Interactive Effects of Atmospheric Ozone and Carbon Dioxide on Photosynthesis, Dry-Matter Production and Yield of Lowland Rice

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Abstract

A japonica lowland rice, cv. Koshihikari, was exposed to the combinations of O_3 (0, 0.1ppm) and CO_2 (400, 800 ppm) atmosphere for up to 2 weeks at the vegetative and reproductive growth stages and their interactive effects on net photosynthetic rate, dry-matter production, yield and yield components were examined. The O_3 (0.1 ppm) inhibited all eco-physiological characters. However, the detrimental effect of O_3 was ameliorated by elevated CO_2 (800 ppm).The reason was considered to be the decline of stomatal conductance induced by elevated CO_2, which suppressed the invasion of O_3 inside the leaf cavity as a physical barrier. The O_3 effect on yield was attributed to increases in infertile caryopses at lower positions of the rachis-branch of panicle.

Media summary

Inhibition of photosynthesis and biomass production in lowland rice due to O_3 was masked by elevated CO_2 through its function on the closure of stomata.

Key Words

Atmospheric O_3, Gas exchange, Growth stage, Elevated CO_2, Stomatal conductance, Yield component

Introduction

The atmospheric ozone (O_3), a major component of photochemical air pollutants, often generates around the urban area during the sunny, summer season in Japan. The O_3 causes injury with visible symptoms, growth inhibition and yield decline of a range of field crops. From now on, under further industrialization and global warming, the occurrence of O_3 is expected to be increased and gives detrimental effects on crop plants. On the other hand, the atmospheric carbon dioxide (CO_2) concentration is increasing year by year due to human activities such as the fossil fuel combustion and deforestation. The elevated levels of CO_2 promote photosynthesis of C_3 plants. For example, in lowland rice, photosynthesis and biomass production are promoted and plant earliness is induced by elevated CO_2. More than 20% of yield increment of rice is often reported under doubled CO_2 conditions. Clearly, the O_3 and CO_2 have opposite effects on production processes of crop plants. However, investigations related to the interactive effect of these two gases on lowland rice are very few (Ishioh and Imai 2003; Kobori and Imai 2003; Olszyk and Wise 1997).

In the present study, we exposed O_3 and CO_2 on lowland rice at vegetative growth stage and at heading to early-maturing stage and analysed plant responses in terms of photosynthesis, dry matter production and yield.

Materials and Methods

A lowland rice (*Oryza sativa* L. cv. Koshihikari) were grown outdoors in small plastic pots containing 2.5 kg soil and 4 g chemical fertilizer (N : P : K=15 : 15 : 15, %) (Experiment 1), or in large pots containing 10 kg soil and 8 g chemical fertilizer (Experiment 2).

Experiment 1 : At vegetative growth stage (a half of the 9^{th} leaf on main stem appeared), plants were transferred into naturally-lit phytotrons and were exposed to the combinations of O_3 (0 or 0.1ppm; 6:30am-6:30pm) and CO_2 (400 or 800ppm; 0:00am-12:00pm) atmosphere for up to 2 weeks under

28/23?C(day/night) and 60% RH conditions as shown in Table 1 and Figure 1. Gas exchange rates were measured on 0, 4, 11, 14, 18 and 21 days from the treatments. After the treatments, plants were measured their leaf areas and separated into leaf-blade, leaf-sheath + stem and root fractions and oven dried for 48hr and weighed.

Experiment 2: At flowering to early maturing stage, plants were treated with O_3 and CO_2 as in Expt. 1. After the treatments, plants were grown outdoors. At maturity, plants were sampled and measured dry weight of each organ, yield and yield components.

Results

At the vegetative growth stage, visible injury on leaf surface appeared rapidly and the leaf function was suppressed severely. A rapid decline of net photosynthetic rate occurred just after the O_3 treatment and this was not recovered when plants were transferred into O_3-free air (Figure 2). Therefore, the plant growth rate was suppressed and both the leaf area and dry-matter production were lowered (Table 2). On the other hand, in a plot with O_3 plus CO_2, stomatal conductance decreased by elevated CO_2 and this avoided the injury of leaf. The net photosynthetic rate and the growth rate were maintained as high as those of the control plot (0ppm O_3 + 400ppm CO_2) (Figure 2).

At the heading to early maturing stage, the effect of treatments on net photosynthetic rate differ with the duration of treatments (Figure 3). The single exposure of O_3 decreased net photosynthetic rate but the overall effect did not reflect to whole plant dry-matter at maturity (Figure 4). The concerning factors may be aging of plant and/or meteorological conditions after the treatment but the clear resolution was not obtained. However, once suffered O_3 fumigation, plants showed the tendency to have infertile caryopses at lower positions of the rachis branch of panicle (Figure 5). This suggests that the translocation of photoassimilate was also suppressed by O_3.

Table 1. O_3, CO_2 and temperature conditions.

Treatment plot	O_3 conc. (ppm)	CO_2 conc. (ppm)	Temperature (day/night, °C)
Control plot (○)	0	400	28/23
H-L plot (■)	0.1	400	
H-H plot (◆)	0.1	800	
L-H plot (▲)	0	800	

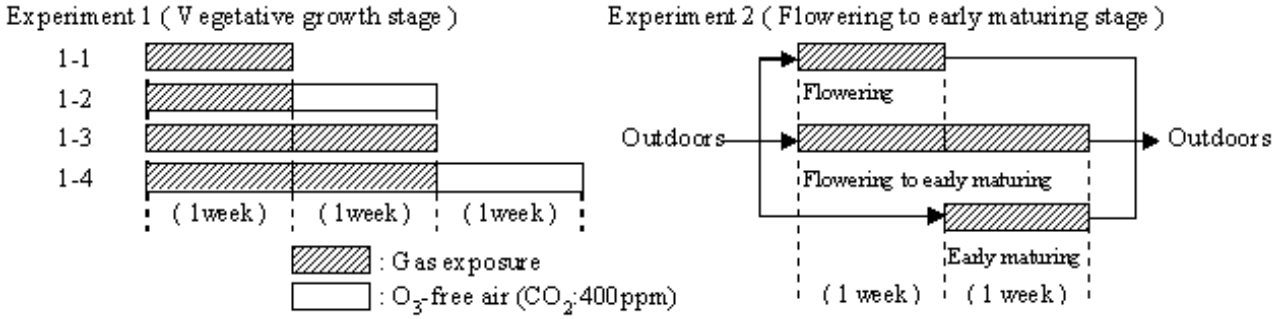


Figure 1. Duration of treatment.

Table 2. Effects of O_3 and CO_2 concentrations on growth and dry-matter production at vegetative stage (Expt. 1).

O_3 (ppm)	CO_2 (ppm)	Duration of treat.	Plant length (cm)		Tiller numbers		Leaf area (cm^2)		Dry weight (g) of: Leaf-blade		Leaf-sheath +stem		Root		Whole plant		Top/root ratio	
0	400	1-1	70.5	a	2.7	a	183.8	a	0.5973	a	0.5595	a	0.2719	a	1.4286	a	4.30	a
0.1			71.3	a	3.0	a	188.7	a	0.5758	a	0.5094	a	0.2440	a	1.3292	a	4.46	a
0.1	800		71.1	a	2.9	a	189.6	a	0.6007	a	0.5713	a	0.2930	a	1.4650	a	4.02	b
0			68.5	a	2.9	a	172.2	a	0.5529	a	0.5407	a	0.2588	a	1.3524	a	4.24	ab
0	400	1-2	82.0	ab	5.4	bc	371.5	b	1.4337	ab	1.3815	b	0.6738	b	3.4889	a	4.18	b
0.1			78.0	b	4.2	c	334.3	b	1.2751	b	1.0708	c	0.4647	c	2.8106	b	5.10	a
0.1	800		81.6	ab	6.1	ab	384.4	ab	1.4419	ab	1.3886	b	0.6897	b	3.5202	a	4.11	b
0			83.2	a	7.4	a	436.5	a	1.5912	a	1.6418	a	0.8187	a	4.0518	a	3.95	b
0	400	1-3	82.7	a	4.1	a	348.5	a	1.2699	a	1.2189	a	0.6337	a	3.1225	a	3.96	b
0.1			75.3	b	3.3	a	286.8	b	0.9792	b	0.8220	b	0.3915	b	2.1927	b	4.60	a
0.1	800		79.4	ab	3.8	a	320.8	ab	1.1473	ab	1.1824	a	0.6475	a	2.9772	a	3.63	c
0			78.4	ab	3.8	a	346.3	a	1.2627	a	1.3954	a	0.7063	a	3.3644	a	3.84	bc
0	400	1-4	92.1	a	9.4	b	580.4	b	2.5544	ab	2.8071	a	1.2562	b	6.6178	ab	4.29	b
0.1			85.1	b	6.8	c	450.1	c	1.9652	c	1.7991	b	0.7352	c	4.4995	c	5.14	a
0.1	800		84.9	b	9.4	b	552.0	b	2.3241	bc	2.2668	b	1.1420	b	5.7329	b	4.06	bc
0			89.2	a	11.2	a	700.7	a	2.9323	a	3.0921	a	1.5186	a	7.5431	a	3.98	c

In each row figures followed by a different letter are significantly different at $P<0.05$.

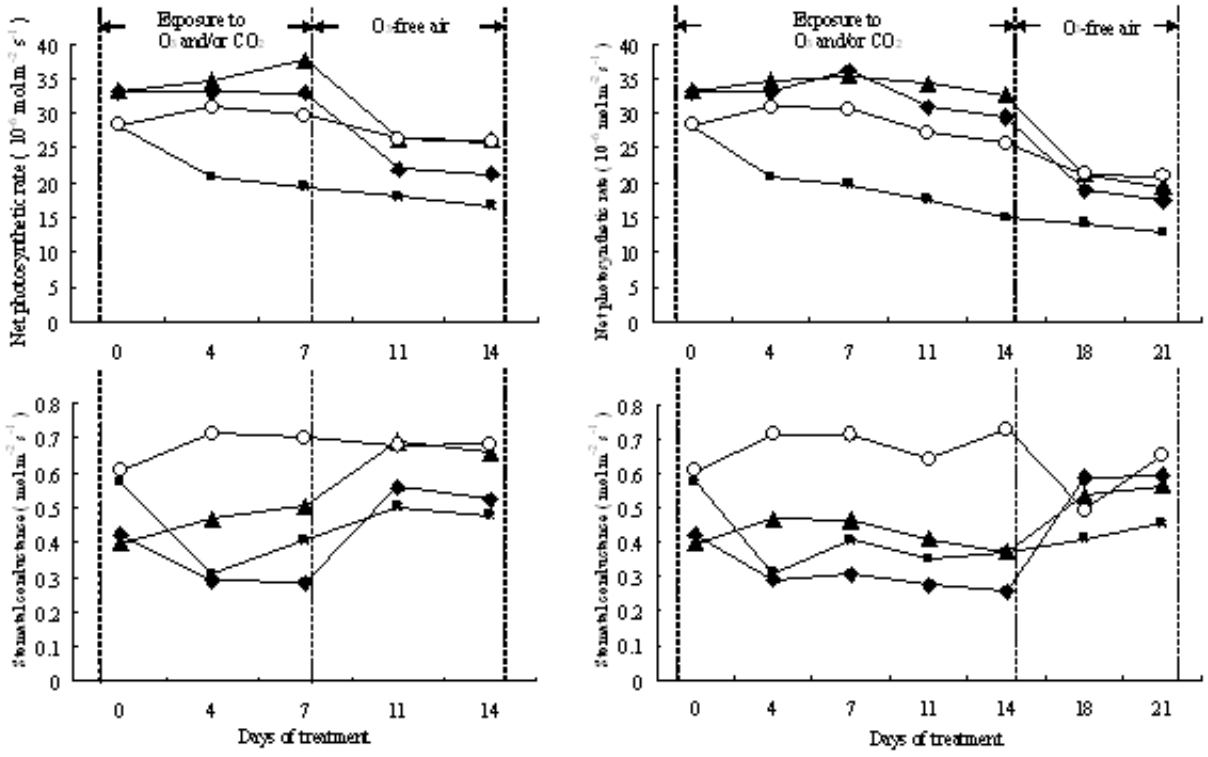


Figure 2. Effects of O_3 and CO_2 concentrations on net photosynthetic rate and stomatal conductance at vegetative stage (Expt. 1). Symbols, see Table 1.

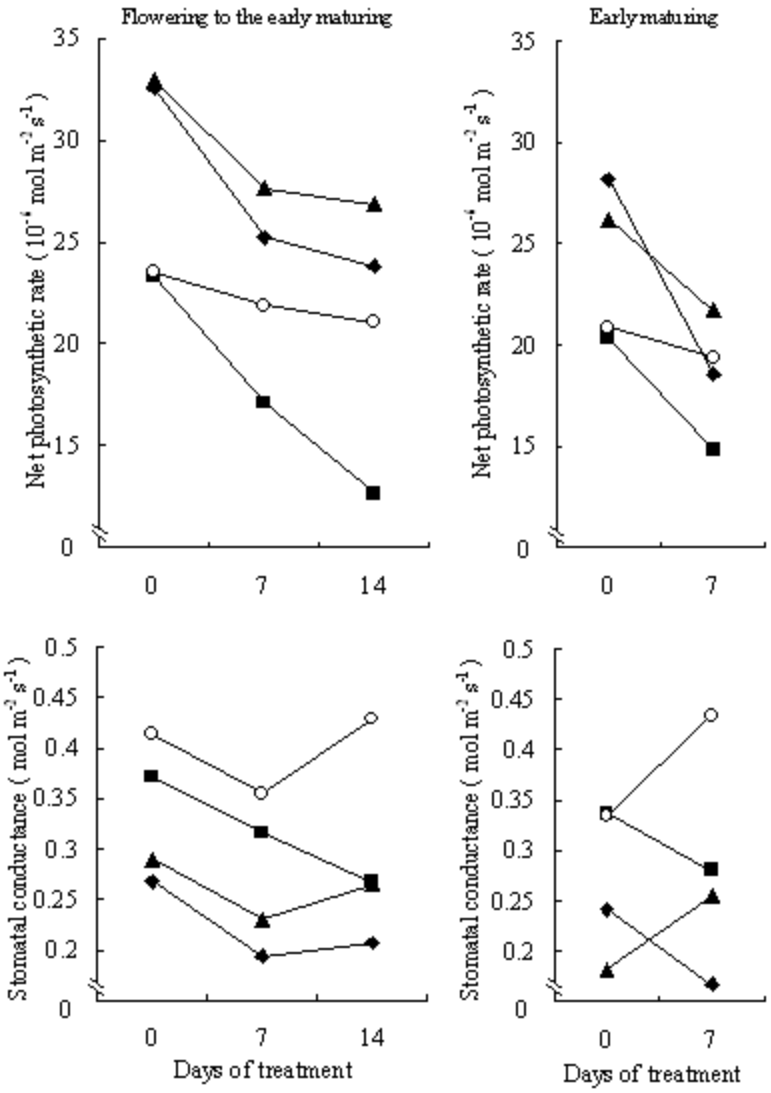
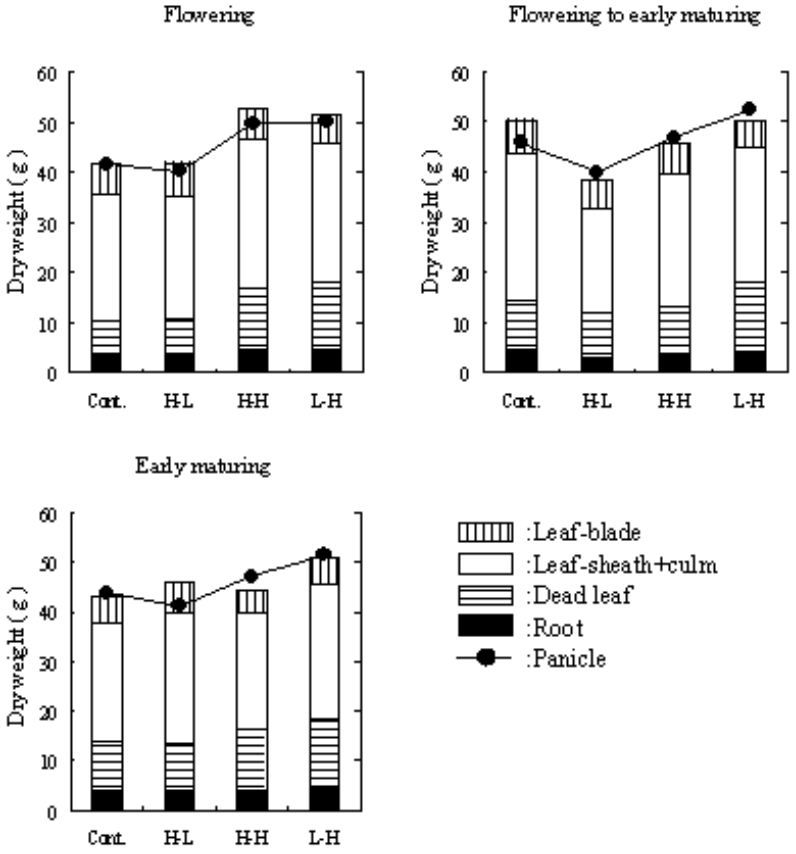


Figure 3. Effects of O_3 and CO_2 concentrations on net photosynthetic rate and stomatal conductance at flowering, flowering to early maturing and early maturing stages (Expt. 2). Symbols, see Table 1.



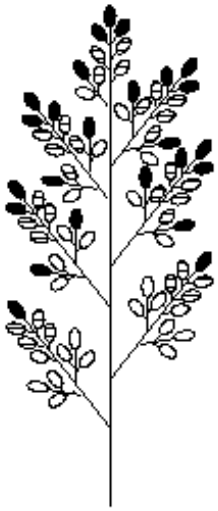


Figure 5. Fertility of caryopses exposed to O_3.
:Fertile.
:Half-fertile.
:Infertile.

Figure 4. Effects of O_3 and CO_2 concentrations on dry-matter distribution and yield at flowering, flowering to early maturing and early maturing stages (Expt. 2).

Conclusion

It was clarified that under the elevated CO_2 (400ppm vs. 800ppm), the detrimental effect of O_3 (0.1ppm) was ameliorated. The major reason was the decline of stomatal conductance by elevated CO_2 which suppressed the invasion of O_3 inside the leaf cavity as a physical barrier. Further investigations are needed by considering the light environment, the age of plant and biochemical reactions at treatment to solve the interaction of O_3 and CO_2 on lowland rice.

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