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Effects of wind blow and sand burial stress on seedling growth and photosynthetic properties of Caragana microphylla

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***Abstract*—A field sand burial experiment and a wind blowing experiment was conducted during 2006 and 2007 in the Horqin Sand Land to investigate the effects of wind blowing and sand burials on seedling growth and photosynthetic properties of *Caragana microphylla*. The results showed that 1) lightly sand burial (1/3 plant height) could synchronously hasten growth of stem and leaf and root and increase of biomass, moderate sand burial (2/3 plant height) only could stimulate root growth and biomass increase and restrain height growth; heavy sand burial (100% height) could result in death of most plant and poor growth of alive plant while all plant died under severe sand burial (130% plant height); 2) in the sweltering summer of Horqin Sand Land, it maybe not beneficial to photosynthesis and transpiration if moving speed of airflow is lower (2m s^{-1}, light air), suitable wind velocity (6m s^{-1} gentle breeze) maybe beneficial to transpiration as well as photosynthesis. transpiration rate not also increased visibly, but also photosynthetic rate decreased in larger rang while wind velocity is more than 8.0m s^{-1} which is not good for plant growth. 3) although *C. microphylla* as a dominant shrub of fixed sand has certain ability to adapt wind blowing and sand burial, but severe sand burial and strong wind blowing should resulted in severe damage so much as death to *C. microphylla*, so it pay much attention that don't plant *C. microphylla* in upper intensively areas of wind-sand activity.**

***Keywords**- wind blow; sand burial; growth; photosynthesis; transpiration*

I. INTRODUCTION

Wind blowing and sand burial is common phenomena in desert areas throughout the world [1~3]. As wind blowing and sand burial could change all aspects of the plant and the soil microenvironment including the soil temperature, moisture, nutrients, oxygen as well as the availability of light [4~6], they may modify physiology and morphology of plants and affect their survival and growth, and sequentially control the distribution and composition of vegetation in desert ecosystem [7~9]. Consequently, wind blowing and sand burial is a common environmental stress encountered by plants in desert area [3, 4, 10], which has been recognized as a major selective force in the adaptability and evolution of desert plant [2, 6, 9].

There is a great body of literature on sand burial effects on physiology and morphology of plants, including studies of the effect of sand deposits on plant morphology and vegetation changes [11, 12], effect of burial on seed germination and seedling emergence [8, 13, 14], plant survival and growth [6, 15, 16], biomass and resource allocation [14, 17] and adaptation of plant to sand burial [7, 18] etc. There are some literatures on effects of wind blowing on physiology and growth properties of desert plant, such as effects of wind blowing on cuticular and stomatal transpiration [1, 19], Photosynthesis and Transpiration of plant canopies [9, 20]), plant gas exchange at high wind speeds[21] and Plant Response to wind [19]. These results have confirmed that the effects of wind blowing and sand burial on plants may change with wind velocity and burial depth [8, 14], response and adaption of desert plant to wind blowing and sand burial stress was different with plant species [2, 15]. However, there are few published studies of the effects of both wind blowing and sand burial on growth and physiological properties of same species [20, 22].

Caragana microphylla, a leguminous shrub, is widely distributed in the Horqin Sandy Land and is a favored plant for restoring vegetation on desertified sandy land [18]. The objectives of this paper are: 1) to examine the differences in seedling growth properties and plant photosynthetic properties of *C. microphylla* among different treatments of wind blowing and sand burial; 2) to analyze effects of different velocities of wind blowing and different depths of sand burial on seedling growth and photosynthetic properties of *C. microphylla*.

II. MATERIALS AND METHODS

A. Study area

The study area is located in Naiman County (42°15' N, 120° 42' E, 345 m a.s.l.) in the eastern part of Inner Mongolia, China. Naiman is located at the hinterland of the Horqin Sand Land and belongs to the continental semi-arid monsoon climate regime in the temperate zone. Annual mean precipitation is 364 mm, annual mean potential evaporation is 1920 mm, and annual mean temperature is 6.3℃. The annual frost-free period is approximately 141 days. The average annual wind speed is 3.4~4.5 m s^{-1} and mean wind speed in the wind erosion season (spring) is 5.0~6.0 m s^{-1}. The landscape in this region is characterized by dunes alternating with gently undulating lowland areas. Most of the lowland area is reclaimed to cropland and the dunes are used for pasture. The soils are identified as degraded sandy Chestnut soils according to the Chinese soil classification system, which are mostly equivalent to the Orthi-Sandic Entisols of sand origin in the FAO-UNESCO system. The sandy soil consists mainly of coarse sand and silt. The natural vegetation consists largely of *Artemisia frigida*, *Artemisia halodendron*, *Pennisetum centrasiaticum* and *Setaria viridis*. The dominant plant species in plantation include *Populus simonii*, *Pinus luestris*, *Caragana microphylla*, *Salix gordejevii* [18].

B. Experimental design

The study was conducted during the summer of 2006 and 2007 in Naiman Desertification Research Station of Chinese academy of Sciences. The experiment consisted of sand burial and wind blowing experiment, with same shrub species of *Caragana microphylla*. The sand burial experiment included five treatments: no sand burial (CTRL), light sand burial (LSB), moderate sand burial (MSB), heavy sand burial (HSB) and severe sand burial (SSB), respectively, with sand burial thickness of 0%, 33%, 66%, 100% and 133% of plant height. All sand burial treatments consisted of three replicates of 72 seedlings. Eight seedlings in each replicate of all treatments was randomly selected at interval of ten days to measured plant height, leaf number, root length, above and ground biomass. These properties for the seedlings was randomly investigate before the experiment began, no significant differences was found ($P > 0.05$) among five treatments. The wind blowing experiment conducted in portable wind tunnel in the same field with the sand burial experiment. The experiment included five wind blowing treatments of 0 m s^{-1} (CTRL), 2m s^{-1}, 4m s^{-1}, 6m s^{-1} and 8m s^{-1} velocity, with same wind blowing time of 120 min. Three young plant of *Caragana microphylla* was selected in each treatment. Photosynthetic rate (*Pn*) and transpiration rate (*Ts*) of the plant were measured by Li-6400 portable photosynthesis system in interval time of 20 min.

C. Data analysis

All data were analyzed using the SPSS program for Windows Version 11.5. Multiple-comparison and one-way analysis of variance (ANOVA) procedures were used to compare the differences among the treatments. Least significant difference (LSD) tests were performed to determine the significance of treatment means at $P < 0.05$.

III. RESULTS AND ANALYSIS

A. Effects of sand burial on seedling livability and leaf number

As shown in Table 1, there were greater differences in different thickness of sand burial effects on seedling livability and leaf number of *C microphylla*. There was not any death of seedling in the CK and LSB and MSB treatments, and only 37.5% seedlings survived in the HSB treatment and 100% seedlings died in the SSB treatment. In the early stage of sand burial (10 days), leaf number was significant more （$P<0.05$） in the LSB treatment than that in other treatments and the differences was not significant ($P>0.05$) among them though leaf number was lesser in the MSB and HSB treatments than that in the CK. In the later stage (30 days), leaf number was significant less （$P<0.05$） in HSB treatment than other treatments.

TABLE I. THE SEEDLING LIVABILITY AND LEAF NUMBER OF *C. MICROPHYLLA* AT DIFFERENT BURIAL TREATMENTS. VALUES WITH THE SAME LETTERS WITHIN COLUMN ARE NOT SIGNIFICANTLY DIFFERENT AT $P < 0.05$.

Treatments	**Seedling livability (%)**	**leaf number**		
		10 d	20 d	30 d
CK	100	13.3±1.2b	17.0±1.2b	22.0±1.7b
LSB	100	22.0±6.2a	22.3±4.5a	28.7±7.6a
MSB	100	10.0±2.0b	22.0±5.0a	21.7±9.9b
HSB	37.5	8.7±4.9b	8.7±5.0c	17.7±3.1c
SSB	0	0±0.00c	0±0.00d	0±0.00d

B. Sand burial effects on plant height and root length

Comparison with CTRL, plant height increased by 6.1% in the LSB treatment, and decreased by 3.7% and 23% in the MSB and HSB treatments, respectively (Figure 1). Root length increased significantly in the LSB and MSB and HSB treatments than that in the CTRL. The increase magnitude was the greatest (49.4%) in the MSB treatment, and the second (31.9%) in the HSB treatment, and the least (26.2%) in the LSB. The differences was significant between the MSB and LSB and SSB treatments （$P<0.05$）, but the differences was not significant between LSB and SSB treatments ($P>0.05$). The results showed that light degree of sand burial could accelerate height growth as well as root growth of *C microphylla* seedling. The moderate and heavy sand burial just could accelerate root growth of the seedling, and had a antiblastic role on seedling height.

C. Sand burial effects on plant biomass and its construction

Comparison with the CTRL, root biomass, above-ground biomass and total biomass increased significantly in the MSB treatment（$P<0.05$）, and root biomass increased slightly （$P>0.05$）and above-ground biomass and total biomass decreased significantly （$P<0.05$）in the HSB treatment, and the differences was significant though root biomass, above-ground biomass and total biomass increased in the LSB treatment (Figure 3). With increase of sand burial thickness, leaf biomass rate decreased significantly（$P<0.05$）, stem biomass rate increased significantly（$P<0.05$）, respectively, in total biomass. The root biomass rate in total biomass was significant higher in MSB and SSB treatments than in CTRL treatment（$P<0.05$）, but the difference was not significant between LSB and CTRL（$P>0.05$）.

D. Wind blowing effects on net photosynthetic rate (Pn)

Photosynthetic rate was significant lower in wind-blown leaf than that in CTRL without wind-blown during continuum wind blowing of 2m s^{-1} velocity (Figure 4).

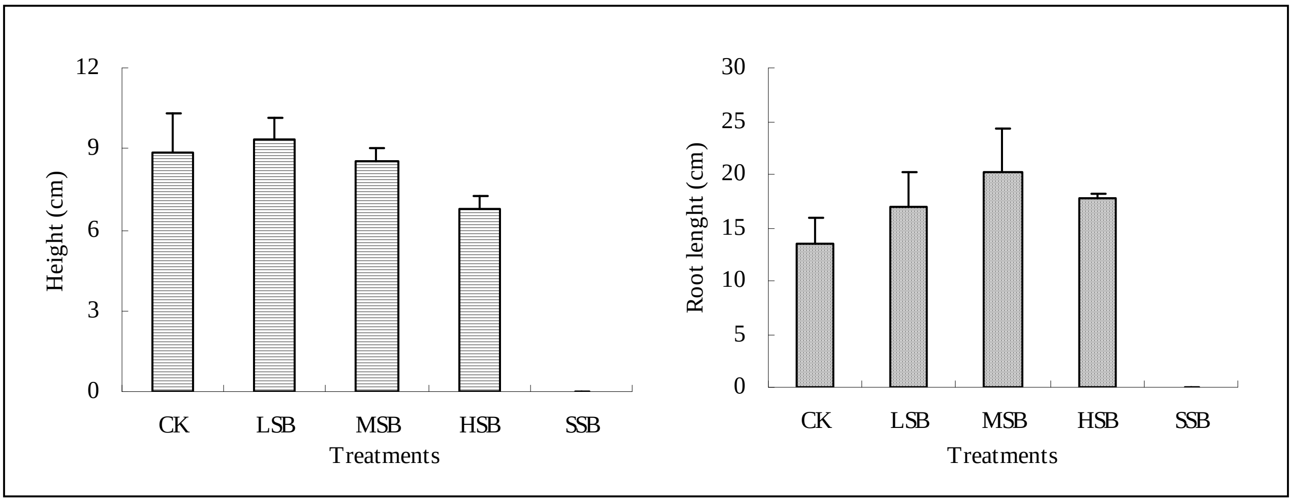

Figure 1. The height and root length of the seedling at different burial treatments

During continuum wind blowing of 2m s^{-1} velocity, two photosynthetic curves of wind-blown leaf and without wind-blown leaf intersected several times, each has his high or low point, and the differences was not significant between the both. During continuum wind blowing of 6m s^{-1} and 8m s^{-1} velocity, Photosynthetic rate was significant higher in wind-blown leaf than that in CTRL leaf without wind-blowing （$P < 0.05$）, and magnitude of increase augmented with increase of velocity. For example, photosynthetic rate increased by 2.3 μmol CO_2 m^{-2} s^{-1} with a increased magnitude of 48.8% in 6m s^{-1} velocity treatment, and by 3.2 μmol CO_2 m^{-2} s^{-1} with increased magnitude of 71.1% in 8m s^{-1} treatment, respectively, compared to the CTRL treatment.

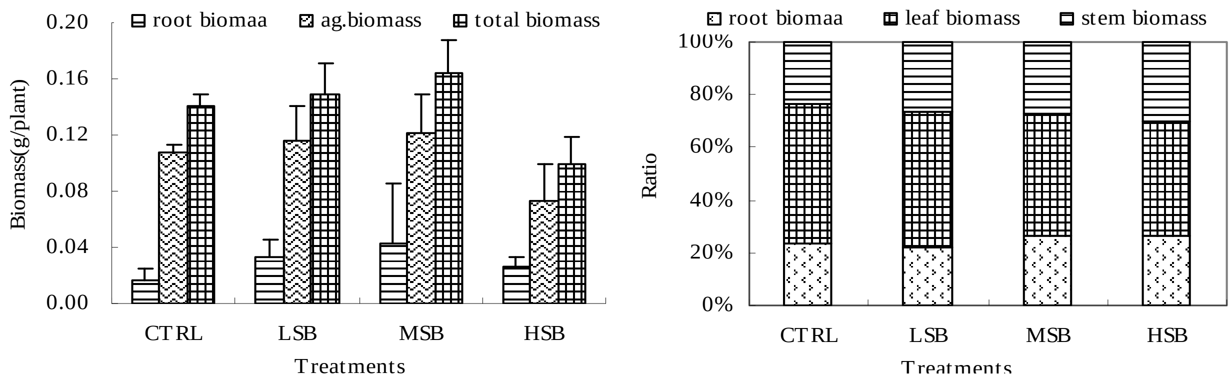

Figure 2. Effects of sand-buried on biomass (Left) and its structures (right)

E. Wind blowing effects on transpiration rate (Ts)

Transpiration rate decreased by 1.1 mmol H_2O m^{-2} s^{-1} with decreased magnitude of 21% in 2m s^{-1} wind blow treatment than that in CTRL without wind blowing (Figure 5). Although leaf transpiration rate was lower in 4 m s^{-1} velocity treatment (2.3～3.8 mmol H_2O m^{-2} s^{-1}) than that in CTRL without wind blowing (3.2～4.1 mmol H_2O m^{-2} s^{-1}), the differences between them was not significant （$P > 0.05$）. Transpiration curve had similar changes in 6 m s^{-1} and 8 m s^{-1} velocity treatments than that in CTRL, but their transpiration rate during wind blowing was significant higher than that in CTRL, with increased magnitude of 24% and 42%.

IV. DISCUSSION

A. *Effects of sand burial on plant and response*

In the present study, effects of five burial treatments on seedling growth of *C. microphylla* had significant difference. Comparison with the CTRL without sand burial, the height, leaf number, root length, above- and ground biomass all increased significantly in the light sand burial treatment. Root length and total biomass increased significantly and changes in plant height and leaf number was not significant in the moderate sand burial treatment. All parameter of measure plant decreased significantly except for root length and 62.5% plant died in the heavy sand burial treatment and all plants died in the severe sand burial treatment. In addition, ground biomass / above biomass and stem biomass / leaf biomass increased with burial thickness in sand. Some studies indicated that sand burial was a primary factor to affect plant survival, growth and reproduction, which also was an important factor determining productivity of ecosystem in many desert areas [2, 8, 13]. The effects of sand burial on plant changes with burial depth [1, 15]. Shallow burial in sand could stimulate plant growth, severe sand burial maybe restrain plant growth so much as survive[16, 17]. Our results showed that light sand burial could stimulate general growth of *C. microphylla*. The moderate sand burial could stimulated increase of root length and biomass and had not significant effects on leaf number and height of *C. microphylla*. The heavy sand burial not also could restrained growth of *C. microphylla* and resulted in death of most plant. When burial thickness in sand exceeded plant height, all plant maybe died. To adapt increase of burial depth in sand, the seedling of *C. microphylla* adjusted growth and mass allocation, quickening growth of root and stem and slower growth of leaf. This result was consistent with the study by Liu and Guo [23] on sand burial effects on growth of *Caragana intermedia*. Why does seedling growth of *C. microphylla* increase following a light burial episode? The growth stimulation may be owing to a number of factors [7, 15, 22]. For example, sand burial may (1) protect the root system of plants from drying out [8, 24], (2) provide increased nutrient input and more soil surface area for the expansion of roots[7, 17], (3) exhibit reactive growth response to burial [11, 16], and (4) decrease interspecific competition through the elimination of species intolerant of sand accretion [12, 14]. Specially, C. micro- phylla.is long to a psammophytes and pioneer plant in Horqin Sand Land, having with stronger adaptability or resistant to sand burial [24]. As Fearnehough et al. [12] and Franks and Peterson [6] suggested, the stimulation of growth is a means by which dune plants are able to survive burial in mobile dune environments. Plant species growing in the foredunes are well adapted to stress imposed by burial [16]. In fact, there is clear evidence that much plant species exhibit enhanced growth following episodes of burial [7, 22]. According to Fearnehough et al.[12] and Maun[2], some plants have become so specialized that they require regular burial to maintain high vigour. But plant had a limit to adapt burial in sand. They should die while thickness and speed of sand sediment exceeded plant resistance to sand burial [18, 25].

B. *Eeffects of wind blowing on Pn and Ts*

Our results by wind blowing experiment showed that comparison with CTRL without wind blowing, photosynthetic rate and transpiration rate of *C. microphylla* decreased significantly in 2m/s velocity treatment and increased significantly in 6m/s and 8m/s velocity. The difference on photosynthetic rate and transpiration rate was not significant between 4m s^{-1} velocity treatment and CTRL. The results showed that wind blowing of slight breeze (2m s^{-1}) could restrain transpiration and photosynthesis of *C. microphylla*, and wind blowing of moderate breeze 6m/s velocity and fresh breeze (8m s^{-1} velocity) could accelerate plant transpiration and photosynthesis, while wind blowing of gentle breeze has not significant effects on transpiration and photosynthesis. This confirmed the viewpoint by Caldwell [21] and Grace and Thompson [20] that effects of wind blowing on transpiration and photosynthesis are complex. Some studies indicate that if there is no wind, the air around the leaf may not move very much, raising the humidity of the air around the leaf. Wind could reduce the thickness of the boundary layer and removes the moisture-laden air from around stomatal openings, replacing it with dryer air and increasing the rate of transpiration [1, 20]. A slight breeze (1.6-3.3m s^{-1}) could mix the air and replace some of the CO_2, gentle breeze can bring more CO_2 close to the stomata, increasing the diffusion of CO_2 into the leaf, causing guard cells to become less turgid, but if the CO_2 level in the leaf canopy is to be maintained, wind speed will need to rise up moderate breeze. Winds of this speed may increase photosynthesis by 10 to 20 percent and respiration 20 to 40 percent if other factors are not limiting [9, 19]. This increase is due to effects on stomatal gas exchange or in response to leaves being ripped or otherwise damaged [18, 19]. In addition, in the case of lower wind velocity, slower diffuse and lower transpiration rate on interface layer of leaf surface was not favorable to decrease of leaf temperature. Higher surface temperature of leaf can result in increase of plant respiration and decrease of photosynthetic rate. In reverse, lower leaf temperature as affected by higher wind velocity is beneficial to photosynthesis because of increase of respiration rate [1, 18]. Our result was not consistent with result by Yu et al.[25] on experiment of wind blowing to *Caragana intermedia* that photosynthetic rate decreased and transpiration rate increased under wind blows of 5.9, 7.9, 9.9 and 14.0m s^{-1} wind velocity. It was attributed to three main reasons that 1) although two species used in the two different experiments belong to a same genus, their adaptability to wind blow stress maybe differences [18]; 2) pure wind was used in the present study and sand-bearing wind was used in the study by Yu et al.[25], with stronger harm to plant in the later than in the former; 3) on the one hand, continual blowing of more stronger wind ($>$8m s^{-1}) not only result in closedown of most stoma and decrease of transpiration rate in leaf stoma, but also result in larger range increase of transpiration rate in leaf keratose layer and missing of a lot water in leaf, which countervail decrease of respiration rate because stoma closed [9, 21]. On the other hand, continual blowing of more stronger wind ($>$8m s^{-1}) not only result in a range decrease of leaf temperature, not only the stoma close should decreased exchange rate of gas and CO_2 concentration in intercellular, which results a larger range decrease of leaf photosynthetic rate [25].

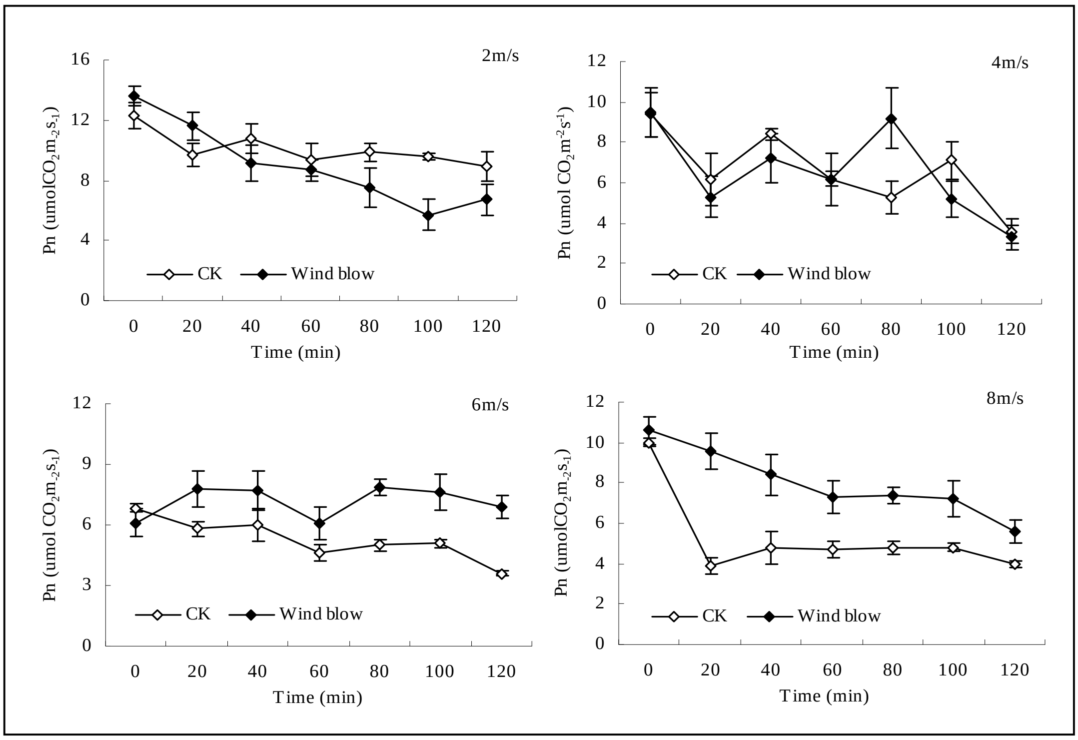

Figure 3. Effects of wind-blowing on the net photosynthesis ratio

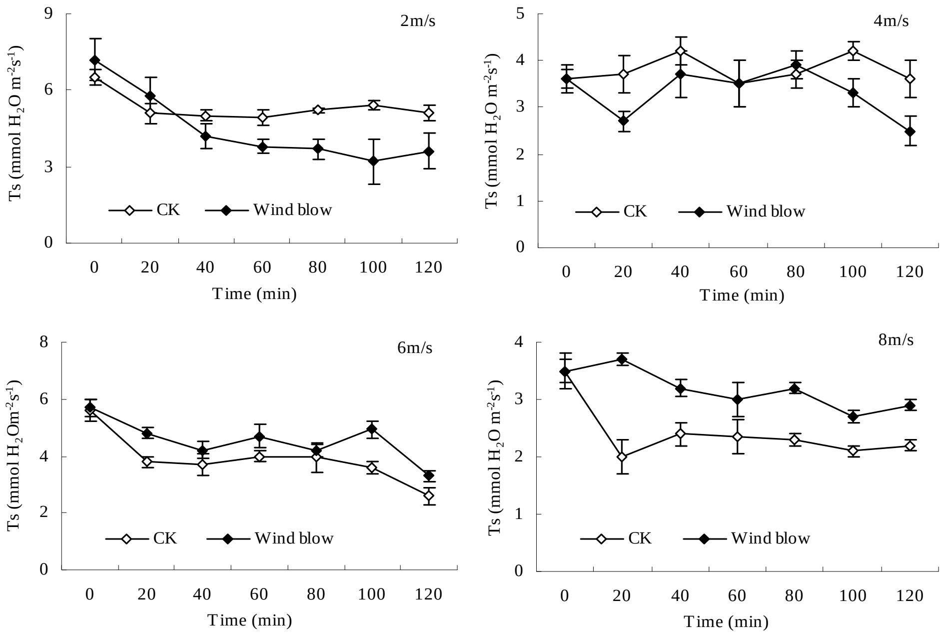

Figure 4. Effects of wind-blowing on transpiration rates

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