Phyton (Austria) Special issue: "APGC 2004"	Vol. 45	Fasc. 4	(595)-(600)	1.10.2005

Ecophysiological Response of Rice to Sandmoving Air Currents

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Key words: Blowing time, ecophysiological responses, rice, sandmoving air current, wind velocity.

Summary

YU Y. J., SHI P. J., LU C. X., ZHENG Y. R. & SHIMIZU H. 2005. Ecophysiological response of rice to sandmoving air currents. - Phyton (Horn, Austria) 45 (4): (595)-(600).

Rice (*Oryza sativa* L.) growth should be affected by sandmoving air current (sand blast), whereas no data of associated damage on rice have been available. Laboratory wind tunnel experiments were conducted to analyze the physiological responses of rice to injury caused by sandblast and its effects on growth and yield. Plants were exposed to sandmoving air currents of varying wind speeds (6, 12, 18 and, 24 m s^{-1}, respectively) for 30 min in each exposure event, ranging from 1 to 3 events during the experimental period of 6 days.

The results showed that increasing wind speed and frequency of exposure events led to reductions of net photosynthetic rate, leaf water content and water use efficiency as compared with control. The photosynthetic rate decreased at wind speeds of 12, 18 and 24 m s^{-1} by 61, 76 and 79 %, respectively after one exposure event. Both wind speed and the frequency of exposure events were the important factors reducing seedling survival and impairing rice development (grain weight, head, maturity, root/shoot ratio, etc.). With increasing number of exposure events from 1 to 3, the average survival rate decreased from 100 to 83 % at 12 m s^{-1}, from 83 to 42 % at 18 m s^{-1}, from 58 to 17 % at 24 m s^{-1}, respectively.

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Introduction

Wind erosion affects 430 million hectares of land or 8 % of the dryland areas worldwide (UNEP 1992). Sandmoving winds occur frequently in the vast arid and semi-arid areas of China. Effects of windblown sand on plants have been investigated since 1950's. Some researchers studied its impact on different crops such as winter wheat (*Triticum aestivum* L.) by WOODRUFF 1956, cotton (*Gossypium hirsutum* L.) by ARMBRUST 1968, tomato (*Lycopersicon lycopersicum* Mill.) by ARMBRUST & al. 1969, soybean (*Glycine max* (L.) Merr.) by ARMBRUST 1982, sorghum (*Sorghum bicolor* L.) by ARMBRUST 1972, tobacco (*Nicotiana tabacum* L.) by ARMBRUST 1979), and so on. Observed damages included abraded leaves, lower survival rate, slower development or lower yield, whereas only few studies focusing on the responses of net photosynthetic rate and transpiration rate to wind sand flow have been conducted and the reaction of water use efficiency (WUE) of plants to sandblast has hardly been analysed.

In the arid and semi-arid areas of China, for example in Ningxia Hui Autonomous Region, irrigated rice is a main crop. Due to loose dry soil and sparse vegetation, strong sandmoving winds occur frequently. Rice plants exposed to sandblast might be seriously affected. However, detailed studies on windblown sand impacts on rice are lacking.

Earlier studies had mainly focused on the intensity of sandblast (WOODRUFF 1956, ARMBRUST & RETTA 2000), the sand concentration in air (ARMBRUST 1977) and the exposure duration (ARMBRUST & RETTA 2000). Variations in the number of exposure events were ignored. Analysis of the importance of this parameter was therefore included into this study. The objective of the present study was thus to investigate and to quantify the effects of sandblast on the growth and other relevant parameters of rice plants.

Material and Methods

The experiments were conducted at the Shapotou Desert Experimental Research Station, Chinese Academy of Sciences, located at the southeastern edge of the Tengger Desert in Zhongwei county, Ningxia Hui Autonomous Region in northwestern China (104°57'6"E, 37°27'40"N, 1500 m alt.). Shapotou is in a temperate arid desert with frequent strong winds.

Rice plants of the variety 'Ningjing-16' were used. The cultivation manner followed agricultural practice in fields as similar as possible. Healthy 20-day-old seedlings were transplanted (6 seedlings/pot) and grown in porcelain pots (36 cm in diameter) with mixed soil consisting of field sand, clay and manure (in a proportion of 3:1:1) for 10 days before experiments.

Each plant (except control) was exposed to 30-minute events of sandblast in a wind tunnel (Length: 36 m; hight: 1.2 m; width: 1.2 m). A set of three pots was placed 11.5 m downwind from the wind intake. Sand obtained from a nearby sandy dune (particle diameter in the range of 0.25-0.05 mm for 92 % of net weight) was placed on a smooth-bottomed floor directly before the plants and 7.5 m behind the air intake. The wind velocity was monitored in the center of the tunnel above the plants, using a Pitot-static tube and incline-gauge alcohol manometer. After each exposure, plants in pots were returned to the experimental farm for growing.

Experimental plants except for control were exposed to sandmoving air current in the wind tunnel for one, two or three times at 6, 12, 18 or 24 m s^{-1}. On the first or second day, experiments were conducted for the first exposure at each wind speed. On the third or forth day, the second exposures were repeated using two third plants which had been exposed once. On the fifth or sixth day, the third exposures were repeated using half of the plants which had been exposed twice.

The parameters included net photosynthetic rate (Pn), transpiration rate (E) measured during 14:00-16:30 on the next day after the last exposure event under the conditions of 31.4-32.2 °C, of 26.5-28.3 % relative humidity and over 1600 µmol m^{-2} s^{-1} photon flux density. Pn and E were determined with a Li-6200 photosynthesis system (LI-COR, USA)by averaging three measurements per leaf (the third leaf from the upper), one leaf per plant, one plant per pot in six replication pots. Relative water content (RWC) was determined for two leaves per plant, one plant per pot in six pots on the same day, and leaf area was measured with a Li-3000A leaf area meter (LI-COR, USA).

The number of survival of plant was recorded on 20 days after the last exposure event, and the dates of the heading, blooming and maturing were recorded during the rice growth period in the field. Four plants per pot were harvested after maturing. The grain weight of each spike was weighed and the dry weight for each whole plant was measured.

To compare the results, the biomass and physiological parameters (Pn, E, RWC, etc.) were expressed as percentages of the control (undamaged) plants. Results were usually analysed by using Duncan's multiple comparison test at 95 % to determine the significant differences. χ^2 test (Chi-Square) was carried out for counting data among the number of plants (survival, with head, flowering, maturing) under different test conditions.

Results and Discussion

Effects of sandmoving air current on rice physiology

Leaf transpiration was increased significantly ($p<0.05$) by sandblast exposures (Fig. 1). This might cause a decrease of RWC and short-term moisture stress resulting from the increased water demand of damaged leaf cells (ARMBRUST 1982). FRYREAR & al. 1975 reported that leaf water potentials (absolute values) of soybeans increased from 4 to 24 hours after sandblast damage. The RWC values were reduced with increasing wind speeds and with increasing number of exposure events from 1 to 3 times, whereas difference was not so significant among the exposed plants under higher wind speed conditions (Table 1).

Photosynthesis is an important physiological process for plant growth. The present research showed that photosynthetic rates were reduced by all wind speeds ranging from 54 % (6 m s^{-1}) to 71 % (24 m s^{-1}), after only one exposure event (Fig. 2). This coincided with the results observed from other crops such as sorghum (ARMBRUST 1982) and tomato (PRECHEUR & al. 1978). GRACE and THOMPSON 1973 measured a reduction of photosynthetic rates of *Festuca arundinacea*, and explained that this reduction might be induced by higher mesophyll resistance in the wind-exposed plants caused by decrease in leaf water content. Moisture stress may also be responsible for the decrease in photosynthesis by reducing the activity of the carboxylating enzymes. HUFFAKER & al. 1970 reported a reduction of RUDP carboxylase activity in barley by moisture stress. Some other investigations also showed that sand particles damaged tissues of plant leaves and stems, thus reducing the active photosynthetic area and consequently the inhibition of photosynthetic rate (GRACE & THOMPSON 1973, PRECHEUR & al. 1978). Our results showed that photosynthetic rate (Pn) was also affected by the number of exposure events. Pn decreased as exposure events increased, especially at 12 m s^{-1} and 18 m s^{-1} (Fig. 2).

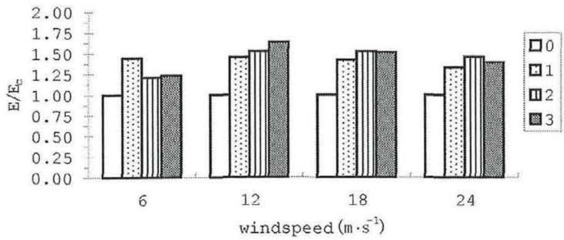

Fig. 1. Transpiration rate (E) dependent on wind speed and exposure events. E/Ec is the E ratio of exposed plant to control one, and 0, 1, 2 or 3 represents the number of exposure events.

Table 1. Relevant parameters of rice plants exposed to sandmoving air current. The same letters in each column mean non-significant difference at 5 % level. In the "treatment" column, I, II or III represents exposure times (1, 2 or 3) and 6, 12, 18 or 24 represents wind speed (m s^{-1}).

Treatment	No. of plant with head	No. of maturing plant	No. of flowering plant	RWC	Root/ shoot ratio	Survival rate (%)	Grain weight (g)	Situation of growth
Control	35^{a}	35^{a}	0	1.03^{a}	0.98^{a}	100^{a}	25.7^{a}	Good
I-6	34^{a}	32^{a}	2^{a}	0.97^{a}	1.01^{a}	100^{a}	26.4^{b}	Good
II-6	34^{a}	29^{a}	5^{ab}	0.85^{b}	0.91^{ab}	100^{a}	25.9^{ab}	Good
III-6	34^{a}	26^{b}	8^{b}	0.76^{c}	0.95^{a}	100^{a}	22.5^{d}	Good
I-12	32^{a}	26^{b}	6^{ab}	0.41^{d}	1.02^{a}	100^{a}	23.8^{c}	Good
II-12	28^{a}	17^{c}	11^{b}	0.28^{e}	0.97^{a}	91.7^{b}	22.6^{d}	Good
III-12	26^{b}	10^{d}	16^{c}	0.21^{f}	1.09^{a}	83.3^{c}	22.7^{d}	Good
I-18	24^{b}	6^{e}	18^{c}	0.26^{e}	0.70^{c}	83.3^{c}	21.1^{e}	Mean
II-18	19^{c}	5^{e}	14^{c}	0.20^{f}	0.65^{c}	83.3^{c}	21.2^{e}	Poor
III-18	2^{e}	0^{f}	2^{a}	0.19^{f}	0.42^{d}	41.7^{e}	21.2^{e}	Poor
I-24	20^{c}	7^{e}	13^{bc}	0.23^{ef}	0.68^{c}	58.3^{d}	21.4^{e}	Poor
II-24	10^{d}	4^{e}	6^{ab}	0.22^{ef}	0.52^{d}	41.7^{e}	21.1^{e}	Poor
III-24	2^{e}	0^{f}	2^{a}	0.21^{ef}	0.38^{e}	16.7^{f}	-	Poor

The water use efficiency (WUE) was decreased by sandblast exposures (Fig. 3), implying that the assimilation requires more water in exposed-rice plants than control. Increase in exposure events could further intensify the reduction of WUE. This might be explained by increased impairment of photosynthesis (Fig. 2). In addition, sandmoving air current might cause waste of more water within plant and further intensify moisture stress with increasing exposure events (Table 1).

Effect of sandmoving air current on growth and yield

Survival of a damaged crop is a grower's primary concern. After exposures, the color of leaf and stem changed to darken. When the damage was extensive, the plant stem became to weaken/break and to die. Survival of rice exposed to sand-moving air current was closely related not only to wind speed but also to exposure events. With increasing exposure events from 1 to 3 times, average plant survival percentages decreased from 100 to 83 % at 12 m s^{-1}, from 83 to 42 % at 18 m s^{-1}, and from 58 to 17 % at 24 m s^{-1}, respectively.

Survival, heading and grain weight of rice are three main factors determining rice yield. According to the experimental results, the increase of both wind speed and exposure events substantially reduced these factors, thus the rice yield decreased markedly. These results coincided with the experiments of green beans by SKIDMORE 1966. Furthermore, the delay of maturing and flowering of rice exposed to sandmoving air current might also cause a reduction of rice yield. This finding was demonstrated by FRYREAR & al. 1975 and ARMBRUST 1968. The delay increased with increase in wind speed and exposure events. When weather conditions would not be optimal, further yield reduction might occur.

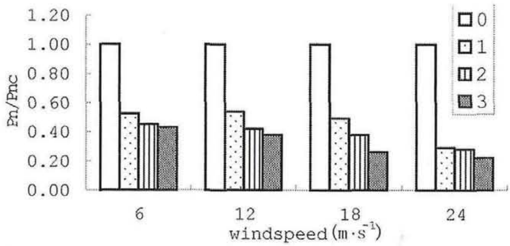

Fig. 2. Photosynthetic rate (Pn) affected by wind speed and exposure events. Pn/Pnc is the Pn ratio of exposed plant to control one, and 0, 1, 2 or 3 represents the number of exposure events.

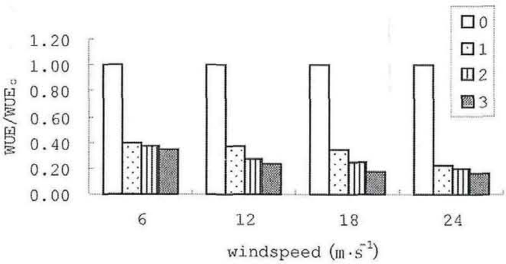

Fig. 3. Water use efficiency (WUE) affected by wind speed and exposure events. WUE/WUEc is the WUE ratio of exposed plant to control one, and 0, 1, 2 or 3 represents the number of exposure events.

Dry weights of roots and shoots were reduced with increasing wind velocity, the ratio of root to shoot did not show a significant increase at relatively lower wind speeds (6-12 m s^{-1}) but showed a significant decrease at 18-24 m s^{-1} (Table 1), which was not found in other studies such as WHITEHEAD 1962. The root/shoot ratio would reduce as exposure times increased with wind speeds above 18 m s^{-1}. This may be explained by the root impairments caused by heavy wind-induced plant shaking and/or by the change of assimilation products partitioning after severe damages on plant shoot and a reduced activity of photosynthesis caused by sandblast. Investigation by ARMBRUST 1982 with sorghum indicated that sandblasting reduced growth by causing a loss of viable area, reducing photosynthesis, and increasing respiration. Similarly FRYREAR & al. 1975 found out that wind erosion damage reduces plant growth and plant height by reducing photosynthesis and increasing respiration. The present study showed similar results for rice. At high wind speed, the sand particles strike the plant shoot with a high energy and may damage the surface of leaves such as puncture, resulting in a loss of active area for photosynthesis.

The present study showed that multiple exposure event was also an important component of sandblast causing plant damage on rice growth, besides wind speed. Especially, a combination of higher wind speeds with frequent exposure events would reduce rice yield considerably. Intensity and frequency of sandmoving air current should therefore be regarded as two major concerns for protecting rice against wind-sand flow damage in vast wind-erosion areas.

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