Effects of rising temperature on growth, yield and dry-matter production of rice grown in the paddy field

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Abstract

Many studies on the crop response to climate change have been examined for the isolated plants or the plants grown in a small-scale population. We constructed the Temperature Gradient Chamber (TGC) in the paddy field of Okayama University to clarify the effect of rising temperature on growth, yield and dry-matter production of rice during the whole growth season. The four experimental plots were arranged by the distance from the intake side, TG1 (control), TG2, TG3, and TG4. The temperature gradient occurred from TG1 to TG4, the daily maximum temperature in TG4 increased 4.0－4.4℃than that in TG1. The number of panicles decreased with rising temperature. The dry weight at maturity was highest in TG3 in 2002 and TG2 in 2003, respectively, and lowest in TG4. The photosynthetic rate of flag leaf decreased rapidly in TG4 (highest temperature plot) than that in TG1, meaning that the higher temperature enhanced the leaf senescence. The brown rice yield was highest in TG2 (2002) and TG3 (2003) due to the higher percentage of ripened grain, and lowest in TG4 because of the decrease in a grain size and increase in sterile grains. The share percentage of heat-damaged white grains increased linearly with higher the temperature. Clearly, grain yield starts to decline when daily mean temperature exceeds 29 ℃, and grain quality decline linearly with higher the temperature.

Media summary

The temperature gradient chamber study reveals that grain yield starts to decline when daily mean temperature exceeds 29 ℃due to the sterility, and grain quality decline linearly with higher the temperature.

Key Words

Grain quality, Grain yield, Photosynthesis, Rice (*Oriza sativa* L.), Rising temperature, Spikelets sterility.

Introduction

The report of the IPCC estimated that the mean global temperature might be increased 1.4－5.8℃during 21st century (IPCC 2001). Recent studies on the crop response to climate change reveal that the doubling of carbon dioxide cause the increase in biomass and grain yield of C3 crops, however, rising temperature may reduce the yield due to the spikelets sterility (Kim et al. 1996). Many studies have been examined by using the pot-grown plants or small-scale field. We constructed the Temperature Gradient Chamber, (TGC) (Horie et al. 1995) in the paddy field to clarify the effect of rising temperature on growth, yield and dry-matter production of rice during the whole growth season.

Materials and Methods

Temperature gradient chamber (TGC) : TGC (30m x 2.1m x 2.1m, length x width x height) was covered with transparent plastic film, which equipped two exhaust fans (one always ventilate and another one work when temperature higher than 35℃), and was constructed in the paddy field of Okayama University, Japan (34?40′N, 133?55′E, elevation 3 m). The air temperature gradient occurred only during the daytime from the intake side to the exhaust side.

Field cultivation and experimental design : The experiment was carried out in 2002 and 2003. Young seedlings of the rice cultivar Nipponbare were transplanted to the TGC at a hill spacing of 15 cm and a row spacing of 30 cm (22.2 hills per m^2). The four experimental plots were arranged by the distance from the intake side, TG1 (control), TG2, TG3, TG4. The each plot size was 7.8 m^2. The slow-release fertilizers (N, P_2O_5 and K_2O) were applied at the rate of 8 g per m^2 as basal.

Measurement of dry weight and yield component : Every 25 days after transplanting, six plants were sampled from each plot for the measurement of dry weight and leaf area. Then crop growth parameters were calculated. Twenty plants were harvested at the maturity from each plot, and yield component, sterility , and brown rice quality (percentages of normal grains and heat-damaged white grains) were measured.

Leaf photosynthesis : The photosynthetic rate of flag leaf in each plot was measured at the interval of 15days after the tillering stage by using a portable photosynthesis measurement system (CIRAS-1, Koito, Japan).

Results and discussion

Air temperature in TGC : Temperature gradient was achieved only for mean and maximum temperatures during plant growth (Table 1). The mean and maximum temperature gradients increased from TG1 to TG4 in both years .. Because of the ventilation during the night, the minimum temperature showed almost same value among the plots. The mean and maximum temperatures of TG4 increased by 2.0 and 1.2 ? dail and by 4.0-4.4? during 2002 and 2003, respectively, compared to TG1.

Table 1. The mean, maximum and minimum temperature during the plant growth recorded from each plot .

Temperature (?)	2002				2003			
	TG1	TG2	TG3	TG4	TG1	TG2	TG3	TG4
Mean	26.8	27.9	28.4	28.8	24.9	25.5	25.8	26.1
Maximum	31.7	33.8	35.0	35.7	30.4	32.3	33.4	34.8
Minimum	21.9	22.0	21.8	21.9	21.2	21.1	21.3	21.1

Growth : ((Plant height was markedly increased in TG2 in 2002 and in both TG2 and TG4 in 2003 compared with the control (TG1)). The plant length at maturity was in the order of TG2 (118.5cm) > TG4(115.3cm) > TG1(114.8cm) TG3(114.7cm) in 2002, and TG4(128.8cm) > TG2(127.7cm) > TG3(126.9cm) > TG1(121.3cm) in 2003, respectively (Table 2). The number of panicles per plant decreased with rising temperature (Figure 1). On average, the number of panicles per plant was lower in year 2002 than in 2003 which was associated with 2.4 C warmer (i.e. 28.0 C vs 25.6C) temperature. The same decreasing tendency was observed by Kakizaki (1991). The dry weight at maturity was highest in TG3 in 2002 and TG2 in 2003, respectively, and lowest in TG4 in both year. The panicle dry weight at maturity was lowest in TG4 and the total dry weight was 11 16% lower than that in TG1. (data not shown).

Table 2. Effect of rising temperature on plant height (cm) in 2002 and 2003.

Year	TG1	TG2	TG3	TG4	LSD (p = 0.05)

2002	114.8	118.5	114.7	115.3	3.14
2003	121.3	127.7	126.9	128.8	5.92

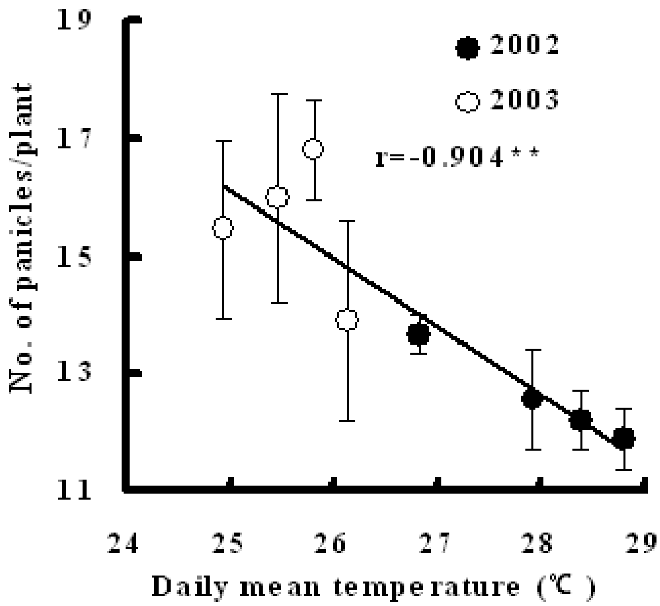

Figure 1. Effect of average temperature during plant growth on the number of panicles in 2002 and 2003.

Bars indicate ?SD (n=3).

Leaf photosynthesis : The photosynthetic rate of flag leaf in each plot was highest during 7 days after full expansion, followed by a sharp decline after the heading stage (Figure 2). At the early ripening stage (84 days after transplanting), photosynthetic rate in TG3 and TG4 were about 20% lower than that in TG1 and TG2. At the middle ripening stage (98 days after transplanting), TG1 marked 30 % decrease in photosynthetic rate from that at the heading stage, however, higher temperature plots (TG2, TG3 and TG4) showed rapid decrease (40-60 %). Clearly, the higher temperature during ontogeny of flag leaf enhanced the senescence, i.e., the rapid decrease in photosynthesis.

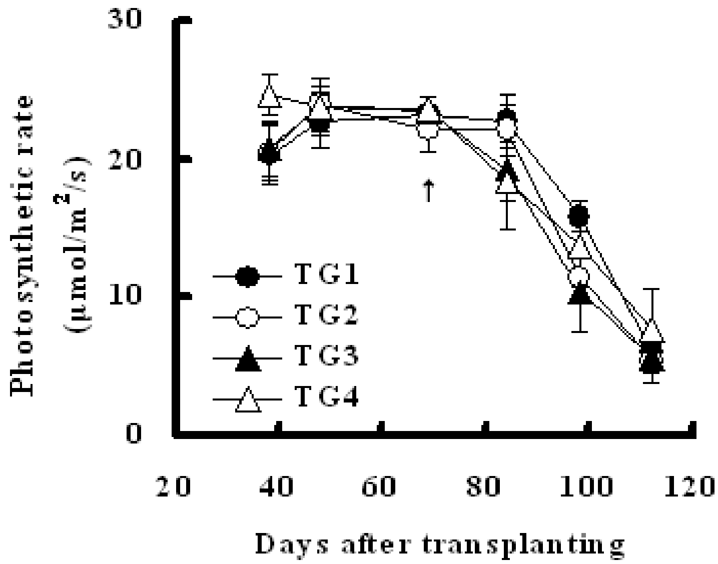

Figure 2. Changes in photosynthetic rate of flag leaf during ontogeny.

Bars indicate ?SD (n=3) and arrow shows heading time .

Measurement conditions were at an air-temperature of 28?, a CO_2 concentration of 370-400µL/L, and a PAR of 1500µE/m^2/s.

Yield and Yield components : The brown rice yield per m^2 in 2002 was in the order of TG2 (453.3g) > TG1 (423.9g) > TG3 (394.7g) > TG4 (328.7g), in TG4 27.5 % lower than in TG2. In 2003, the yield was higher in TG3 (463.0g) and TG2 (460.2g), followed by TG1 (450.0g), and lowest in TG4 (336.7g), in TG4 27.3 % lower than in TG3. Although the number of spiklets per m^2 was not different among plots in 2002, was little reduced in TG4 in 2003 due to the decrease in the number of panicles. The 1000-grain weight in TG4 (19.9g) was 5.2 % lower than that in TG1 (21.0g). However, it was almost same among plots in 2003 (20.1?0.1g). The percentage of sterile grains was in the order of TG4 > TG3 > TG2 > TG1 in both years. The positive correlation was observed between the percentage of sterile grains and the daily maximum temperature during the flowering stage (data not shown).

Table 3. Yield, yield component and percentage of sterility grains.

Year	Plot	No. of panicles m^2	No. of spikelets /panicle	No. of spikelets $10^3/m^2$	Percentage of ripened grains	1000-grain weight g	Brown rice yield g/m^2	Percentage of sterility grains
2002	TG1	322.8	96.1	31.0	65.4	21.0	423.9	4.4
	TG2	297.9	107.9	32.1	69.3	20.3	453.3	6.8
	TG3	320.1	98.3	31.4	61.4	20.4	394.7	11.7

	TG4	297.9	105.3	31.2	52.9	19.9	328.7	19.4
LSD (p=0.05)		ns	10.6	ns	12.3	0.8	99.5	4.7
2003	TG1	319.1	105.7	33.7	66.3	20.1	450.0	8.1
	TG2	314.5	106.9	33.6	67.9	20.2	460.2	12.0
	TG3	317.3	103.4	32.8	70.6	20.0	463.0	14.4
	TG4	284.9	100.5	28.6	64.1	20.0	366.7	19.2
LSD (p=0.05)		37.5	3.1	4.1	7.9	ns	88.9	5.1

Note; ns, not significant

Grain quality : The share percentage of heat-damaged white grains was in the order of TG4 > TG3 > TG2 > TG1. Consequently, the share percentage of normal grain decreased with higher the daily mean temperature during twenty days after heading (Figure 3).

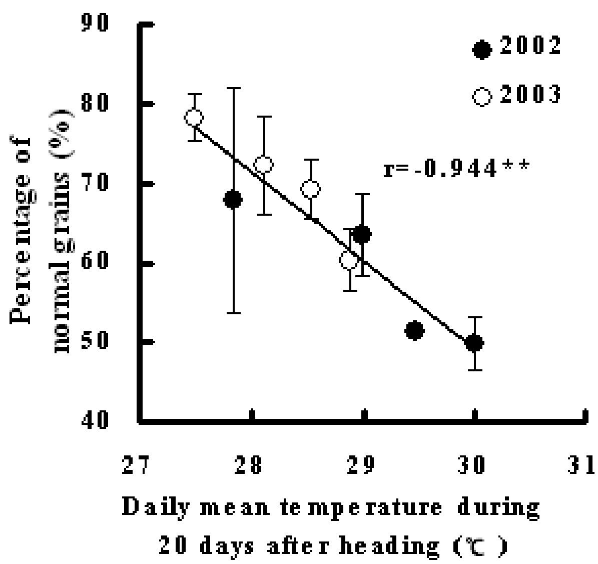

Fig. 3. Effect of rising temperature on the percentage of normal grains.

Bars indicate ?SD (n=3).

Conclusion

The number of panicles decreased with rising temperature. The dry weight at maturity was highest in TG3 in 2002 and TG2 in 2003, respectively. The photosynthetic rate of flag leaf decreased rapidly in TG4 (highest temperature plot) than that in TG1, showing that the higher temperature enhanced the leaf senescence. The brown rice yield was highest in TG2 (2002) and TG3 (2003) due to the higher percentage of ripened grain, and lowest in TG4 associated with both the decreased grain weight and increased sterility. . The share percentage of heat-damaged white grains increased linearly with higher the temperature. Clearly, grain yield starts to decline when mean temperature exceeds 29 ℃, and grain quality decline linearly with higher the temperature. Increaded temperature during grain filling period decrased the the grain weight which suggested that the physiological sink activity declined due to the higher temperature. The decrease in enzymatic activity of the starch synthesis (in developing grain ???) was observed under the high-temperature condition (Gibson and Paulsen 1999). The rising temperature may limit the source activity through the rapid decrease in photosynthesis. Further study was needed for analysing the heat-reduction in the grain weight from the aspects of the sink and source activity.

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