Impacts of Tropospheric Ozone on Growth and Yield of Rice (*Oryza sativa* L.)

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Abstract

Sixteen rice cultivars (Koshihikari, Nipponbare, Akitakomachi, Hitomebore, Toyonishiki, Kinuhikari, Asanohikari, Sainokagayaki, Sakihatamochi, IR8, Boro8, Dawn, Te-tep, M401, Lemont and WSS-2) were exposed to three levels of ozone (O_3): $< 8 \text{ nl l}^{-1}$, ambient levels, and $\times 1.5$ ambient levels in growth chambers placed at the Center for Environmental Science in Saitama (Kisai, Saitama Pref.) for 100 days between 29 June and 6 October 2003. The average concentration of O_3 in mid-day (0900-1700h) and the accumulated exposure to O_3 above a threshold of 40 nl l^{-1} (AOT40) in the mid-day during experimental period was 41.0 nl l^{-1} and $37.71 \mu\text{l l}^{-1} \text{ h}$, respectively. The rice growth and its yield were reduced by exposure to O_3 . However, the reduction rate of yield affected by O_3 was different among cultivars. In addition, the reduction rates of yields in Japanese rice cultivars were smaller than those in other cultivars. According to the prediction maps of yield-loss of rice affected by O_3 in the Kanto district, Japan by using the method of AOT40 - yield of rice response relationship, yield-loss in Japanese rice cultivars were about 25-35% larger compared with ambient O_3 concentration.

Key words: Growth, Ozone, Prediction maps, Rice (*Oryza sativa* L.), Yield

1. Introduction

Industrial emissions of NO_x and volatile organic compounds have led to increasing tropospheric ozone (O_3) concentration (Penkett, 1988). The O_3 is recognized as a widespread phytotoxic air pollutant (Chameides *et al.*, 1994), and many experimental studies have shown that O_3 causes reductions in photosynthetic activity and dry matter production of crop plants (eg. Fuhrer *et al.*, 1997). In Japan, relatively high concentrations of O_3 have been detected, especially in urban areas, such as the Kanto district, and may be closely related to reduction of growth and yield of crops (Kobayashi, 1988).

Rice (*Oryza sativa* L.) is one of the most primary agricultural crops in Japan. There are studies on effects of O_3 on rice growth and yield (Asakawa *et al.*, 1981, Kats *et al.*, 1995). Although the extent of O_3 damage is different among cultivars of plants (Izuta *et al.*, 1999), information about the influence of O_3 on rice cultivars yield is rather limited. In addition, O_3 dose - crop growth or yield response relationship have been derived in Europe and America (Fuhrer, *et al.*, 1997). The concept of using the AOT (accumulated exposure to O_3 over a threshold) to define long-term O_3 exposure has been demonstrated to be appropriate for several types of vegetation (Fuhrer, *et al.*, 1997). However, there are few

reports which evaluated the influence of O_3 on Japanese crop cultivars using the AOT concept (Kobayashi, 1999).

The object of this research is to evaluate sixteen cultivars sensitivity to O_3 , and to make prediction maps of yield-loss of rice affected by O_3 in the Kanto district, Japan by using the method of O_3 dose (AOT) - yield response relationship.

2. Materials and Methods

2.1 Plant materials and stress treatments

Sixteen cultivars of rice (*Oryza sativa* L.) were exposed to three different concentrations of O_3 in growth chambers in 2003. Japanese rice cultivars of 'Koshihikari', 'Nipponbare', 'Akitakomachi', 'Hitomebore', 'Toyonishiki', 'Kinuhikari', 'Asanohikari', 'Sainokagayaki' and 'Sakihatamochi', and other rice cultivars, originated from Southeast Asia and America, of 'IR8' (Philippine), 'Boro8' (Pakistan), 'Lemont' (America), 'M401' (America), 'Dawn' (America), 'Te-tep' (Vietnam) and 'WSS-2' (Vietnam) were used for this experiment. The Japanese rice cultivars in our experiment were collected as relatively major cultivars in the Kanto district. All the rice seeds were obtained from the Saitama Prefectural Agriculture and Forestry Research Center. Rice seeds were pre-germinated in

water for 4 days, three seeds sown into each plastic pots (30 cm in depth $\times$ 25 cm in diameter) filled with sand and grown in a greenhouse. After 10 days, the seedlings were moved into chambers and were then grown for 100 days from 29 June to 6 October 2003. Fertilizer (N-P-K=8:8:8) was applied before sowing at 8.9 g per pot. The growth chambers (3.2 m² of growth space and 2 m in height; OTC-type 180, Koito Co. Japan) were located at the Center for Environmental Science in Saitama (36°04'N, 139°31'E; Kisai, Saitama, Japan). three levels of O₃ treatments described above were designated as charcoal-filtered air (CF), non-filtered air (NF) and proportional addition of O₃ to achieve 1.5 times ambient O₃ levels (1.5NF).

The concentration of O₃ at the plant canopy height in each treatment was continuously monitored at 6-minute intervals with an UV absorption O₃ analyzer (Model 1100, Dylec Inc., Japan). The O₃ was generated from ambient air with an electrical discharge O₃ generator (MO-5A, Nippon Ozone Co., Japan), and was then injected into the 1.5NF treatment during daytime. Average O₃ concentration and the accumulated exposure to O₃ over a threshold of 40 nl l⁻¹ (AOT40) for 8 hours (from 0900 to 1700h local time) in CF, NF and 1.5NF treatments are shown in Table 1.

On 6 October 2003 (100 days after treatment), all rice cultivars were harvested. Leaves and panicles from harvested plants were separated. Panicles were threshed to obtain the grain number and grain weight per plant.

2.2 Prediction maps

The data of O₃ concentration from 1990 to 2000year in the Kanto district (Tokyo Metropolitan, Saitama Prefecture, Kanagawa Pref., Chiba Pref., Gunma Pref., Tochigi Pref. and Ibaraki Pref.) was provided from the 'Hourly Ambient Air Quality Data File' of Atmospheric Environmental Regional Observation System in the National Institute for Environmental Studies. Data of photochemical oxidant (O_x) concentration was considered as data of O₃ concentration, because its monitoring system recorded O_x concentration only. The number of monitoring stations of O_x concentration in Tokyo, Saitama, Kanagawa, Chiba, Gunma, Tochigi and Ibaraki were 43, 59, 40, 67, 17, 20, and 31, respectively. In each monitoring station, the average AOT40 was calculated by using the data of hourly O₃ concentrations for 8 hours (from 0900 to 1700h local time) during the growth period for 100 days between 1990 and 2000year. The process of estimating for AOT40 in 2050year is described below. The increase rate of average hourly O₃ concentrations for 8 hours (from 0900 to 1700h local

Table 1. Average O₃ concentration, and the accumulated exposure to O₃ over a threshold of 0 and 40 nl l⁻¹ (AOT0 and AOT40) for 8 hours (between 0900 and 1700h local time) in CF, NF and 1.5NF treatments during the experimental period of 100 days from 29 June to 6 October 2003.

Treatment	Ave. O ₃ con. (nl l ⁻¹)	AOT0 (μ l l ⁻¹ h)	AOT40 (μ l l ⁻¹ h)
CF	5.0	4.75	0
NF	41.0	37.71	12.30
1.5NF	58.3	53.57	28.89

time) during the growth period for 100 days per year was calculated by using linear regression based on the data of hourly O₃ concentrations from 1980 to 2000year. And then, at each monitoring point, the average hourly O₃ concentrations and AOT40 in 2050year was estimated. Analyzing and mapping of these data were done by ArcGIS™ 8 (Arc View 8 and Spatial Analyst, ESRI Japan., Japan). The tension type of spline methods for estimation and interpolation of the values of O₃ concentration among monitoring points were used.

2.3 Statistical analysis

The statistical analyses were performed with an SPSS statistical package (SPSS 10.0.5J, SPSS Japan Inc., Japan). The means were calculated from the three replicate blocks, and each block consisted of four seedlings. The grain yield relative to yield at the CF treatment was tested for best liner fit against the O₃ dose (AOT40).

3. Results and Discussion

3.1 O₃ concentration and temperature

During the growth period of 100 days, the AOT40 in CF, NF and 1.5NF treatments were 0 μ l l⁻¹ h, 12.30 μ l l⁻¹ h and 28.89 μ l l⁻¹ h, respectively (Table 1). In the NF treatment, the O₃ concentration was a relatively an average level compared with recent five years (data not shown). On the other hand, average daily air temperatures were 22.3°C in July and 25.5°C in August, and 23.3°C in September in 2003year. Compared with the recent five years' average temperature, low temperatures were recorded (-3.4°C in July, -1.6°C in August, and -0.4°C in September).

3.2 Growth and yield

Figure 1 illustrates the leaf number (a), the grain number (b), and the grain yield (c) relative to rice cultivars yield at the CF treatment. Table 2 shows the linear regression between relative grain yield at the CF treatment and AOT40, because the use of 40 nl l⁻¹ O₃

Fig. 1 Effects of O_3 on the leaf number (a), grain number (b), and grain yield (c) relative to yield at the CF treatment of rice cultivars. The accumulated exposure to O_3 over a threshold of 40 nl l^{-1} for 8 hours during the growth period of 100 days (AOT40) in CF, NF and 1.5NF treatments were 0, 12.3 and $28.9 \mu\text{l l}^{-1} \text{ h}$, respectively (Table 1).

(giving the AOT40) as a threshold concentration gives a good linear fit to the growth or yield responses of plants (Fuhrer, *et al.*, 1997). The reduction rates in all measurements were increased by the exposure to O_3 . However, growth responses (the number of leaves and panicles) affected by O_3 were different from yield responses (the number of grains, and grain yield). Younglove *et al.* (1994) reported that response of plants to O_3 changed during phenological growth stages. Especially, O_3 exposures occurring before flowering and during pod filling may substantially affect yield (Kout and Laurence, 1983). We were unable to clarify the reason for the change in the responses by O_3 fumigation, but similar works demonstrate that physiological responses were different among some crop cultivars (eg. Izuta *et al.*, 1999). Furthermore, the reduction rates of yields in the Japanese rice cultivars were smaller than those in other cultivars originated from Southeast Asia and America. In Japanese rice cultivars, the sensitivity to O_3 on yield was high in order of 'Akitakomachi', 'Sakihatamochi', 'Koshihikari', 'Asanohikari', 'Hitomebore', 'Sainokagayaki', 'Nipponbare' and 'Kinuhikari'. 'Koshihikari', the cultivar with the largest planted area (37%) in Japan (Ministry of Agriculture, Forestry and Fisheries of Japan, 2004), had a relatively high O_3 sensitivity on grain yield among Japanese rice cultivars. On the other hand, in other rice cultivars, the sensitivity to O_3 on yield was high in order of 'IR8',

'WSS-2', 'M401', 'Te-tep', 'Dawn', 'Lemont' and 'Boro8'.

Table 2. Linear regression between relative grain yield at CF treatment (%; Y_g) and AOT40 ($\mu\text{l l}^{-1} \text{ h}$; D). The data originated from Fig. 1. Japanese rice cv. means Koshihikari, Nipponbare, Akitakomachi, Hitomebore, Toyonishiki, Kinuhikari, Asanohikari, Sainokagayaki and Sakihatamochi. other rice cv. means Lemont, M401, IR-8, WSS-2, Boro8, Te-tep and Dawn. p value: $^{\dagger} p < 0.1$, $^* p < 0.05$, $^{***} p < 0.001$.

Cultivar	Regression line	Coefficient (R^2)
All 16 cultivars	$Y_g = -0.95D + 99.7$	0.60 ^{***}
Japanese rice cv.	$Y_g = -0.67D + 99.3$	0.69 ^{***}
Other rice cv.	$Y_g = -1.31D + 99.6$	0.76 ^{***}
Koshihikari	$Y_g = -0.82D + 99.5$	0.99 [*]
Nipponbare	$Y_g = -0.49D + 102.1$	0.83
Akitakomachi	$Y_g = -1.06D + 97.2$	0.93
Hitomebore	$Y_g = -0.61D + 99.0$	0.96
Toyonishiki	$Y_g = -0.63D + 100.4$	0.99 [*]
Kinuhikari	$Y_g = -0.21D + 99.6$	0.96
Asanohikari	$Y_g = -0.72D + 98.6$	0.96
Sainokagayaki	$Y_g = -0.53D + 98.9$	0.96
Sakihatamochi	$Y_g = -0.89D + 103.2$	0.88
Lemont	$Y_g = -1.03D + 102.4$	0.94
M401	$Y_g = -1.37D + 93.3$	0.79
IR-8	$Y_g = -1.77D + 95.4$	0.93
WSS-2	$Y_g = -1.71D + 102.3$	0.98 [†]
Boro8	$Y_g = -0.85D + 98.9$	0.98 [†]
Te-tep	$Y_g = -1.37D + 104.3$	0.90
Dawn	$Y_g = -1.07D + 100.5$	0.99 [*]

Fig. 2 Prediction map of yield-loss in Japanese rice cultivars in the Kanto district, Japan by using the method of AOT40 - rice yield response relationship (Table 2). (a) Ambient level of O_3 (Average AOT40 during 1990 to 2000). (b) Increasing of O_3 (AOT40 computed the prediction of O_3 concentration in 2050).

3.3 Prediction maps

Figure 2. illustrates prediction maps of yield-loss affected by O_3 in the Kanto district by using the method of O_3 dose (AOT40) - yield of rice response relationship (Table 2). Japanese rice yield was reduced about 5-10% by ambient O_3 concentration. In the areas of Tokyo, Saitama and Gunma, relatively higher reduction rate of rice yield was observed. On the other hand, according to the prediction of yield-loss in 2050 year, the reduction rate of rice yield would be larger in almost all the Kanto area, and its would be about 25-35% large compared with the ambient levels of O_3 . Especially, rice yield in the areas of Gunma and Ibaraki would be reduced by exposure to O_3 . In the present study, the prediction of yield-loss of rice was based on the result of an average of nine Japanese cultivars, but 'Koshihikari' with the largest planted area (64%) in the Kanto district had a larger yield reduction rate affected by O_3 . Thus, it is possible that the estimation of yield loss would be an underestimate. We predicted using only one experiment, but experiments over many years are required to raise the accuracy of the prediction.

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