Effects of Frequent Clean Wind Episodes of Different Intensities on Photosynthetic and Transpiration Characteristics of Pinus sylvestris var. mongolica Seedlings: Postprint

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Abstract

To understand the effects of frequent clean-wind events at different intensities on the photosynthetic and transpiration characteristics of Mongolian pine seedlings, changes in photosynthetic rate, transpiration rate, water use efficiency, and other indicators were studied in the Horqin Sandy Land of Inner Mongolia in spring 2013. Seedlings were subjected to four blowing events under six wind speed treatments of 0 (control), 6, 9, 12, 15, and 18 m/s (equivalent to 0, 4, 5, 6, 7, and 8 on the Beaufort scale, respectively). The results showed that frequent clean-wind exposure did not alter the diurnal variation patterns of photosynthetic and transpiration rates in Mongolian pine seedlings, but prolonged the duration of the "midday depression" and intensified the extent of dormancy in photosynthesis and transpiration. With increasing wind intensity, daily average photosynthetic capacity and transpiration rate decreased significantly, with the 18 m/s treatment showing reductions of 27.6% and 22.3% compared to the control, respectively. Stomatal conductance and intercellular CO2 concentration initially decreased then recovered with increasing wind intensity; except for intercellular CO2 concentration in the 18 m/s treatment, which was significantly higher than CK, all other treatments were significantly lower than CK. Water use efficiency and light use efficiency initially increased then decreased with increasing wind intensity; specifically, water use efficiency in the 18 m/s treatment was significantly lower than CK, light use efficiency in the 6 m/s treatment was higher than CK, while water use efficiency in all other treatments was higher than CK and light use efficiency was lower than CK. The decrease in daily average photosynthetic and transpiration rates was primarily attributed to reduced stomatal conductance, while changes in water use efficiency and light use efficiency were governed by variations in photosynthetic and transpiration rates.

Full Text

Preamble

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Effects of Frequent Gusts of Wind at Different Intensities on Photosynthetic and Transpiration Characteristics of *Pinus sylvestris* var. *mongolica* Seedlings

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Abstract

To understand the effects of frequent gusts of wind at different intensities on the photosynthetic and transpiration characteristics of *Pinus sylvestris* var. *mongolica* seedlings, a field wind-blowing experiment was conducted in spring 2013 in the Horqin Sand Land of Inner Mongolia. The experiment employed six wind speed treatments (0 [CK], 6, 9, 12, 15, and 18 m/s) with four episodes of wind blowing. The results showed that: (1) Frequent wind blowing did not alter the diurnal variation patterns of photosynthetic and transpiration rates in the seedlings, but extended the midday depression period and increased the degree of dormancy in photosynthesis and transpiration. (2) Increasing wind strength led to significant decreases in the average daily rates of photosynthesis and transpiration, with reductions of 27.6% and 22.3%, respectively, in the 18 m/s treatment compared to the control. With increasing wind strength, stomatal conductance and intercellular CO concentration first increased then decreased, and were significantly lower in all treatment groups compared to CK, except for intercellular CO concentration, which was higher in the 18 m/s group. (3) Water use efficiency tended to increase with wind strength, except for a significant decrease in the 18 m/s treatment compared to CK. Light energy use efficiency also showed an initial increase followed by a decrease, with a significant increase only in the 6 m/s treatment compared to CK. (4) Decreases in the average daily rates of photosynthesis and transpiration resulted from reduced stomatal conductance, while changes in water use efficiency and light energy use efficiency were constrained by changes in photosynthetic and transpiration rates.

Keywords: *Pinus sylvestris* var. *mongolica* seedlings; frequent wind blowing; photosynthetic properties; transpiration rate; water use efficiency; light energy use efficiency

1. Study Materials and Methods

1.1 Study Area Overview

The study area is located in Naiman Banner, Tongliao City, Inner Mongolia, situated in the hinterland of the Horqin Sand Land (42°55 -42°57 N, 120°41 - 120°45 E, elevation 340-370 m). The region has a temperate semi-arid continental climate with an average annual precipitation of 356.9 mm, average annual evaporation of 1900 mm, and mean annual temperature of 6.4°C. The frost-free period is 151 days with 10°C accumulated temperature of 3190°C. The average annual wind speed is 3.4 m/s, with 20-30 days of blowing sand annually. The landscape is characterized by alternating high and low dunes with gentle meadows or farmland. Soils are predominantly aeolian sandy soils or sandy meadow soils. The natural plant community consists of mid-xerophytic vegetation, with main species including *Agriophyllum squarrosum*, *Corispermum marocarpum*, *Salsola collina*, and *Caragana microphylla*. *Pinus sylvestris* var. *mongolica* is widely planted as an evergreen species in artificial forests in this region.

1.2 Experimental Design

Natural wind occurs primarily as gusts with short, frequent characteristics. Previous studies have indicated that a 10-minute duration is representative for studying wind gusts. This research employed a gradient wind speed experimental design with six wind speed treatments: 0 (CK), 6, 9, 12, 15, and 18 m/s, equivalent to 0, 4, 5, 6, 7, and 8 Beaufort scale wind episodes, respectively. The wind-blowing experiment was conducted using a self-made portable wind tunnel (ZL 200810182207X) with dimensions of 62 cm × 62 cm and a wind speed range of 0-23 m/s. The experiment was set up at the field wind tunnel test site of the Naiman Desertification Research Station, Chinese Academy of Sciences, located in the hinterland of the Horqin Sand Land.

The experimental material consisted of uniformly growing 2-year-old *Pinus sylvestris* var. *mongolica* seedlings. In autumn 2012, seedlings were transplanted into pots (21 cm diameter, 15 cm height) and managed with timely, appropriate watering and winter freeze protection to ensure safe overwintering. Plants with no significant differences in height were selected as experimental materials. Each replicate consisted of 3 seedlings, and each treatment had 3 replicates. The wind-blowing trials were conducted on clear, windless mornings in late May 2013. Before the experiment, biological characteristics including plant height and basal stem diameter were measured.

Each wind-blowing episode lasted 10 minutes, with four episodes conducted at 20-minute intervals. Photosynthetic measurements were taken before the last wind episode and immediately after the final blowing event. Leaf relative water content was measured after the last wind episode. During measurement, upper adjacent leaves were uniformly selected from each plant (as wind could cause lower leaf abscission). Measurements were taken using a Li-6400 portable photosynthesis system (LI-COR Inc., Lincoln, NE, USA) from 6:00 to 18:00.

For each plant, three leaves were measured, and after data stabilization, three readings were taken per leaf and averaged. Since the measured needles were semi-elliptical, leaf area was calculated by directly measuring the diameter at both ends of the leaf chamber. Water use efficiency was calculated as the ratio of photosynthetic rate to transpiration rate, and light energy use efficiency as the ratio of photosynthetic rate to photosynthetically active radiation.

1.3 Data Analysis

SPSS 13 software was used for statistical analysis. One-Way ANOVA and Least Significant Difference (LSD) tests were employed to compare differences between treatment groups, and Pearson correlation coefficients were used to evaluate relationships between different parameters.

2. Results

2.1 Comparison of Diurnal Photosynthetic Rate Patterns

The diurnal variation curve of photosynthetic rate for the non-wind treatment (CK) showed a bimodal pattern, with peaks appearing at 10:00 and 14:00. With increasing wind intensity, the shape and timing of peaks changed. Both peaks decreased significantly under the 6 m/s treatment, with the first and second peaks decreasing by 17.1% and 33.4%, respectively. Under 9 m/s and 12 m/s treatments, both peaks increased slightly, while under 15 m/s and 18 m/s treatments, both peaks decreased. The minimum photosynthetic rate during the midday depression period also tended to decrease with increasing wind intensity, with the most significant reduction (41.0%) occurring in the 18 m/s treatment. Although the diurnal variation curve remained bimodal under wind treatments, the "midday depression" period was extended and deepened.

[Figure 1: see original paper] Diurnal variation curves of photosynthetic rate at different wind speed treatments

2.2 Comparison of Diurnal Transpiration Rate Patterns

The diurnal variation curve of transpiration rate for the control treatment also showed a bimodal pattern, with peaks at 10:00 and 14:00. With increasing wind intensity, the transpiration rate curve maintained its bimodal shape, but both peaks decreased. The first peak occurred earlier (6:00–8:00) under 6 m/s treatment, while the second peak appeared at 16:00. Under 9 m/s treatment, peaks appeared at 10:00 and 14:00, while 12 m/s, 15 m/s, and 18 m/s treatments showed peaks at 10:00 and 14:00. The valley value during the midday period also decreased with increasing wind intensity.

[Figure 2: see original paper] Diurnal variation curves of transpiration rate at different wind speed treatments

2.3 Comparison of Daily Average Photosynthetic and Transpiration Rates

With increasing wind intensity, the daily average photosynthetic rate of *Pinus sylvestris* var. *mongolica* seedlings showed a fluctuating decline. Compared to CK, the daily average photosynthetic rate decreased by 11.3%, 17.7%, 16.2%, 7.3%, and 27.6% under 6, 9, 12, 15, and 18 m/s treatments, respectively, with all wind treatments showing significant differences from CK ($P < 0.05$). Similarly, the daily average transpiration rate showed a fluctuating decline, decreasing by 18.1%, 28.3%, 28.6%, 18.1%, and 22.3% under the respective wind treatments, with all differences from CK reaching significant levels ($P < 0.05$).

[Figure 3: see original paper] Daily average photosynthetic rates and transpiration rates at different wind speed treatments

2.4 Comparison of Daily Average Stomatal Conductance and Intercellular CO Concentration

With increasing wind intensity, daily average stomatal conductance showed a fluctuating decline, decreasing by 18.2%, 27.3%, 27.3%, 18.2%, and 22.7% under 6, 9, 12, 15, and 18 m/s treatments, respectively, with all wind treatments significantly different from CK ($P < 0.05$). Intercellular CO concentration showed a decreasing then increasing trend, decreasing by 3.7%, 5.6%, 7.1%, and 7.1% under 6, 9, 12, and 15 m/s treatments, but increasing by 6.3% under 18 m/s treatment, with all treatments significantly different from CK ($P < 0.05$).

[Figure 4: see original paper] Daily average stomatal conductance and intercellular CO concentration at different wind speed treatments

2.5 Comparison of Daily Average Water Use Efficiency and Light Energy Use Efficiency

With increasing wind intensity, daily average water use efficiency (WUE) showed an initial increase followed by a decrease. WUE increased by 7.3% under 6 m/s treatment but decreased under other treatments, with significant differences from CK ($P < 0.05$). Light energy use efficiency also increased initially then decreased, rising by 15.8% under 6 m/s treatment but decreasing by 10.5%, 15.8%, 10.5%, and 36.8% under 9, 12, 15, and 18 m/s treatments, respectively.

[Figure 5: see original paper] Daily average WUE and light energy use efficiency at different wind speed treatments

2.6 Correlations Between Different Indices

Changes in photosynthetic rate showed very significant positive correlations with changes in transpiration rate and stomatal conductance ($P < 0.01$), but non-significant negative correlations with intercellular CO concentration. Transpiration rate changes were very significantly positively correlated with stomatal

conductance changes ($P < 0.01$). Water use efficiency showed non-significant correlations with photosynthetic rate, transpiration rate, and stomatal conductance. Light energy use efficiency was very significantly positively correlated with photosynthetic rate ($P < 0.01$), but significantly negatively correlated with transpiration rate and stomatal conductance ($P < 0.05$), and very significantly negatively correlated with intercellular CO concentration ($P < 0.01$).

Correlation coefficients among different indices

3. Discussion

The diurnal variation curves of photosynthetic and transpiration rates for *Pinus sylvestris* var. *mongolica* seedlings under wind treatments were bimodal, consistent with previous studies on 18-year-old Mongolian pine seedlings. As wind stress increased, the shape of the photosynthetic rate curve remained generally unchanged, still showing a bimodal pattern, but the two peaks shifted from 10:00 and 14:00 to 8:00 and 16:00, respectively. The minimum photosynthetic rate during the midday period also tended to decrease, with the maximum reduction reaching 41.0% under 18 m/s treatment. Similarly, the diurnal variation curve of transpiration rate showed no significant change in shape, but the minimum transpiration rate during midday decreased significantly with increasing wind intensity.

These findings indicate that frequent gusts of clean wind did not significantly alter the diurnal patterns of photosynthetic and transpiration rates in Mongolian pine seedlings, which continued to follow bimodal curves. However, wind stress extended and deepened the "midday depression" period. This differs from wind-sand flow treatments, where transpiration rate curves changed significantly and the midday depression period shortened. The extended midday depression under clean wind represents a stress response, suggesting that seedlings are more sensitive to midday high light and low humidity conditions under wind stress. To reduce damage from intense light and water loss, the seedlings extended and intensified photorespiration and transpiration suppression, which appears to be a protective mechanism against wind stress.

With increasing wind intensity, both daily average photosynthetic and transpiration rates showed fluctuating declines, decreasing by 27.6% and 22.3%, respectively, under 18 m/s treatment. This contrasts with wind-sand flow treatments, where transpiration rates increased significantly. The difference indicates that clean wind stress has less impact on transpiration than wind-sand flow. Stomata control both photosynthesis and transpiration, and the observed decreases resulted from reduced stomatal conductance. Photosynthetic rate was very significantly positively correlated with transpiration rate and stomatal conductance, and very significantly negatively correlated with intercellular CO concentration, indicating that stomatal limitation was the primary mechanism reducing photosynthetic and transpiration rates.

Water use efficiency increased under moderate wind speeds (6 m/s) but de-

creased under higher intensities, suggesting that moderate clean wind stress can improve WUE while strong winds reduce it. Light energy use efficiency followed a similar pattern, increasing only under 6 m/s treatment. Since water availability is a major limiting factor for plant growth in arid and semi-arid sandy regions, the improved WUE under moderate wind stress could enhance water resource utilization efficiency. Although photosynthetic rates and light energy use efficiency declined with increasing wind intensity, light resources are not typically limiting in these regions, so reduced light use efficiency may not affect survival but could inhibit biomass production, potentially explaining the slow growth of Mongolian pine in these habitats.

4. Conclusion

Based on the analysis and discussion of results, the following conclusions can be drawn:

1. Frequent clean wind gusts did not change the diurnal variation patterns of photosynthetic and transpiration rates in *Pinus sylvestris* var. *mongolica* seedlings, but extended and deepened the midday depression period.
2. With increasing wind intensity, daily photosynthetic capacity and transpiration rates decreased significantly, with reductions of 27.6% and 22.3%, respectively, under 18 m/s treatment compared to the control.
3. Water use efficiency tended to increase with wind intensity, except under 18 m/s treatment where it decreased significantly. Light energy use efficiency increased only under 6 m/s treatment and decreased under higher wind speeds.
4. The decreases in daily photosynthetic and transpiration rates primarily resulted from reduced stomatal conductance and increased stomatal resistance. Changes in water use efficiency and light energy use efficiency were constrained by changes in photosynthetic and transpiration rates, with photosynthetic rate reduction being the main cause of decreased light energy use efficiency.

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Note: Figure translations are in progress. See original paper for figures.