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Impacts of ozone on the biomass and yield of rice in open-top chambers

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Abstract: The impacts of different O_3 concentration on the biomass and yield of rice were studied by using OTC-1 open-top chambers. Experimental treatments included the activated charcoal-filtered air (CFA), 50 nl/L (CF50), 100 nl/L (CF100) and 200 nl/L (CF200) concentrations of O_3. The O_3 treatments significantly decreased the total biomass per plant. The elevated O_3 exposure resulted in a more decrease in the root growth than in the shoot growth. Assessments of yield characteristics at the final harvest revealed an O_3-induced decrease in the number of grains per plant, resulting from fewer ears per plant, fewer grains per ear and more unfilled grains per ear. The 1000 grain dry weight and the harvest index (HI) were not changed significantly under 50 nl/L or 100 nl/L O_3 exposure, but reduced by 17.0% and 4.8% by 200nl/L O_3 treatment, respectively. Compared to the CFA treatment, CF50, CF100 and CF200 treatments caused a 8.2%, 26.1%, 49.1% decrease of the grain yield per plant, and a 14.2%, 31.7%, 51.7% decrease of the total biomass per plant, respectively. Linear regression showed that the 7h – daily mean O_3 concentration exposure for 3 months (July-September) and AOT40 (cumulative exposure accumulation over threshold 40 nl/L) were well correlated with the relative grain yield. A yield loss of 10% was estimated to be at 46.9 nl/L O_3 for 7h-daily mean O_3 concentration exposure or at 12930 nl/(L·h) O_3 for AOT40.

Key words: open-top chambers; ozone; rice; biomass; yield

Introduction

Ozone (O_3) formed as photochemical smog is the most danger and widespread component in the air pollution. Nowadays, the typical daily maximum O_3 concentrations in urban-suburban and areas have reached 100 ~ 400 nl/L and 50 ~ 120 nl/L, respectively. Under certain meteorological condition rural O_3 concentrations can exceed suburban one (Colbeck, 1994). Many studies have demonstrated that ambient O_3 reduces the growth and productivity in a wide range of crop in North America (Heck,1983; Altshuller, 1988), Europe (Fuhrer, 1997), and in many parts of the developing world (Wahid,1995a,b), in the USA, the National Crop Loss Assessment Network (NCLAN) study has estimates of economic losses resulting from the impacts of O_3 pollution on crop in excess of $\$3 \times 10^9$ per year (Adams, 1988). Moreover, the duration and frequency of photochemical episodes are expected to continue to increase. Long-term records show that the tropospheric O_3 concentration in the north hemisphere is increasing at a rate of 1% ~ 2% per year (Fishman, 1991). To protect agricultural crops from O_3 pollution in long term, regulatory policies are designed such as air quality standards (US), objectives (Canada), guidelines (FRG) and critical levels (Europe). The Europe critical level to protect vegetation against the adverse effects of O_3 is specified as the accumulated exposure over a threshold of 40 nl/L (AOT40) (Grunhage, 1999).

Rice (*Oryza sativa* L.) constitutes the most important agricultural crop in China, consisting of 34.54% of the total cereals plants, occupying an area amounting to 31765.19 × 10^3 hm^2 (China Agriculture Yearbook, 1998a; 1999). Thus, effects of chronic exposures to elevated levels of O_3 on this crop are of great concern to growers, scientists and governments. But in the past research on effects of ozone on crop growth was taken seriously in China. This paper demonstrated that O_3 could make a great impact on the biomass and yield of rice. This paper may be helpful for assessment of crop loss from the O_3 pollution and identification of an critical level to protect crops against adverse effects by O_3 in China.

1 Materials and methods

1.1 Fumigation and cultivation

Experiments were performed at the Agricultural Meteorological Experimental Station of the Chinese Meteorological Bureau, at Dingxing County, Hebei Province. The OTC-1 open-top chamber is octagon, at 3m in diameter, 2.4m in height and 16 m^3 in volume. The construction and performance of the OTCs have been described in detail by Wang Chunyi *et al*. (Wang, 1993). Ozone was generated from pure oxygen by electric discharge (QHG-1 Ozonator, Qinghua University, Beijing). O_3 flux was controlled by a rotor flowmeter to control O_3 flux, and it was mixed with activated charcoal filtered flesh air (CFA), then was applied to chambers through a sublateral tube

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to provide desired O_3 concentrations, which in each chamber was measured in the center of the OTC. A teflon tubing was used to draw an air sample from each OTC. Control and feedback adjustments of the O_3 concentration were made using an O_3 analyzer model APOH-350E linked to a datalogger (Singlechip, model MCS51).

On 1 May 1999 rice seeds were planted under field condition. Then on 9 June rice seedlings were transplanted to crock pots 36 cm in diameter at top, 26 cm in depth containing surface soil of the field, sand loam in texture and were grown outdoors. In each pot there were 20 plants (4 plant × 5). On 1 July plants were transferred to OTCs to acclimate micro-environment of OTCs. Then plants were exposed to CFA or CFA with different O_3 concentrations for 7 h/d (09:00 – 16:00) from 4 July to 1 October except on rainy days. Four O_3 exposure levels were used: CFA (5 nl/L), 50 nl/L, 100 nl/L and 200 nl/L, referred to as CFA, CF50, CF100 and CF200, respectively. The plants were well fertilized and were watered with tap water as required. Same agronomic measures were applied to all plots to provide the same cultivation regime over whole growing period.

1.2 Crop measurements

At the final harvest stage (October 2), after seed ripening, 20 plants were harvested from each pot. The root separated from the shoot and the each part of the plant was dried at 70℃ to constant weight before recording the total biomass (dry weight (DW)), the DW of the straw and the root as well as the 1000 grain weight. The number of ear, grain per ear, infertile floret per ear on each plant were also calculated. These data provided the basis for calculation of the straw and the grain weight per plant, the harvest index (HI: ratio of the grain DW to the total above ground DW) and the root: shoot allometric coefficient (K) according to Hunt (Hunt, 1990).

1.3 Statistical analyses

Statistical analyses of data were performed using SPSS 8.0 (SPSS Inc., Chicago, USA), Data were subjected to ANONA to investigate the influence of Chamber/Pot and O_3 on measured variables and to determinate the significant differences among treatments with the Student's *t* test. No significant differences among chambers/pots were found. Relative yield was regressed linearly against the 7h-daily mean O_3 concentration and AOT40, respectively.

2 Results

2.1 Biomass production

No visible symptoms characteristic of O_3 injury or premature senescence were observed under 50 nl/L O_3 exposure during the experiment. But relatively elevated O_3 exposure (CF100 and CF200 treatments) resulted in visible injuries or leaf senescence such as small lightgreen, yellowish or brown dots, necrotic flecks and chlorotic leaves, and it shortened the growth period to some extent. Effects of elevated O_3 on the total biomass per plant at final harvest are shown in Fig.1. O_3 fumigation was found to significantly decrease the total biomass per plant. 50 nl/L, 100 nl/L and 200 nl/L resulted in a large decrease in both straw yield (−16.1%, −29.0%, −44.1%, respectively; $P<0.01$) (Table 1) and the total biomass per plant (−14.2%, −31.7%, −51.7%, respectively; $P<0.01$). The partitioning of dry matter between root and shoot, as indicated by K, was significantly altered by O_3. A larger decrease in the root growth than in the biomass above ground was observed in the relatively elevated O_3 (100 nl/L and 200 nl/L).

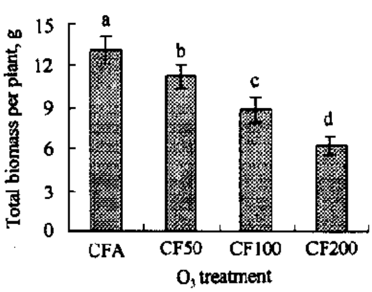

Fig.1 Effects of elevated O_3 on the total biomass per rice plant. Values represent mean ± *SE* (n = 20). Different letters above the histogram indicate significant difference among the treatments; $P<0.01$

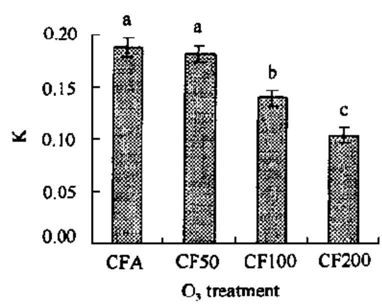

Fig.2 Effects of elevated O_3 on the allometric root: shoot coefficient (K) of rice plant. Different letters above the histogram indicate significant difference among the treatments; $P<0.01$

2.2 Yield components

The effects of the elevated O_3 on yield components at the final harvest (October 2) are shown in Table 1. Significant effect of elevated O_3 on grain yield per plant were observed. Compared to the CFA treatment, CF50, CF100 and CF200 treatments caused a −8.17% (P<0.01), 26.07% ($P<0.01$), −49.05% ($P<0.01$) decrease in grain yield per plant, respectively. Elevated O_3(CF50, CF100 and CF200) resulted in significant decrease in the number of filled grains per plant——a consequence of an O_3−induced reduction in the number of ears per plant (−1.91%, −6.55%, −16.68%, respectively), in the number of filled grains per ear (−5.22%, −17.92%, −26.45%, respectively) and increase in the number of unfilled grains per ear (30.4%, 62.57%, 157.85%, respectively). However, there were no significant effects of exposure to elevated O_3 on the 1000 grain DW except a reduction (P<0.01) of the 1000 grain DW induced by 200 nl/L O_3(−16.99%). The decrease in grain yield per plant, coupled with the reduced above ground biomass and root biomass per plant, resulted in a large impact of elevated O_3 on both the straw yield and the total biomass per plant. The partitioning of dry matter between the grain and the straw (i.e. HI) was not changed significantly by elevated O_3 exposure except CF200 treatment.

2.3 Exposure-crop response

Grain yield per plant in each treatment was calculated and plotted as relative to the yield of CFA treatment. In Fig.3 it was shown that the linear model was able to accurately predict the relative grain yield as a function of the seasonal (July-September) 7h (9:00−16:00)-daytime mean O_3 concentration ($R^2=0.991$). It was calculated that yield losses of 10% occured at seasonal daytime mean concentration of 46.9 nl/L O_3. In Fig.4 it is shown that the relatively grain yield also well regressed in linearity against AOT40 ($R^2=0.971$). The estimated accumulated O_3 exposure corresponding to a grain yield loss of 10% was at 12930 nl/(L·h) for AOT40.

Table 1 Effects of elevated O_3 on the yield components of rice plant

No.	Yield component	Treatment			
		CFA	CF50	CF100	CF200
1	Ears per plant	2.20 ± 0.25^a	2.16 ± 0.17^a	2.06 ± 0.19^a	1.83 ± 0.12^b
2	Grains per ear	96.1 ± 11.52^a	91.1 ± 9.41^b	78.9 ± 10.62^c	70.7 ± 9.32^d
3	Infertile florets per ears	3.82 ± 1.26^a	4.98 ± 1.34^b	6.21 ± 1.81^c	9.85 ± 2.37^d
4	1000 grain dry weigh, g	25.0 ± 3.1^a	24.7 ± 2.8^a	24.1 ± 2.4^a	$20.8+2.5^b$
5	Grain yield per plant, g	5.28 ± 0.57^a	4.85 ± 0.55^b	3.90 ± 0.47^c	2.69 ± 0.37^d
6	Straw yield per plant, g	5.70 ± 0.41^a	4.78 ± 0.39^b	4.05 ± 0.57^c	3.19 ± 0.46^d
7	Harvest index, %	48.1 ± 7.1^a	50.4 ± 6.3^a	49.1 ± 5.4^a	45.8 ± 4.9^b

Notes: Values represent mean ± SE; $n=60$ for No.2,3; $n=20$ for No.1,5,6; $n=4$ for No.4,7. Different letters after the means indicate significant difference among treatments; $P<0.05$. Harvest index (%) indicate the ratio of the grain DW to the total above ground DW

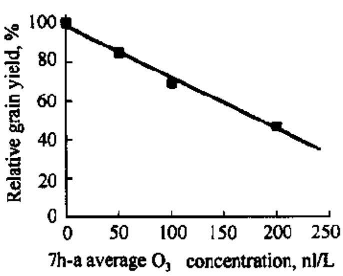

Fig.3 Linear regression for the relative grain yield of rice plant as a function of the seasonal (July-September) 7h-daily mean O_3 concentration
Model equation: $y=-0.259x+102.12$ ($R^2=0.991$); where y is relative yield (%) and x is mean O_3 concentration.

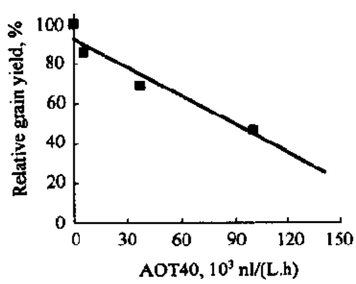

Fig.4 Linear regression for the relative grain yield of rice as a function of AOT40
Model equation: $y=-0.465x+96.01$ ($R^2=0.971$); where y is relative yield (%) and x is AOT40

3 Discussion

The productivity of rice, the most commonly cereal in China, was found to be significantly decreased as a result of exposure to elevated concentration of O_3 in the open-top chambers. The most common strain of rice in the US was found to be relatively insensitive to O_3(Adams, 1988). However, our data suggest that common strains of rice used in China are considerably sensitive. Interestingly, the detrimental impacts of the 50 nl/L O_3 on plant often occurred before any typical visible symptoms of O_3 damage were observed-supporting the view that visible damage is not a reliable index for the effects of O_3 on the growth and yield of plant(Davison, 1998).

The reduction in grain yield per plant induced by O_3 was the result of (1) a decrease in the number of ears per plant; (2) a decrease in the number of grains per ear; (3) a increase in the unfilled grains per ear and (4) decreases in the 1000 grain DW or the harvest index under 200ppb treatment. No significant effect of O_3 pollution the 1000 grain DW or the harvest index was found under 50ppb or 100ppb treatment in the present study. The reduction in individual grain size has been related to decreased photosynthesis, accelerated flag leaf senescence, and/or a limitation to the translocation of photoassimilates from the flag leaf. In the present study, CF200 treatment significantly altered K (− 61.6%) or HI (− 4.8%), indicating there were significant influence on the priority of biomass allocation, and shortening the growth period-premature about 4 days ahead compared to CFA treatment. Those results caused a large decreases in the 1000 grain DW and the grain yield per plant (− 17% , − 49% , respectively).

Regression analyses showed that the relative grain yield of rice was correlated linearly with the 7h-daily mean O_3 concentration and AOT40. Considering the ambient daytime O_3 concentration in site, was very probably beyond 47 nl/L which may an cause 10% yield losses, about 30 − 80 nl/L (data not shown in detail here) from July to September. Thus, the ambient O_3 concentration is sufficiently high to cause adverse effect on rice in the open field to large extent.

Finally, the deposition of O_3, and thus the dose, is restricted by a number of resistance in the crop field (Leuning, 1979), which be different from those in OTC. The boundary layer conditions around the exposed plants may allow a faster O_3 deposition compared to the canopy boundary layer in the cultivated field (Heagle, 1988). Thus, the yield loss observed in this experimental system could probably be overestimated compared to that in the natural field situation. Reich suggested that O_3 uptake by plants may be a more suitable parameter accounting for O_3 effects on the plant than O_3 concentration itself (Reich, 1987). Thus, at present, lack of knowledge concerning O_3 uptake by plant in the chamber may impose some limitations to the predictive capacity of the OTC as a test system for a quantitative estimation of crop loss due to the O_3 air pollution.

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