophyll content was calculated using the acetone extraction method (Hao *et al*., 2004). Healthy plant leaves were randomly selected for the measurement of chlorophyll content. Chlorophyll was extracted from the leaves using a mixed solvent of ethanol and acetone (1: 1). The absorption spectra of the ethanol-acetone extract was measured with the spectrophotometer using a bowl. The concentrations of chlorophyll a and b were calculated from the absorbance measured at 645 and 663 nm according to the Zhang formula (Li, 2000).

Foliar $\delta^{13}C$ was measured with Stable Isotope-Ratio Mass Spectrometers (Thermo Finnigan), Institute of Applied Ecology, Chinese Academy of Sciences. Five to six individual plants of the same species were selected and three to seven healthy leaves from individual plants were randomly collected. The sampled leaves were first washed with distilled water and then oven dried at 80°C for approximately 48 h to a consistent weight. The leaves of the same species were grounded using a sample mill (MF10, IKA, Germany), sieved with a 1 mm mesh screen and then measured (Zheng and Shangguan, 2007). The samples were collected in August 2012 and measured in April 2013.

Leaf water potential was measured using Dewpoint Potential Meter (WP4, Decagon Devices, Inc., USA) throughout the day on June 23, July 20 and August 22, 2013 at 2 h intervals from 6:00 to 18:00. These three days were all bright, sunny days. Three individual plants were selected for each species, and five to eight fully expanded leaves were collected from the middle and southern canopy of each plant. Measurements were all taken as soon as possible (Liu *et al*., 2003).

Transpiration rate: Transpiration rate measurements were made using the quick-weighing method (Wang *et al*., 1999), with a1/10,000 electronic balance and expressed as milligrams per gram fresh weight per hour. The transpiration rates of three random samples of the three leaves in the plant were measured at 2 h intervals from 6:00 to 18:00 on July 21 and August 23, 2013, which were both sunny days.

Data Analysis and Statistics

Statistical analysis: Excel and the SAS software were used to process and analyze data. Subordinate function values of drought resistance were calculated using the fuzzy function method. First, idiographic subordinate values of these measured indexes in different plant species were calculated. When indexes were positively correlated with drought resistance, formula (1) was used. For negative correlations with formula (2), cumulative total subordinate values for all indexes were averaged to obtain the SV of drought resistance with formula (3):

$$Z_{ij} = \frac{X_{ij} - X_{i\min}}{X_{i\max} - X_{i\min}} \quad (1)$$

$$Z_{ij} = 1 - \frac{X_{ij} - X_{i\min}}{X_{i\max} - X_{i\min}} \quad (2)$$

$$\overline{Z_{ij}} = \frac{1}{n}\sum_{i=1}^{n} Z_{ij} \quad (3)$$

Group mean cluster analysis (GCA) was performed using SPSS 19.0 (SPSS Inc., Chicago, USA). Grey correlation analysis is a method of treating and analyzing data according to grey system theory. Its premise is to judge the degree of correlation according to the geometrical similarity of discrete series (Hu and Xie, 2013). In this paper, the grey correlation analysis method was used to evaluate the effectiveness of the indexes as indicators. When correlative degree analysis was conducted on sequences with different units or different initial values, mean values or initial values required pre-treatment to remove the dimensions of the test data. For pretreatment of the initial value, let

$$y_i = \frac{x_i}{x_i(1)}, i = 0,1,\cdots,N \quad (4)$$

Where y_0 is the initial value sequence of the main factor, and y_i (i=0, 1, ⋯, N) is the initial value sequence of sub-factors.

Let x_o be a sequence of the main factor, $x_0 = \{x_0(k)|k = 1,2,\cdots,n\}$; and x_i be a sequence of the sub-factor, $x_i = \{x_i(k)|k = 1,2,\cdots,n; i = 1,2,\cdots,N\}$.

Then, the grey correlation coefficient is defined as follows:

$$\xi_i(k) = \frac{\min\limits_i \min\limits_k |x_0'(k) - x_i'(k)| + p \max\limits_i \max\limits_k |x_0'(k) - x_i'(k)|}{|x_0'(k) - x_i'(k)| + p \max\limits_i \max\limits_k |x_0'(k) - x_i'(k)|}$$

(Where p=0.5). To calculate the average value of the correlative degree, $\xi_i(k)$ (k=1,2,⋯,n) for different points:

$$r_i = \frac{1}{n}\sum_{i=1}^{n} \xi_i(k)$$

Where r_i is the grey correlation degree. r_i indicates the degree to which r_i influences x_0. Greater r_i values indicate a stronger influence.

Results

Grey Correlation Analysis of Seven Indexes of Drought-resistance

The results of grey correlation analysis revealed the degree to which the physiological index influenced the drought resistance of plants. The correlative degree of seven different indexes of drought resistance is shown in Table 4. In decreasing order of degree, these indexes were ranked in the following order: specific leaf area > chlorophyll content>water saturation deficit>transpiration rate>leaf water potential>foliar $\delta^{13}C$ value>water-retaining capacity. These seven indexes of drought resistance were all closely related to the degree of drought resistance membership (> 0. 60). Thus, all of these indexes can be considered to be robust indicators of drought resistance. Of these indexes, specific leaf area can be considered to be the most effective index of drought resistance capacity.

Table 1: Description of thirteen and-fixing species

Species	Description
C. korshinskii	*Caragana korshinskii* is a deciduous perennial shrub found in sandy grassland and desert ecosystems. The species is distributed across half-fixed and fixed sandy regions in northwest China and Mongolia. *Caragana korshinskii* is the main species initially employed for vegetation restoration in desert areas in China (Fu, 1989).
C. microphylla	*Caragana microphylla*, a leguminous shrub, is the dominant plant species and is widely used in vegetation reestablishment programs to stabilize shifting sand in the semi-arid Horqin sand land of north China (Su, 2003).
E. angustifolia	*Elaeagnus angustifolia* is one of the native dominant species in the ecotone between oasis and desert and the desert riparian ecosystems in the arid region of northwest China. It is also an important economic tree species and is used for windbreaks (Wang, 1993).
E. bungeanus	*Euonymus bungeanus* is a tree species with high drought resistance and salt tolerance, and is also widely used in urban forest development in north China (Wen *et al*., 1996).
H. fruticosum	*Hedysarum fruticosum* is a pioneer species largely distributed in shifting sand dunes. Due to its sand-fixation ability it is well-adapted to drought and shifting sand conditions compared with other sand species (Chen, 1986).
H. rhamnoides	*Hippophae rhamnoides*, which is a thorny nitrogen-fixing deciduous perennial shrub, is grown widely in northern and southwestern China. Owing to its high resistance to environmental stresses, such as cold, drought and UV-B radiation, *H. rhamnoides* has been widely used in forest restoration as a pioneer species. It plays an important role in preventing soil erosion, soil water loss and regulating climate, as well as in retaining ecological stability in this region (Li *et al*., 2004).
P. mongolica	*Picea mongolica* is an endemic but endangered species in Inner Mongolia China. The ecosystem made of *P. mongolia* is a special forest ecosystem type because it is a sandy forest type, and it is found at the ecotone between the forest zone and the steppe zone, between agricultural districts and pastoral areas, which is also a transitional zone from the Daxinganling Mountains to the Hunshandake Desert (Xu *et al*., 1998).
P. sylvestris	*Pinus sylvestrisvar.mongolica* is one of the key tree species used in plantation establishment. Because it is drought resistant, *P.sylvestris* has been broadly introduced on sandy land in the "Three North"regions of China (Zhu *et al*., 2005).
S. vulgaris	*Sabina vulgaris* is an evergreen conifer species and is widespread in northern and northwestern China. The stems of *S. vulgaris* are prostrate and spread rapidly. Their height is usually less than 1.5 m, but they attain 15 m in canopy diameter (Ohte *et al*., 2003). Water requirement of the species is small, it can survive under low rainfall conditions. Thus, *S. vulgaris* is an effective species for rehabilitating desertified areas in the sand land (He and Zhang, 2003).
S. gordejevii	*Salix gordejevii* is an indigenous and pioneer shrub on moving and semi-moving dunes. It can endure drought, resist wind erosion and bear sand coverage. The mature plant is approximately 1–3 m in height, with its vertical and horizontal roots extending up to 3.5 and > 20 m, respectively (Ren *et al*., 2001).
S. matsudana	*Salix matsudana* is a cold- and drought-tolerant tree species. *S.matsudana* forests are commonly found in the Horqinsand land, where forest stands play a vital role in combating desertification in the semi-arid and arid regions in China (He and Dong, 2003).
U. pumila	*Ulmus pumila* is a widespread tree species in North China, especially in semi-arid sandy land. It grows rapidly, is high quality, is adaptable, and is resistant to drought. This species has often been used as a major forestation species of shelter forest, especially in the semi-arid sand land.
X. sorbifolia	*Xanthoceras sorbifolia* is a native tree in northern China, which is highly adaptable (drought, cold and salt resistance) This plant can survive well below −40°C, except on saline-alkali land or waterlogged fields (Kuang *et al*., 2001).

Table 2: Description of seven drought resistance indexes

Indexes	Description
Specific Leaf Area (SLA)	Specific leaf area is defined as the leaf area per unit leaf dry weight. It is generally used as an alternative indicator of plant drought-resistance capacity. Species with low specific leaf area values are suited for conserving acquired resources because of their large dry matter content, high concentrations of cell walls and secondary metabolites, and high leaf and root longevity (Marron *et al*., 2003). Lower specific leaf area values generally indicated higher water-retaining capacity and an increased capacity for drought resistance (Wilson *et al*., 1999).
Water saturation deficit (WSD)	The water saturation deficit of plants is an important index for representing both the degree of water deficiency and the degree of drought. Higher water saturation deficits generally indicate higher drought- resistance capacity (Chen and Liu, 1997).
Water-retaining capacity	Water-retaining capacity closely tied to drought resistance in plants. Higher water-retaining capacity results in the relatively slow loss of water under drought conditions.
Chlorophyll content (Chl)	Chlorophyll is one of the main components in chloroplasts for photosynthesis. Chlorophyll provides an important medium for converting inorganic C, N to its organic forms, and is one of the most important indexes for indicating the photosynthetic capacity and nutritional status of plants (Guo and Li, 2000). Studies have shown that stay-green has an association with transpiration efficiency and the rate of carbon exchange under water-limited conditions in plants. Chlorophyll content is generally considered to be an index of drought resistance (Araus *et al*., 1998).
Foliarδ^{13}C value	Water-use efficiency (WUE), expressed as the ratio of net photosynthetic rate and transpiration rate, is one of the most important parameters that can be used to evaluate the adaptive capability of plants to cope with water scarcity (Wright *et al*., 1988). The foliar δ^{13}C value is widely used for studying the photosynthetic pathway and for estimating WUE of plants in natural vegetation assemblages (Holtum and Winter, 2005). Generally, higher foliarδ^{13}C indicates higher WUE and a more conservative water-use pattern. The measurement and analysis of foliarδ^{13}C can provide information that integrates important plant physiological characteristics spatially and temporally (Wright *et al*., 1988).
Leaf water potential (LWP)	Leaf water potential is one of the most direct indexes estimating plant moisture conditions and reflects the ability of plants to absorb moisture from the soil or neighboring cells (Li *et al*., 2011). Water potential and potential gradients influence water flow and are key links in the hydrologic cycle. Changes in LWP reflect the capacity of plants to adapt to arid environments (Han *et al*., 2008).
Transpiration rate (Tr)	Free water is lost through transpiration and excessive loss can result in the wilt or death of plants, as the higher the transpiration rate and the poorer the water retention, the lower the drought resistance (Wang *et al*., 2003). Transpiration is one of the most important eco-physiological traits describing the adaptive strategy of plants. Studies on transpiration rate of different species have attracted increased attention from eco-physiologists (Ji *et al*., 2006).

Comprehensive Evaluation of Drought-Resistance Capacity of Thirteen Plant Species

Values of seven drought resistance indexes of thirteen plant species obtained from experimental testing are showed in Table 5. The drought resistance mechanism is not a function of one factor. Instead, drought resistance mechanisms appear to be a function of several morphological, structural and physiological characteristics. Comprehensive surveys of the drought resistance ability of plants are important. According to the drought resistance subordinate function values from the fuzzy function method (Table 6),

Table 3: Basic characteristics of thirteen plant species

Species	Age (a)	Height (cm)	Crown (cm × cm)	Base diameter (cm)	Branch number
C. korshinskii	4	225	140×125	4.2	7
C. microphylla	4	160	53×45	1.2	2
E. angustifolia	4	130	113×105	2.3	2
E. bungeanus	4	220	145×160	5.3	—
H. fruticosum	4	175	220×132	1.5	11
H. rhamnoides	4	140	96×100	3.0	—
P. mongolica	4	174	110×118	4.8	—
P. sylvestnis	4	145	147×135	5.6	—
S. vulgaris	4	55	130×50	1.5	1
S. gordejevii	4	245	155×145	1.2	13
S. matsudana	4	480	150×215	6.3	3
U. pumila	4	230	190×165	4.1	—
X. sorbifolia	4	177	240×237	5.0	2

Table 4: Correlation of different indexes with drought resistance

Index	Correlation
Specific leaf area	0.707
Water saturation deficit	0.674
Chlorophyll content	0.696
Foliarδ^{13}C value	0.643
Leaf water potential	0.654
Transpiration rate	0.658
Water-retaining capacity	0.641

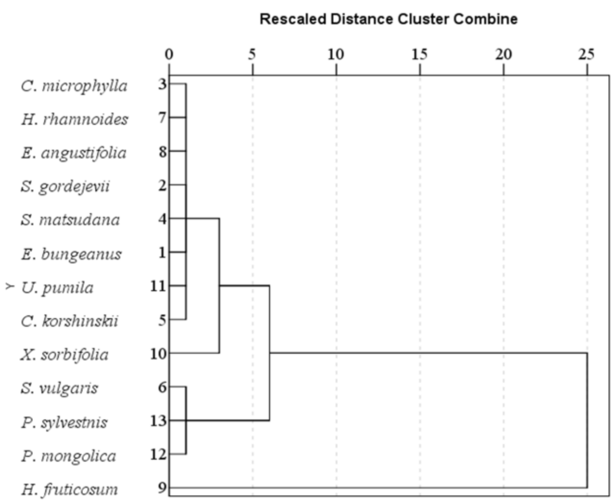

Fig. 1: Rescaled distance clusters for thirteen species

the rank order of drought resistance capacity of thirteen plant species from the highest to the lowest was the following: *S. vulgaris>P. mongolica>P. sylvestris>H. rhamnoides>E. angustifolia>C. microphylla>S. gordejevii>X. sorbifolia >C. korshinskii>S. matsudana> E. bungeanus>U. pumila> H. fruticosum*. The thirteen plant species was classified into three groups by the group mean cluster analysis method. The rank order of drought resistance capacity from the highest to the lowest was the following: (1) *S. vulgaris*, *P. mongolica*, and *P. sylvestris*; (2) *H. rhamnoides*, *E. angustifolia*, *C. microphylla*, *S. gordejevii*, *X. sorbifolia*, *C. korshinskii*, *S. matsudana*, *E. bungeanus*, and *U. pumila*; (3) *H. fruticosum* (Fig. 1). *S. vulgaris*, *P. mongolica*, and *P. sylvestris* are all evergreen conifer species, and all belong to the group with the strongest drought resistance capacity based on the group mean cluster analysis. *H. fruticosum* fell into the least drought resistant group. Members of this group had the lowest water-retaining capacity and the highest transpiration rate (Fig. 1 and Table 5). Species with the highest level of water resistance are preferred for restoring degraded sand dunes in Horqin sand land.

Discussion

The gray correlation analysis is more reasonable compared to single trait variance analysis and is more accurate for the evaluation of the performance of drought resistance indexes (Zhong *et al*., 2011; Luo *et al*., 2015). There are several indexes for evaluating the drought resistance of plants. However, no index is completely independent, and the contribution of each index to the evaluation of drought resistance evaluation is different. Grey correlation analysis is a common method used for screening drought resistant indexes. He *et al*. (2009) concluded that three indexes, including ground biomass, MDA content and chlorophyll a content were important in drought stress, as inferred from by grey correlative degree analysis. Zhou *et al*. (2012) found that the physiological and biochemical indexes of relative water content, relative conductivity, and the contents of malondialdehyde, soluble carbohydrates，proline and chlorophyll of the plant leaves can all be used as indexes of for the evaluation and selection of the drought-resistant plant species for ecological regeneration on rocky slopes.

In this study, specific leaf area was the most effective index among the seven drought-resistance indexes. This result was inconsistent with previous studies (Chen *et al*., 2013; Li *et al*., 2015). Previously, chlorophyll content, the water potential of leaves, relative water content and electrical conductivity have been considered to be the most important indexes of drought resistance evaluation in *Tamarix ramosissima*, *Platycladus orientalis* and *Sympegma regelii* (Li *et al*., 2006). Transpiration rate,

Table 5: Values of seven drought resistance indexes of thirteen plant species

Species	Leaf water status						
	Specific leaf area (cm^2/g)	Water saturated deficit (%)	Chlorophyll content (mg/g)	Foliar $\delta^{13}C$ value (‰)	Leaf water potential (MPa)	Transpiration rate (mg/(g·h))	Water-retaining capacity (%)
C. korshinskii	111.7	21.1	2.04	-28.795	-1.97	1301.8	75.8
C. microphylla	99.3	24.7	1.96	-28.578	-2.15	928.5	62.9
E. angustifolia	121.7	28.6	2.19	-27.923	-1.70	960.9	34.0
E. bungeanus	121.3	12.3	1.12	-29.623	-2.41	1132.8	19.6
H. fruticosum	116.8	19.2	1.87	-28.755	-1.95	2579.5	84.4
H. rhamnoides	90.4	22.7	2.30	-25.324	-1.83	917.5	38.9
P. mongolica	76.9	30.9	1.23	-26.489	-2.72	375.8	23.7
P. sylvestris	57.3	25.0	1.10	-25.731	-2.26	293.8	10.3
S. vulgaris	50	34.5	1.13	-24.767	-2.15	264.2	6.7
S. gordejevii	121	11.9	2.38	-28.576	-2.57	802.1	61.3
S. matsudana	117.9	15.8	1.94	-27.618	-1.83	861.6	73.8
U. pumila	131.5	19.0	1.65	-28.308	-1.90	1132.6	50.8
X. sorbifolia	113.4	20.7	2.50	-28.474	-2.14	1625.5	77.5

Table 6: Drought-resistance subordinate function values of the seven physiological indexes in thirteen tree species

	Membership function values							
	Specific leaf area	Water saturation deficit	Chlorophyll content	Foliar$\delta^{13}C$ value	Leaf water potential	Transpiration rate	Water-retaining capacity	Mean value
C. korshinskii	0.24	0.41	0.67	0.17	0.27	0.55	0.11	0.35
C. microphylla	0.40	0.57	0.61	0.22	0.44	0.71	0.28	0.46
E. angustifolia	0.12	0.74	0.78	0.35	0	0.70	0.65	0.48
E. bungeanus	0.13	0.02	0.01	0	0.70	0.63	0.83	0.33
H. fruticosum	0.18	0.32	0.55	0.18	0.25	0	0	0.21
H. rhamnoides	0.50	0.48	0.86	0.89	0.13	0.72	0.59	0.60
P. mongolica	0.67	0.84	0.09	0.65	1	0.95	0.78	0.71
P. sylvestris	0.91	0.58	0	0.80	0.55	0.99	0.95	0.68
S. vulgaris	1	1	0.02	1	0.44	1	1	0.78
S. gordejevii	0.13	0	0.91	0.22	0.85	0.77	0.30	0.45
S. matsudana	0.17	0.17	0.60	0.41	0.13	0.74	0.14	0.34
U. pumila	0	0.31	0.39	0.27	0.20	0.62	0.43	0.32
X. sorbifolia	0.22	0.39	1	0.24	0.43	0.41	0.09	0.40

relative water content and electrical conductivity are considered to be important indexes of drought resistance evaluation of five desert plants (Yang *et al.*, 2009). Water potential, V_a/V_s, residual moisture content, bound water, transpiration rate and constant weight time were selected to evaluate the drought resistance of shrubs in Ulan Buh desert area (Jia *et al*., 2015). The degree of adaptation to drought is variable in different plants. Some plants may have several mechanisms to resist drought. Obtaining perfect consistency in the precise order of the degree to which physiological indexes influence drought resistance of plants is challenging.

The fuzzy function method was used to comprehensively evaluate a number of indicators through fuzzy relations established by subordinate functions. This method is a common way to evaluate drought resistance using multiple-indexes (Zhuang *et al*., 2005; Wang *et al*., 2013; Chi, 2017). A comprehensive evaluation of the drought resistance of thirteen plant species was conducted using values of the subordinate function analysis in Horqin sand land. These results are consistent with previous studies. Zhang (1981) concluded that the physiological index of drought resistance of *E. angustifolia* is much lower than those of *Nitraria tangutorum* and *Haloxylon ammodendron*. *E. angustifolia* is a xeromesophyte. Zhong-liang (2005) concluded that the drought resistance of *C. korshinskii* is superior to that of *H. fruticosum* through the simulation of natural drought condition indoors. Zhu (2009) found that the drought resistance of *P. sylvestris* is superior to that of *Populus simonii*. In addition, Zhu (2009) found that, *P. sylvestris* var. *mongolica* is a more appropriate plant for the Horqin sand land. The transpiration strength of *P. sylvestris* is lower than *P. simonii*, and *P. sylvestris* is a more appropriate plant for the Horqin sand land (Zhu, 2009). Zhang *et al*. (2006) found that the ability of *C. microphylla* to endure aridity is stronger than that of *U. pumila*. Yue *et al*. (2006) found that the drought tolerance of *S. gordejevii* was lower than that of *C. microphylla.*

The drought resistance capacity of evergreen conifer species is generally stronger than that of deciduous broad-leaved plants. *Sabina vulgaris* is characterized as drought resistant by its external morphology and tissue structure, its small blade, degraded scales, small and sunken porosities, developed palisade tissue, lack of spongy tissue, thick cuticle, and strong mechanical tissue (Su *et al*., 2008). *P. mongolica* grows well under severe sandy conditions with a developed root system. The root length of first-year seedlings is 4–5 times that of aboveground plants (Zou *et al*., 2003). As for morphological characteristics, *P. sylvestris* has a developed cuticle, sunken stoma at low densities, compact superficial cells, and developed root systems (Lei *et al*., 1996).

Conclusion

In this paper, the drought resistance of thirteen plant species was studied based on seven physiological indexes using subordinate function values analysis in the Horqin sand land. The most effective index, as inferred from grey correlation analysis, out of the seven drought resistance indexes was specific leaf area. The rank order of the drought resistant characteristics of the thirteen plant species was *S. vulgaris>P. mongolica>P. sylvestris>H. rhamnoides>E. angustifolia>C. microphylla>S. gordejevii>X. sorbifolia> C. korshinskii>S. matsudana> E. bungeanus>U.pumila> H. fruticosum*, and thirteen plant species were classified into three types through group mean cluster analysis: high drought-resistant species, medium drought-resistant species and low drought-resistant species. The drought resistance of evergreen conifer species was stronger than that of deciduous broad-leaved species.

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