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Water Use Efficiency in Five Different Species of One-year-old Seedlings Grown in a Field Nursery in Mongolia*

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ABSTRACT

This study was conducted to examine the water use efficiency (WUE) in five species of one-year-old seedlings grown in a field nursery in Mongolia. *Larix sibirica* and *Pinus sylvestris* are the most dominant coniferous species while *Ulmus pumila* is an important deciduous species known well-adapted in harsh conditions such as in semi-arid forests and Gobi desert regions. *Caragana arborescens* (Siberian pea shrub) and *Hippophae rhamnoides* are N-fixing shrubs in Mongolia. Thirty one-year-old seedlings were sampled from each of the five species (a total of 150 samples) and measured for net photosynthetic rate (*Pn*) and transpiration rate (*E*). The *Pn* and *E* were used to calculate and compare the WUE of each species.

Pn differed significantly among the five species ($p < 0.05$). However, there was no significant difference in *Pn* between *L. sibirica* and *H. rhamnoides* ($p > 0.05$). *C. arborescens* showed the highest *Pn* whereas *U. pumila* did the poorest. *E* differed significantly among the five species ($p < 0.05$). *L. sibirica* and *U. pumila* showed considerably lower *E* than other species. Thus, WUE values of coniferous species such as *L. sibirica* and *P. sylvestris* were significantly greater than deciduous or shrub species such as *U. pumila*, *C. arborescens* and *H. rhamnoides* ($p < 0.01$). It may result that conifers showed relatively high water use efficiency than deciduous or shrub trees due to their lower transpiration rates, which resulted in morphological and physiological characteristics of their leaves. This may indicate that *L. sibirica* and *P. sylvestris* can be widely used for rehabilitation works in Mongolia attributed to their dominant distributions but also their high drought-resistance properties.

Keyword : rehabilitation, net photosynthetic rate, transpiration rate, water use efficiency, Pinus sylvestris, Larix sibirica, Ulmus pumila, Caragana arborescens, Hippophae rhamnoides

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Introduction

Mongolia is situated in the Central Asia and its territory covers 1,566 thousand km^2, which is 1.2% of the land surface in the world. The land surface area of Mongolia is seven times bigger than the Korean peninsula. Steppe and pasture areas accounted for about 76 % of land area in Mongolia while only about 10 % is occupied by forest land area. The forests in Mongolia occur mainly in the northern part of

the country, which form a transition between the Siberian taiga and the central Asian steppe (The World Bank, 2002). Most of them are located between 800 and 2,500 m above sea level (asl.). Most forests in Mongolia are larch forests with Siberian larch (*Larix sibirica*) covering about 59% of the closed forest area. Other important tree species include the Scots pine (*Pinus sylvestris*) and Siberian pine (*Pinus sibirica*), covering over 5 % and almost 8 %, respectively. Birch (*Betula platyphylla*) covers almost 9%. Growing stock of the forest is estimated at 1,363 million m^3, of which about 600 million m^3 are considered exploitable. The average volume per hectare is estimated at about 125 m^3 (Ministry of Nature and Environment of Mongolia, 1999).

Mongolia also has tremendous problems that may negatively affect its environmental condition and may reduce the capacity of the ecosystem due to exploitation and inadequate management. Some 1.6 million ha of forest area have been completely lost between 1974 and 2000 due to fire, improper and illegal logging, overgrazing, mining activities and also due to pests and diseases causing severe ecological stress. Mongolia experiences serious drought and desertification. More than 40% of the territory is composed of arid and desert areas and over 90% of the territory is referred to as arid, semi arid, moderate arid and moisture deficient regions. 41.3% of its territory is occupied by a Gobi desert region which makes the issue of drought and desertification of special prominence (United Nations Development Programme, 1998).

Rehabilitation activity in Mongolia started in 1971. During the period of 1972~1998, reforestation was carried out in 76,000ha of the country and 50% was replanted with young forests. Although positive results were shown in response to the activities, replanted areas have been reduced due to harsh climate conditions (low precipitation and relatively long winter time), inefficient working system (increased cost of products and use of outdated equipment/facilities etc.), lack of professionals in the field and without of any silvicultural treatment and monitoring after rehabilitation (United Nations Environment Programme, 2002). In order to conduct rehabilitation and restoration successfully, it is necessary that seed orchard and field forest nursery should be established to produce high-resistant and well-adaptive tree seedlings against the harsh Mongolian climate conditions (Burley, 2002; Koo and Lee, 2002).

As mentioned before, water is one of the most limiting environmental factors for tree survival and growth in Mongolia. Thus, selecting trees for improved drought-tolerance may represent the best option to improve rehabilitated tree survival and growth rate on a large scale. Many studies were conducted to compare water use efficiency (WUE) in several species used by several techniques to understand genetic variations in drought-resistance and physiological responses from water stress (Farquhar *et al.*, 1989; Ni and Pallardy, 1991; Cregg, 1993; Li, 1999; Wang *et al.*, 1999; Wang, 2001; Niu *et al.*, 2003).

The objective of this study was to investigate WUE differences measured by photosynthesis and transpiration in five native species, which are commonly used in rehabilitation works in Mongolia. The results can be important to understand drought-resistance variations within those species and also assist in determining suitable plantation species at arid or semi-arid forests in Mongolia.

Materials and Methods

Study site and species

This study was conducted using 5 different species of 1-year-old seedlings growing at the Dambadarjaa nursery, which is located at 7 kilometers from Ulaanbaatar, Mongolia(N47° 59'15, E106° 57'31''). One-year-old seedlings of *Pinus sylvestris* L., *Larix sibirica* Ldb., *Ulmus pumila* L., *Caragana arborescens* Lam. and *Hippophae rhamnoides* L. were grown for rehabilitation

Table 1. The physical and chemical soil characteristics at the Dambadarjaa nursery

Soil layer	Organic matter (%)	Texture	pH (1:5)	NH_4^+ N ($mg \cdot kg^{-1}$)	NO_3 N ($mg \cdot kg^{-1}$)	P_2O_5 ($mg \cdot kg^{-1}$)	Ca	Mg	K	Na
							($cmol^+ \cdot kg^{-1}$)			
A	10.3	Clay loam	7.2	2.50	4.29	569.4	37.27	7.49	1.49	0.94
B	13.2	Clay loam	7.6	2.18	12.71	153.3	54.30	9.85	2.24	1.91

Table 2. Average height and diameter (standard error) of all study species

Growth	*P. sylvestris*	*L. sibirica*	*U. pumila*	*C. arborescens*	*H. rhamnoides*
Height (cm)	4.2±0.5	9.4±1.7	16.9±4.2	24.6±4.9	13.9±2.3
Diameter (mm)	0.8±0.1	1.3±0.2	2.4±0.6	2.3±0.5	2.1±0.4

at degraded forests and research purposes in the nursery jointly supported from Northeast Asian Forest Forum (NEAFF) and Korea Forest Research Institute (KFRI) in 2003 (Park, 2003). The soil characteristics of the nursery were shown in Table 1.

All study species are native and mostly distributed in Mongolia. *Larix sibirica* and *Pinus sylvestirs* are mostly dominant coniferous species while *Ulmus pumila* is an important deciduous species that is well-adapted in harsh site conditions such as semi-arid forests and Gobi desert regions. *Caragana arborescens* (Siberian pea shrub) and *Hippophae rhamnoides* are mostly distributed at Steppe-Forest and Steppe regions in Mongolia and very useful shrubs for improving soil quality by N-fixing with either *Rhizobium* or *Frankia*, respectively (Grubov, 1982).

Average height and root diameter of each species are shown in Table 2. The deciduous and shrub species, such comprising *U. pumila*, *C. arborescens* and *H. rhamnoides* showed significantly higher growth rates than coniferous species as for *P. sylvestris* and *L. sibirica* in the first year ($p < 0.05$).

Measurement of net photosynthetic rate (*Pn*) and transpiration rate (*E*), and determination of water use efficiency (WUE)

The response of *Pn* to gradual changes in PPFD (photosynthetic photon flux density) was measured using a portable photosynthesis analyzer (LI-6400; Li-Cor Inc., Lincoln, NE, USA). Each series of PPFD was maintained for at least 5 minutes for stable change of PPFD. *Pn*-PPFD curves were plotted using the mean and standard error values of *Pn* measured at each PPFD. Three replications of all species were made.

To calculate and compare WUE of each species, thirty 1-year-old seedlings were sampled from each of the 5 species (a total of 150 samples) and measured for net photosynthetic rate (*Pn*) and transpiration rate (*E*). Photosynthetically active radiation (PAR) inside the chamber was artificially set at 1,500 mol m^{-2} s^{-1} as an average light intensity during the daytime period using a LED light source and leaf temperature was set at 20℃. Water use efficiency (WUE) was calculated as *Pn*/*E*.

Results and Discussion

Pn-PPFD curves

Photosynthesis was given a greater consideration than other study variables for two reasons. First, it is regarded as a reliable estimator and as an excellent and sensitive integrator of plant function under stress. Second, high photosynthesis rate is one of the main goals in the selection of resistant species for various

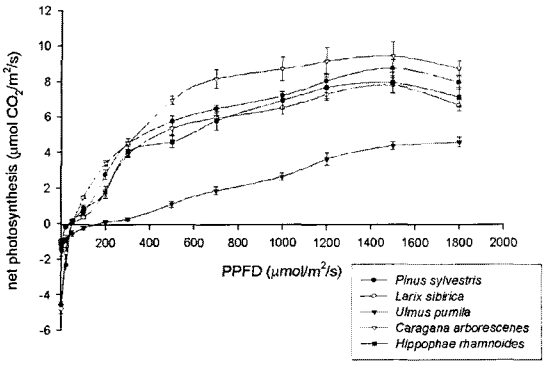


Fig. 1. Irradiance (PPFD) response curves of net photosynthetic rate (*Pn*) in each species

environmental stress such as drought and air-pollution (Woo *et al.*, 2003).

The response of *Pn* to several PPFD (at 0, 20, 50, 100, 200, 300, 500, 700, 1,000, 1,200, 1,500 and 1,800 mol m^{-2} s^{-1}) for each species is shown in Figure 1. *Pn* of all species except for *U. pumila* was saturated at 1,500 mol m^{-2} s^{-1} and then sharply declined. From 0 to 500 mol m^{-2} s^{-1}, all species except for *U. pumila* increased rapidly and then, the curves reached gradually at a plateau. At all of the PPFD, *Pn* of *C. arborescens* was higher than those of other species, whereas *Pn* of *U. pumila* increased very slowly. This indicated that *Pn* of each species reflected the different mechanism in radiation use efficiency.

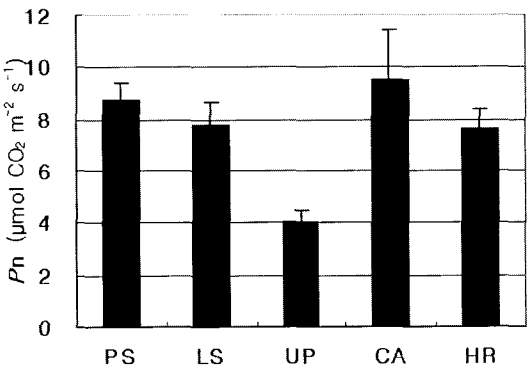
Net photosynthetic rate (*Pn*) and transpiration rate (*E*)

Pn differed significantly among the species ($p < 0.05$) (Figure 2). However, no significant differences in *Pn* were found between *L. sibirica* and *H. rhamnoides* ($p > 0.05$). *C. arborescens* showed the highest *Pn* whereas, *U. pumila* did the lowest.

There were significant differences in *E* among five species ($p < 0.05$) (Figure 3). *L. sibirica* and *U. pumila* exhibited considerably lower *E* values than other species. *C. arborescens* has shown the highest transpiration rate, which may indicate high water loss through transpiration. It may result that conifers showed relatively lower transpiration rates due to the morphological and physiological characteristics of their needles such as leaf area, leaf tissues and stomatal conductance (Garten and Taylor, 1992).

Water use efficiency (WUE)

WUE values of coniferous species such as *L. sibirica* and *P. sylvestris* were significantly greater than those of deciduous and shrub species such as *U. pumila*, *C. arborescens* and *H. rhamnoides* ($p < 0.01$) (Figure 4). It may result that conifers showed



* PS : *P. sylvestris*, LS : *L. sibirica*, UP : *U. pumila*, CA : *C. arborescens*, HR : *H. rhamnoides*

Fig. 2. Comparison of *Pn* in each species

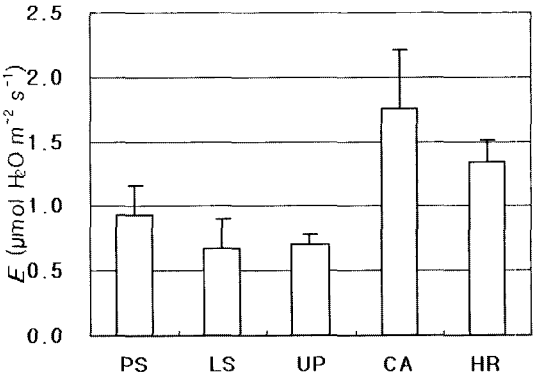


Fig. 3. Comparison of *E* in each species

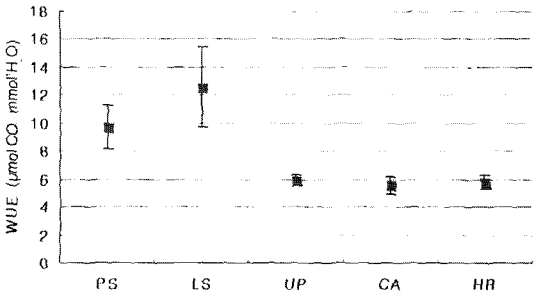


Fig. 4. WUE values for each species

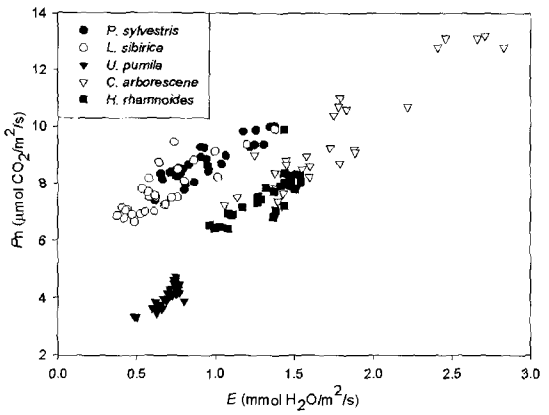


Fig. 5. Relationship between *Pn* and *E* for each species

relatively lower transpiration rates, compared to their photosynthetic rates (Figure 5).

High WUE was been asserted as a general adaptation of drought-tolerant plants but this claim is often not substantiated by experimental data (DeLucia and Heckathorn, 1989; Ni and Pallardy, 1991). WUE is expressed as an instantaneous measure derived form photosynthesis and transpiration rate data obtained from concurrent measurements of both parameters (Kozlowski and Pallardy, 1997).

Thus, there has been considerable interest in using carbon isotope discrimination ($\delta^{13}C$) values to estimate integrated WUE in trees. This is a very useful tool for investigation of genetic variance in different species or populations with response to WUE. The result of this study should be compared to that of carbon isotope discrimination experiment for clearer understanding in selecting drought resistant species for rehabilitation of degraded and harsh areas in Mongolia.

Conclusion

Water is one of the most limiting environmental factors for successful rehabilitation in arid or semi-arid areas in Mongolia. Thus, selecting trees for improved drought-tolerance may represent the best option for the survival and growth of planted trees on a large-scale effect. In this study, we compared water use efficiency of five representative species(two conifers, one deciduous species and two shrubs) in Mongolia.

L. sibirica and P. sylvestris had relatively higher net photosynthetic rates and lower transpiration rates compared to other deciduous and shrub species. Thus, higher WUE values were calculated. This may indicate that *L. sibirica* and *P. sylvestris* can be widely used for rehabilitation works in Mongolia attribute to their dominant distributions but also their high drought-resistance properties.

U. pumila showed much lower photosynthetic and transpiration rates which resulted in low WUE values. However, *U. pumila* showed very low transpiration rate which is very important for successful rehabilitation in harsh areas. *U. pumila* is recommended for rehabilitation at arid or semi-arid areas.

C. arborescens showed the highest photosynthetic rate among the five species but its high transpiration rate resulted in low WUE value. *C. arborescens* and *H. rhamnoides* are very important native shrubs for soil quality improvement, medicinal uses and rehabilitation of degraded forest, steppe and desert areas. It is recommendable that *C. arborescens* and *H. rhamnoides* can be planted under conifers stands in harsh areas to improve soil quality and biomass production.

For successful rehabilitation of degraded forests or harsh climate areas in Mongolia, standard techniques

for species selection and improvement of rehabilitation effects should be integrated in silvicultural treatments and molecular genetic techniques for increased water use efficiency and stress tolerance.

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