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Growth and Yield Responses of Two Rice Cultivars to Ozone Treatment under Different Nutrient Supply

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ABSTRACT : Two rice cultivars of the japonica type, ozone-resistant Ilpumbyeo (IL) and and ozone-susceptible Keumobyeo#1 (KM) were exposed to ozone (O_3) at 0.15 ppm for 30 days. The available nutrient regimes were varied by doubling the supply of nitrogen (N), phosphorus (P) and potassium (K) within a basic fertilizer status (N, P, K; 15, 12, 12 kg $10a^{-1}$). There was little difference on plant height between ozone-treated and nontreated plants. The most significant ozone stress on tiller number was shown on the 30th day of ozone exposure. Slight recovery from ozone stress was noted on the 60th day. On the 30th day, tiller number was greatly decreased by 40.8% in IL and 64.6% in KM, whereas at a high nitrogen supply regime (2N), it was decreased by 21.4% in IL and 42.7% in KM as compared to the control not treated with ozone at basic fertilizer status. The inhibition of tiller production caused by ozone exposure was alleviated on the 60th day. In both cultivars, number of spikelets per plant and weight of 100 grains were affected little by the ozone treatment irrespective of nutrient regime. However, the number of panicles per plant and yield were reduced significantly. In both cultivars, yield of ozone-treated plants with 2N status was 12.4-16.1% higher than that of the ozone-treated plants with basic nutrient status. A significant yield decrease of 47.8% and 33.4% was observed for IL and KM, respectively, in ozone-treated plants with higher potassium (2K) status.

Keywords : fertilizer, nutrient supply, ozone, rice, yield components

The effect of ozone pollution stress on the productivity of many plants has been of concern for several decades (Heagle *et al.*, 1998; Slaughter *et al.*, 1989). Current ambient levels of ozone are known to be high enough to visibly damage sensitive vegetation, impair plant growth and reduce crop yields in many parts of the world and any further increase is expected to intensify the detrimental effect of the pollutant on sensitive terrestrial ecosystems. When plants are exposed to ozone, their susceptibility is affected by a variety of environmental factors. High carbon dioxide (CO_2), humidities, temperatures or photosynthetically active radiation increase plant sensitivity to ozone (Barnes and Pfirrmann, 1992; Miller *et al.*, 1998). While drought, low humidities, reduced temperatures and either low light or darkness decrease plant sensitivity (Cox, 1984; Rao *et al.*, 1992).

Aside from ozone pollution stress, nutritional disorders also are serious constraints to the stability of crop production. The effect of nutrient supply and ozone stress on plant growth and productivity have been determined separately for a large number of species (Nouchi *et al.*, 1991; Salim and Saxena, 1991; Barnes and Pfirrmann, 1992). However, very little attention has been paid to the interaction between ozone pollution stress and different combinations of nitrogen (N), phosphorus (P) and potassium (K).

The experiment was carried out to : (a) investigate the effect of long term exposure to ozone with an ambient level ozone on the plant height, dry weight, total content of nutrient, number of tiller and yield components, (b) evaluate the effect of the interaction between ozone stress and nutrient supply on growth and yield, and (c) compare two rice cultivars, IL (resistant to ozone) and KM (susceptible to ozone), in terms of growth response and yield.

MATERIALS AND METHODS

Plant materials and fertilizer levels

Two rice cultivars (IL and KM) belonging to the japonica group were used in this study. Sohn and Lee (1997) reported that IL was resistant to ozone and KM was susceptible. Seeds were pregerminated for 48 hr in tap water in the dark at 30°C. Then, 100 g of rice seeds was sown in a seedling tray (30 × 60 × 2.6 cm). Ten days after sowing, seedlings were transplanted with three plants per pot, into a wagner pot (1/5000a). The soil on each pot was fertilized with four levels; B (N, P, K; 15, 12, 12 kg $10a^{-1}$), 2N (N, P, K; 30, 12, 12 kg $10a^{-1}$), 2P (N, P, K; 15, 24, 12 kg $10a^{-1}$) and 2K (N, P, K; 15, 12, 24 kg $10a^{-1}$), where B is the basic fertilizer level. Each pot was watered once or twice everyday. Experiments

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were carried out in three replicates.

Ozone treatment

Twenty days after transplanting, the plants were exposed everyday to a mean ozone concentration of 0.15 ppm. This was half of the ozone concentration alarm system in Korea. Exposure to ozone lasted 6 hr (10 a.m. to 4 p.m.) daily from June 1 until June 30. The pots were randomly rotated everyday within the chamber to increase the uniformity of ozone exposure among plants. Ozone generator and monitoring system is presented in Table 1.

Growth and yield components

Rice plants were harvested on 10, 30 and 60 days after 30 days of continuous ozone exposure for the measurement of plant height and the number of tillers. To measure dry weight and nutrient content, plants were sampled on the 30th day after 30 days of ozone exposure. Harvested plants were dried in an dry oven at 80°C for two days and then weighed. Dried samples were ground with 5 ml of 60% nitric acid (HNO_3) and mineral nutrient contents were determined using the ICP spectrophotometer (USA).

Yield and yield components data such as number of panicle, number of spikelets per panicle, 100 grains weight and ripening ratio were obtained 60 days after 30 days of ozone exposure.

The statistical design was used split plot design with three replications. Data on plant height, number of tiller, dry weight, yield and yield components data were compared by least significant difference test ($P \leq 0.05$).

Table 1. Ozone generator and monitoring system.

Classification	Function
Ozone generator	
Ozone fumigated velocity	0~4 g/hr^{-1}
Air volume	10 l/min^{-1}
Ozone measuring instrument	
Ozone measuring range	0.00~9.99 $\mu l\ l^{-1}$
Ozone monitoring instrument	IN-2000 UV absorption analyzer
Chamber	
Mode	Open-top chamber
Dimension	200 × 100 × 150 cm

RESULTS

Plant height and number of tillers

Data summarizing the effects of ozone and fertilizer treatments on plant height and number of tillers of the two rice cultivars, ozone-resistant IL and ozone-susceptible KM are presented in Tables 2 and 3. In both cultivars, it was observed that ozone had no significant effect on plant height on the 10th, 30th and 60th day after 30 days of ozone exposure except for IL on the 30th days. On sixty days after 30 days of ozone exposure, plant height of KM with basic fertilizer status had increased by 12% compared to the control (not-treated with ozone at basic fertilizer level). Number of tillers produced per plant was significantly lower on 30 days after 30 days of ozone exposure at basic fertilizer level compared to the control in both cultivars. Particularly, the number of tillers of KM with basic fertilizer level was decreased by

Table 2. Effect of ozone and fertilizer levels on plant height and number of tiller in Ilpumbyeo.

Treatment	Fertilizer (N-P-K kg/10a)	Days after ozone treatment					
		10		30		60	
		Plant height	Tiller	Plant height	Tiller	Plant height	Tiller
Ozone	15-12-12	99.7†	65.4†	101.4†	59.2†	104.2†	91.5†
	30-12-12	94.7	73.3	95.9	78.6	110.3	87.0
	15-24-12	91.1	70.9	97.7	68.4	107.3	70.6
	15-12-24	90.9	90.3	96.7	80.7	101.2	87.7
	Mean	94.0	74.0	97.9	70.5	105.7	83.5
Control	Mean	100	100	100	100	100	100
LSD(5%) – between means of ozone treatment :		1.6	2.1	ns	2.3	1.7	1.4
– between means fertilizers withinof ozone treatment		1.5	1.1	2.3	1.4	ns	1.4

†The unit represents percent against control.

Table 3. Effect of ozone and fertilizer levels on plant height and number of tiller in Keumobyeo.

Treatment	Fertilizer (N-P-K kg/10a)	Days after ozone treatment					
		10		30		60	
		Plant height	Tiller	Plant height	Tiller	Plant height	Tiller
Ozone	15-12-12	89.7†	89.2†	98.5†	35.4†	112.0†	85.4†
	30-12-12	97.6	88.0	96.7	57.3	105.0	85.0
	15-24-12	95.4	79.4	95.6	68.7	100.9	89.3
	15-12-24	89.6	100.0	96.7	72.3	110.7	100.0
	Mean	93.0	88.9	96.8	56.1	104.0	90.0
Control	Mean	100	100	100	100	100	100
LSD(5%) : – between means of ozone treatment		2.3	ns	2.0	1.8	1.3	ns
– between means of fertilizers with ozone treatment		2.1	1.1	1.3	ns	1.2	2.3

†The unit represents percent against control.

Table 4. Effect of ozone and fertilizer levels on dry weight in rice.

Treatment	Fertilizer (N-P-K kg/10a)	Ilpumbyeo		Keumobyeo	
		30 DAT†‡	60 DAT‡	30 DAT‡	60 DAT‡
Ozone	15-12-12	66.6†	94.0†	50.2†	86.0†
	30-12-12	69.1	81.7	53.9	84.0
	15-24-12	90.8	97.0	89.1	90.0
	15-12-24	95.5	100.0	77.7	88.4
	Mean	78.4	92.0	64.6	87.1
Control	Mean	100	100	100	100
LSD(5%) : – between means of ozone treatment		0.5	ns	0.3	1.9
– between means of fertilizers with ozone treatment		1.0	2.4	0.6	1.3

†The unit represents percent against control
‡DAT; days after ozone treatment
§above soil part dry matter weight except panicle.

reduced the detrimental effects of ozone on the number of tillers. On sixty days after 30 days of ozone exposure, the number of tillers IL and KM with 2N status increased by 18% and 41% compared to control, respectively. Similar tendencies were found in 2P and 2K treatments.

Dry weight

The effects of altered fertilizer supply and ozone treatment on dry weight were investigated at two growth periods. The first period was 30 days after 30 days of ozone exposure because this period showed the greatest ozone effect among the investigated dates. The second period was 60 days after 30 days ozone exposure (Table 4). Compared with IL, dry weight of KM which is ozone-susceptible was more significantly affected by the ozone treatment. On thirty days after ozone exposure at basic fertilizer level, the dry weights of IL and KM were reduced by 33.4% and 49.8%, respectively. Ozone treatment reduced the dry weight of both rice cultivars at the fertilizer levels, 2N, 2P and 2K status significantly. The dry weight of IL and KM with 2N fertilization was decreased by 30.8% and 46.1%, respectively. At the harvest (60 DAT), ozone-treated plants with high nitrogen (2N) status showed the decreased dry weights of 18% for IL and 16% for KM. Treatments of 2P and 2K showed significantly less reduction of dry weight than those of basic fertilizer and 2N.

Table 5. Effect of fertilizer levels on nutrient concentration at 30 days after treatment in Ilpumbyeo exposed to ozone.

Fertilizer (N-P-K kg/10a)	Nutrient (%)					
	N	P	K	Ca	Mg	Si
15-12-12	116.3†	98.2	133.8	86.7	95.1	111.0
30-12-12	106.7	75.8	93.5	72.2	97.7	104.8
15-24-12	133.1	85.9	115.9	73.5	105.1	97.1
15-12-24	115.7	83.1	100.6	76.9	100.0	93.9
Mean	117.5	85.1	111.1	77.1	97.6	101.3
Control	100	100	100	100	100	100
LSD(5%) : – between means of ozone treatment	0.2	ns	ns	0.2	ns	ns
– between means of ns fertilizers with ozone treatment	ns	0.5	ns	0.4	ns	ns

†The unit represents percent against control.

Table 6. Effect of ozone and fertilizer levels on nutrient concentration at 30 days after treatment in Keumobyeo.

Treatment	Fertilizer (N-P-K kg/10a)	Nutrient (%)					
		N	P	K	Ca	Mg	Si
Ozone	15-12-12	109.2†	91.5†	97.7†	62.5†	102.7†	84.1†
	30-12-12	128.1	69.4	98.0	75.8	112.8	114.2
	15-24-12	110.9	77.6	101.0	72.7	105.1	108.2
	15-12-24	114.3	100.0	94.3	76.7	121.2	105.1
	Mean	115.5	84.8	97.5	71.9	110.8	101.8
Control	Mean	100	100	100	100	100	100
LSD (5%) : – between means of ozone treatment		0.2	0.9	ns	0.3	ns	ns
– between means of fertilizers with ozone treatment		0.2	0.9	ns	0.4	ns	ns

†The unit represents percent against control.

Macro nutrients

As in Table 5 and 6, the macro nutrient concentrations in both IL and KM exposed to ozone were not significantly different in K, Mg, and Si from the control. Ozone-treated IL and KM plants, regardless of fertilizer treatments, showed higher concentrations of N than the control. Meanwhile IL ozone, at all fertilizer levels the two cultivars had lower Ca content than the control.

Yield and yield components

The responses of yield and yield components to ozone treatment in basic fertilizer status were very similar in the two rice cultivars. The yields of IL and KM were decreased by 35.6% and 31.5%, respectively (Table 7 and 8). Number of spikelet per plant was not affected by the ozone treatment at basic fertilizer status, while number of panicle per plant in IL and KM decreased by 20.5% and 23.6%, respectively. Also observed was a slight decrease in the 100 grains weight in the ozone-treated plants with basic fertilizer status in both cultivars. The higher number of spikelets per plant were observed in ozone-treated plants with 2N status compared to the control in IL and KM. The most significant decrease of yield among the treatments was observed in O_3-treated plants with fertilizer treatment of 2K, showing yield decline of 47.8% and 33.4% in IL and KM, respectively.

DISCUSSION

Sohn and Lee (1997) have noted that the response of 75 rice cultivars to ozone exposure for 2 to 4 hr at 0.3 ppm were

Table 7. Effect of ozone and fertilizer levels on yield and yield components in Ilpumbyeo.

Treatment	Fertilizer (N-P-K kg/10a)	Panicle	Spikelet	100 grain wt.	Ripening ratio	Yield
Ozone	15-12-12	79.5†	100.0†	94.8†	85.5†	64.3†
	30-12-12	91.9	108.8	92.5	83.4	76.7
	15-24-12	61.8	104.9	95.9	90.0	56.8
	15-12-24	84.1	73.0	92.9	89.1	52.2
	Mean	79.3	96.8	94.1	87.0	63.8
Control	Mean	100	100	100	100	100
LSD(5%) : – between means of ozone treatment		0.9	ns	0.7	7.9	4.3
– between means of fertilizers with ozone treatment		1.8	ns	ns	ns	6.5

†The unit represents percent against control.

Table 8. Effect of ozone and fertilizer levels on yield and yield components in Keumobyeo.

Treatment	Fertilizer (N-P-K kg/10a)	Panicle	Spikelet	100 grain wt	Ripening ratio	Yield
Ozone	15-12-12	76.4†	106.0†	97.0†	87.1†	68.5†
	30-12-12	77.7	126.0	95.7	91.0	84.6
	15-24-12	90.0	109.7	96.9	87.3	83.7
	15-12-24	85.0	89.5	97.7	90.1	66.6
	Mean	89.5	107.1	96.9	89.1	76.1
Control	Mean	100	100	100	100	100
LSD (5%) : – between means of ozone treatment		1.4	ns	0.5	5.7	4.4
– between means of fertilizers with ozone treatment		1.8	ns	0.5	ns	3.8

†The unit represents percent against control.

tested and the resistant and susceptible rice cultivars were classified based on the leaf injury caused by O_3. These researchers indicated that most of the indica and Tongil (indica × japonica) type rice cultivars were more resistant than the japonica type. This study used two rice cultivars belonging to the japonica group, the ozone resistant cultivar IL and the susceptible cultivar KM. It was sought to examine the effect of the interaction of O_3 and different nutrient supplies. The 0.15 ppm ozone used in this experiment represents half the range of concentration in Korean ozone alarm system.

Growth response

The growth response to ozone and fertilizer supply revealed significant difference among the sampling time, 10, 30 and 60 days after 30 days of ozone exposure. The most significant suppression on the number of tiller and dry weight was observed on the 30 days after the 30 days exposure to ozone. Thereafter, growth reduction due to ozone was alleviated on the 60th day. Although little difference were noted in the plant height between ozone-treated plants and the control, dry weight was significantly reduced by ozone exposure irrespective of the rice cultivars resistant or susceptible to ozone. Dry weight of IL and KM (exposed to ozone and with basic fertilizer level) on the 30th day decreased by 33.4% and 69.2%, respectively (Table 4). This result was confirmed in many other plant species such as radish (Reinert & Sanders, 1982), sunflower (Shimizu *et al.*, 1981) and rice (Nouchi *et al.*, 1991). Nouchi *et al.* (1991) reported that exposure to 0.1 ppm ozone reduced the dry weight of whole plants by 50% at 6 weeks, and thereafter the reduction of the dry weight of whole plants was gradually alleviated. Increased fertilizer supply (2N, 2P and 2K level) diminished the dry weight reduction by ozone exposure on the 30 DAT. Fertilizer supply of 2P and 2K level was more effective than 2N fertilizer level in the alleviating dry weight reduction.

Rice yield

Yields in rice are determined by the number of panicles and spikelets per plants and weight of 100 grains. The two rice cultivars had a similar yield response to ozone. Number of spikelets and weight of 100 grains per plant were slightly affected by ozone treatment regardless of fertilizer treatments. However the number of panicles per plant and yield were reduced in both cultivars. IL, the resistant rice cultivar, also had a reduction of yield and number of panicles by 35.6% and 20.5%, respectively. For KM, known as the susceptible rice cultivar, yield was reduced by 31.5% and the number of panicles by 23.6%. Yield of the ozone-treated plants with 2N fertilizer level was 23.3 and 15.4% higher than that of basic nutrient status in IL and KM, respectively. The above results were very closely related with the results of tiller number and dry weight of O_3-treated plants with 2N status. On sixty days after 30 days of ozone exposure, the number of tillers of plants with basic nutrition status as well as higher fertilizer treatments were significantly decreased in the both of IL and KM. This study indicated that the higher nitrogen supply compared to basic nutrition status sustained relatively higher panicle number for IL and number of spikelet per panicle for KM. Pell and Dann (1991) reported that the growth and formation of mycorrhiza were enhanced by the supply of enough nitrogen for growth and repairing of ozone induced disturbances in protein metabolism. Significant decreases in yield by 57.8% and 31% were observed for IL and KM, respectively, in ozone-treated plants with 2K status. Yield decrease in IL was related with the decreased number of spikelet per panicle. These results indicated that for ozone-treated rice plants, higher potassium concentration had more negative effects on rice yield than the basic nutrient status. Tingey *et al.* (1986) reported that ozone exposure increased the concentration of phosphorus and potassium in shoot and root tissues indicating enhanced uptake of these nutrients from the growth medium. Exposure to ozone significantly reduced dry weight in the early phase of growth, affecting the final yield. There was little difference in yield response to ozone between the two rice cultivars IL and KM, although the resistant cultivar IL exhibited higher resistance to ozone than the susceptible cultivar KM during the early growth stage.

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