IMPACT OF AMBIENT AIR POLLUTION ON LOCALLY GROWN RICE CULTIVARS (*ORYZA SATIVA* L.) IN MALAYSIA

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(Received 15 April 2002; accepted 25 November 2003)

Abstract. This study presents the first experimental evidence of the sensitivity of rice plants to ambient air pollution from the Southeast Asian tropical region. Two widely adopted local cultivars of rice (*Oryza sativa* L.), MR84 and MR185, were grown in open top chambers ventilated with charcoal-filtered air and non filtered air, and in adjacent open plots on the campus of University Putra Malaysia. This is located on the south side of the Klang Valley, a rapidly developing area embracing Kuala Lumpur and other satellite cities, but where agriculture remains important The experimental period was from October 2000 to January 2001, corresponding to the main rice growing season in peninsular Malaysia. Adverse impacts on rice growth and yield were observed and were attributed to phytotoxic levels of ambient ozone. There was a clear difference in the sensitivity of the two selected cultivars. A yield reduction of 6.3% was observed for cultivar MR185 ($p < 0.01$) which was largely due to an increase in grain sterility, whilst the yield reduction for cultivar MR84 was not statistically significant. The reasons for these differing responses are discussed, and a comparison of the present findings with crop responses to ozone found under European conditions suggests a higher sensitivity in our study crops. With increasing industrialisation and urbanisation, this study highlights the need for further examination of the sensitivity of a wider range of crops and cultivars to ambient air pollution in this region, and also points to the potential for appropriate cultivar selection to ameliorate impacts.

Keywords: ambient air pollution, Klang Valley, Malaysia, open-top chamber, *Oryza sativa* L., ozone, Southeast Asian countries

1. Introduction

The impacts of air pollution on vegetation have been studied extensively. In particular, tropospheric ozone is recognised as the pollutant most likely to cause widespread crop damage and yield loss, and it has thus been the focus of major coordinated research efforts in the United States and Europe. However, comparatively few studies have been conducted in developing countries. This is a serious omission because of the adverse implications of these impacts in developing countries where there is an increasing demand for crop production in the face of growing populations, and rapid deterioration of ambient air quality associated with

Water, Air, and Soil Pollution **154:** 187–201, 2004.

industrialisation and urbanisation (Marshall *et al.*, 1997). In addition, many of these countries are situated in the equatorial region with high temperatures and high levels of solar radiation which are particularly conducive to the formation of photochemical pollutants such as ozone (O_3) (Ashmore and Bell, 1991).

Asia currently has more than half of the total population of developing countries (ADB, 2000) and evidence from the last 30 yr clearly shows that countries in the Asia and the Pacific region have been developing at a faster rate than anywhere else in the world (UNEP/EAPAP, 1997). Rice is undoubtedly the most important crop in the region as production accounts for more than 90% of total world output, of which over 99% was in South, Southeast and East Asia in 2000 (FAO STAT, 2002).

Despite differences in methodologies adopted, adverse impacts on rice growth and yield have been commonly observed in response to air pollutants in other Asian countries such as Japan (Asakawa *et al.*, 1981; Nishi *et al.*, 1985), India (Nandi *et al.*, 1985; Anbazhagan *et al.*, 1989a; Anbazhagan and Bhagwat, 1991; Tripathi and Tripathi, 1992) and Pakistan (Maggs *et al.*, 1995; Wahid *et al.*, 1995). Nevertheless no studies have been carried out in Southeast Asian countries, where rapid industrialisation, urbanisation, growth of motor traffic, and their associated pollutant emissions are taking place simultaneously, in close proximity to agricultural areas. This study investigated the responses of two Malaysian local rice cultivars to current ambient air pollution levels in an urban fringe area of Kuala Lumpur. This is situated in the Klang Valley, and is fairly typical of many Southeast Asian urban fringe areas where agricultural crops could be exposed to a mixture of phytotoxic pollutants including nitrogen dioxide and ozone from neighbouring cities.

2. Materials and Methods

2.1. OPEN TOP CHAMBER SYSTEM AND TREATMENT

The experimental site was located inside the Universiti Putra Malaysia (UPM) campus, approximately 20 km south of Kuala Lumpur. This site is typical of other peri-urban agricultural areas in the region, without specific pollution point sources.

Six open top chambers were constructed with aluminium pipes, PVC sheet and Perspex®, which are available locally. They were of octagonal shape, 1.9 m high, with a basal area of 2.74 m^2 and 5.2 m^3 capacity. The diameter of the open-top end of the chamber was 0.74 m, and its edge was tilted slightly inwards in order to minimise the ingress of ambient air. A half cylinder shaped length of Perspex® (diameter 0.2 m), containing 144 holes was constructed around the bottom of the chamber wall to act as a manifold. All chambers were pre-checked that they had a similar air exchange rate of 3.0–3.4 times per minute with installation of appropriate filters. Two types of filters were used, a charcoal filter (Emcel filters, U.K.) and a dust filter constructed of layers of cotton cloth sandwiched between fine plastic mesh (1 × 1 mm). The cotton cloths were replaced every 2 weeks and the chamber walls were washed every week.

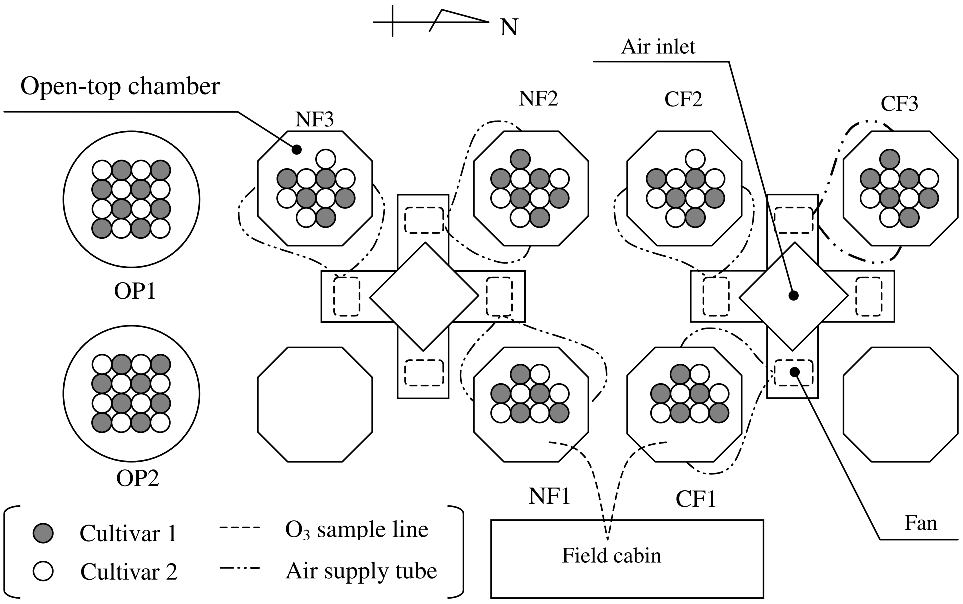

Figure 1. Diagram of the experimental site.

Figure 1 shows the diagram of experimental site. There were three treatments, namely charcoal filtered air in open top chambers (CF), non-filtered air treatment in open top chambers (NF) and chamberless outside plots (OP). Outside plots were prepared to assess any chamber effects; they were adjacent to the open top chambers and were identical except for the absence of chambers and their ancillary equipment. The filtration treatment was operated from 08:00–20:00 hr daily, which covered the whole daylight period of plant growth. During the experimental period, lightening strikes interrupted the electric supply and thus the experimental filtration system for several hours on a number of occasions. However the impact on the results was considered minimal because these incidents were always accompanied by heavy rain when the concentration of air pollutants and the temperature were relatively low. As a result, a total of 1177 and 1129 hr of filtration was carried out for two experimental cultivars, corresponding to 91.2 and 92.4% of their daylight period over the entire plant life. The charcoal filter efficiencies were 53.8, 34.5 and 65.5% for O_3, NO_2 and SO_2, respectively.

2.2. PLANT CULTURE

The experiment was conducted from 20 September 2000 to 25 January 2001, which corresponded to the main rice growing season in peninsular Malaysia. Rice cultivars MR84 and MR185 were selected because of their local agricultural importance, which accounted for over 90% in Selangor state and more than 80% of rice production in peninsular Malaysia during the 1998/1999 main season (Department of Agriculture Malaysia, 2000b). Rice seeds were obtained from the Malaysian Agricultural Research and Development Institute and Department of Agriculture. In order to mimic local paddy rice cultivation, plants were grown in pots (approximately 25 cm in diameter and 20 cm in depth without holes). Clay based soil from the nearest paddy field (Tanjung Karang, Kuala Selangor) was filled up to 7–10 cm below the top. Ten seeds were sown directly into each pot on 20 September 2000. After successful germination, seedlings of uniform size were selected and thinned down to one plant per pot at 9 days after emergence (9DAE). At this point, pots were flooded with water, giving a depth of water of approximately 7–10 cm from the top. Plants were then placed in the experimental plots and chambers, and filtration commenced on 4 October 2000 (10 DAE). The standard farming practise was employed for water management, fertiliser and pesticide application (Department of Agriculture, Malaysia, 1999). At the end of the experiment, a single destructive harvest was carried out from 13 to 15 January 2001 for MR185 (at 111 to 113 DAE) and from 21 to 25 January 2001 for MR84 (at 119 to 123 DAE) when the plants completed their final maturity.

2.3. MICROCLIMATE, AIR POLLUTION AND PLANT DEVELOPMENT MEASUREMENT

During the filtration treatment, hourly temperature and relative humidity (Thermic 2001A, Eto Denki, Japan), were measured more than once a week in total of 24 days and hourly photon flux density (PFD) (LI-COR LI-189, LI-COR, U.S.A.) every Monday in total of 15 days. Recording was carried out manually in selected plot from each treatment in turn due to the lack of an automated system. Air pollution monitoring also concentrated on non-filtered (NF) and charcoal filtered (CF) plots since a pre-experimental measurement proved that differences in O_3 and NO_2 concentration between NF and OP plots was minimal (0–3 ppb) and pollution uptake by the system (Amiro *et al.*, 1984) was negligible. Moreover, chambers of the same treatment shared a common inlet and the quality of air drawn to these chambers was considered identical. Air pollution monitoring was carried out in the chambers adjacent to the field cabin, which housed a continuous UV photometric O_3 analyser (Dasibi 1008-PC, Dasibi, U.S.A.) to monitor O_3 for a total of 60 days during the course of experiment. Diffusion tubes (Gradko International, England) monitored weekly nitrogen dioxide (NO_2) concentration (Palmes *et al.*, 1976). For sulphur dioxide (SO_2), the titration method (air pump as HS-7, Kimoto, Japan) with hydrogen peroxide adjusted to pH 4.0 solution was used (AEA Technology, 1999). The monitoring for SO_2 was implemented for 09:00–17:00 hr for an average of twice a week in total of 27 days during the experiment due to limited access to laboratory facilities at the experimental site. The sampling inlet was regularly adjusted to the plant height.

Parameters for plant development were selected so that they would be comparable to other rice studies from different regions. Weekly measurements consisted of leaf number, tiller number, panicle number and percentage of the leaves with more than 50% senescence. At final harvest, yield parameters such as number of total, filled and unfilled grain, total grain weight, 1000 grain weight, harvest index (grain yield/total dry weight) were obtained in addition to dry weights of leaf blade, leaf sheath, stem, root, panicle. The dry weight was determined after drying the material in an oven at 70–80 °C for 3 to 4 days until the weight became constant.

2.4. FINAL REPLICATION AND STATISTICAL ANALYSIS

The experimental design was a one-way completely randomised design. 16 plants were initially assigned for each treatment. However, six rogue plants showed characteristics of ‘paddi angin (wind paddy)’, rice plants which have a distinctly high plant height and very low yield because most grains of these plants are dropped immaturely (Department of Agriculture, Malaysia, 1999). In addition, the result of Dixon’s test (Sokal and Rohlf, 1998) on two damaged plants showed 8 and 10 out of all measured parameters as outliers ($p < 0.05$) (data not shown). Thus, 8 plants in total were considered not to represent the assigned cultivars and were excluded from the analysis. Ultimately, the final viable replication for cultivar MR84 and MR185 consisted of 15 plants for both from the outside chamberless (OP) plots, 12 and 15 plants from the non-filtered treated (NF) plots and, 16 and 15 plants from the charcoal filtered treated (CF) plots, respectively. All collected data were subjected to statistical analysis. Every plant was regarded as a single replicate and circulated both inside and across the chambers of the same treatment every day in order to achieve complete randomisation (Milliken and Johnson, 1984). Normality and homogeneity of variance were examined for viable samples and appropriate transformation of data was also applied if necessary (Day and Quinn, 1989; Sokal and Rohlf, 1998). A single classification analysis of variance (ANOVA) F test and unplanned multiple comparison with Tukey’s honest significant difference (HSD) test were used. Where non-normality or heterogeneity of variance still occurred after transforming data, Welch’s ANOVA (W test) and T3 method for multiple comparisons were used since these are known to be statistically robust to deal with this situation (Day and Quinn, 1989). All analyses were run with the software, STATISTICA® (version 5.5a StatSoft Inc., U.S.A.) and Microsoft Excel® (2000 Microsoft, U.S.A.)

3. Results and Discussion

3.1. AIR POLLUTION CLIMATE AT EXPERIMENTAL SITE

In the present study, the 8 hr mean O_3 concentration on monitoring days was 32.5 ppb and average diurnal hourly mean concentration exceeded 40 ppb during the early afternoon (Figure 2) with an hourly maximum level of 90.8 ppb. These O_3 levels were regarded as likely to be phytotoxic on the basis of evidence from

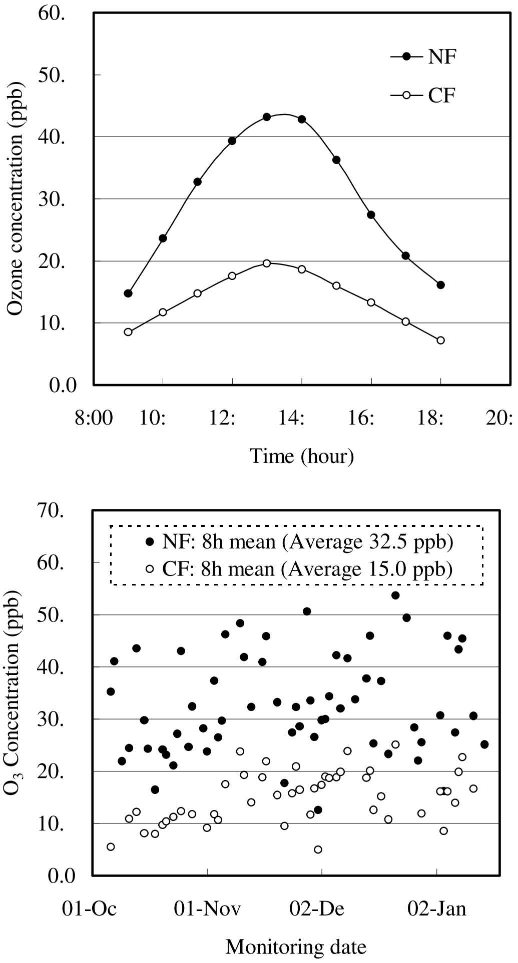

Figure 2. Ambient air pollution monitoring data of ozone (bottom) and hourly average concentration of ozone (top), during the rice growing season, October 2000–January 2001, at UPM site.

previous studies in other regions. The AOT40 value, i.e. accumulated hourly O_3 exposure over a threshold of 40 ppb (Grünhage *et al.*, 1999), was calculated as 2990 ppb hr for cultivar MR185 and 3007 ppb hr for cultivar MR 84. On days when there was no monitoring, appropriate hourly concentrations were calculated from the average of the days monitored most closely before and after. The AOT40 values obtained were close to the European critical levels expected to cause a 5% yield reduction for agricultural crops, which is 3000 ppb hr for daylight hours during three summer months (UNECE, 1996). These data are a cause for concern, particularly in the context of the apparent deterioration of air quality in the region. Ozone monitoring in 1985, showed seasonal maximum hourly mean concentrations of 30 ppb in both Kuala Lumpur and at the UPM monitoring station (Abidin *et al.*,

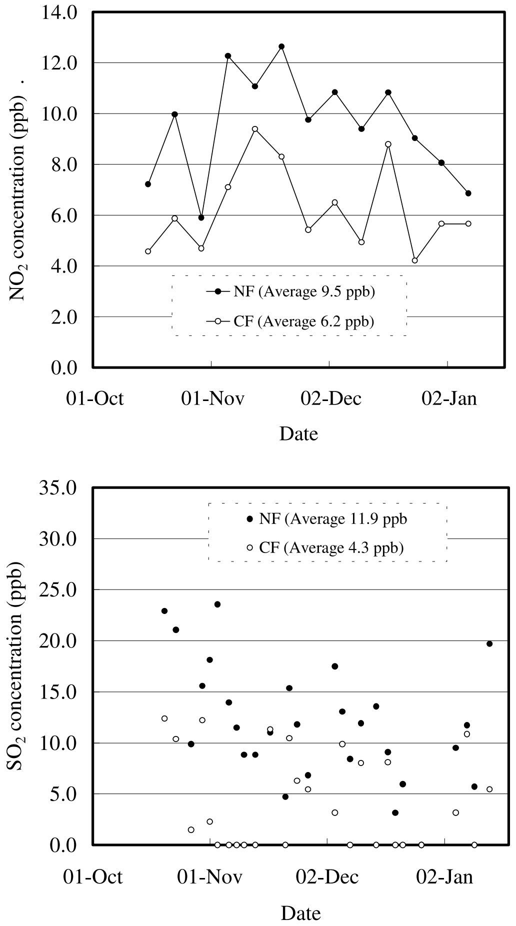

Figure 3. Ambient air pollution monitoring data of nitrogen dioxide (top) and sulphur dioxide (bottom) during the rice growing season, October 2000–January 2001, at UPM site. Note: zero value given for sulphur dioxide concentration indicated undetectable level.

1988), whilst in the current study, the mean ozone concentration at UPM exceeded 40 ppb.

The concentrations of other potentially phytotoxic pollutants, namely NO_2 and SO_2, were relatively low (9.5 ppb for weekly and 11.9 ppb for daytime 8 hr mean, respectively) (Figure 3). As it was assumed that an annual mean concentration of these pollutants would be similar or lower level than these because little seasonal variation is expected for NO_2 (Abidin, 1996) and SO_2 concentration are likely to be lower during the night due to less traffic movement, they were regarded to be under the WHO European Air Quality Guidelines for protecting agricultural crops (approximately 16.0 ppb for NO_2 and 11.5 ppb for SO_2) (WHO, 2000). In addition, research findings from other rice studies might support the hypothesis that at these levels, there is unlikely to be either any direct adverse impact on crop yield, or

TABLE I

Comparison of morphological parameters of reference plants

Parameters	cv. MR84		cv. MR185	
	Reference	Experiment	Reference	Experiment
Growth duration (days)	115	119–123	112	111–113
Plant height (mm)	800–850	935.7–985.9	830	896.5–932.8
Number of tillers	13–17	20	13–16	19–20
Total grain number per panicle	121–130	102–111	140	124–131
1000 grain weight (g)	26.0	18.9–20.0	25.3	19.4–19.5

indeed any synergistic impact in combination with the ozone present. For example, open top chamber studies with three Californian cultivars of rice found no direct effect of SO_2 fumigation with 50 ppb (24 hr mean) over 15 weeks (Kats *et al.*, 1985). Also, Maggs and Ashmore (1998), working with Pakistani rice cultivars found no impact of NO_2, either singly or in combination with O_3 on final plant growth or yield after fumigating with an average of 24–26 ppb (24 hr mean) over 42 days in greenhouse chambers.

Increasing trends of NO_2 and SO_2 levels have also been an observed since 1985, though it was not as dramatic as O_3. Data from UPM in 1985 showed that the seasonal mean of NO_x (measured as the sum of NO and NO_2) was just above 10 ppb and SO_2 concentrations were less than 5 ppb (Abidin *et al.*, 1988).

3.2. Plant responses to air pollution

The phytotoxic levels of O_3, combined with relatively low levels of other phytotoxic pollutants at the experimental site, clearly indicate that the adverse impacts (see below) on local rice cultivars found in the unfiltered air as compared with the filtered chambers were due to O_3.

A significant grain yield reduction of 6.3% was found with an estimated AOT40 value of 2990.0 ppb hr for cultivar MR185 ($p < 0.01$). The degree of impact observed for this cultivar might suggest that the European critical level for agricultural crops (5% reduction by AOT40 3000 ppb hr) (UNECE, 1996) might be a good indicator for impacts on Malaysian crops. However, it is possible that Malaysian crops could be more susceptible to O_3 than European ones, because rice is known to be relatively insensitive to air pollution compared to other agricultural crops (Katase *et al.*, 1983; Heagle, 1989). Thus, it might be expected that ambient O_3 levels could induce larger impacts on other locally grown crops (Department of Agriculture, Malaysia, 2000a) such as long bean (*Vigna sinensis* L.), leaf mustard (*Brassica chinensis* L.) and Chinese spinach (*Amaranthus spp.*).

TABLE II

Growth parameters of cultivars MR84 and MR185

	Treatment		
	OP	NF	CF
cv. MR84			
Sample number	15	12	16
Maximum tiller number	43.1±0.80^{a}	37.7±0.87^{b}	37.9±0.54^{b}
Maximum leaf number	213 (+11.7, –11.1)^{a}	200 (+6.2, –6.0)^{ab}	199 (+5.2, –5.1)^{b}
Maximum panicle number	20 (+1.7, –1.6)	20 (+1.0, –0.9)	20 (+0.8, –0.8)
Maximum plant height (mm)	935.7±13.37^{a}	985.9±7.63^{b}	971.8±5.08^{b}
Panicle initiation date (DAE*	90±0.4^{a}	87±0.7^{b}	86±0.7^{b}
cv. MR185			
Sample plant number	15	15	15
Maximum tiller number	42.3±1.12^{a}	34.7±0.73^{b}	35.4±0.73^{b}
Maximum leaf number	213.6±4.00^{a}	191.5±3.27^{b}	194.7±2.38^{b}
Maximum panicle number	19.1±0.39	19.4±0.32	19.9±0.26
Maximum plant height (mm)	932.8±6.59	896.5±13.63	916.7±11.72
Panicle initiation date (DAE*)	81 (+2.3, –2.3)^{a}	77 (+0.4, –0.4)^{b}	77 (+2.4, –2.4)^{b}

Values are expressed as means ± s.e., where data transformation was implemented, 95% upper and lower confidence limit are given instead of s.e. in parenthesis; Different letters indicate statistically significant difference at $p < 0.05$.

* Days after emergence of plant.

Sterility is known to be one of the most vulnerable developmental parameters in rice, which can be affected even by wind and temperature (Nishiyama; 1995; Satake, 1995; Tsuboi, 1995), and it was confirmed that the parameter was also readily affected by O_3. The experimental results clearly indicated that the observed yield reductions were primarily due to grain sterility, which was 31.7% higher in the unfiltered air treatment MR185 (Table IV). There was apparently no impact on the grain filling stage as demonstrated by the 1000 grain weight, or on vegetative parameters closely associated with yield (e.g. number of reproductive tillers and grain number per panicle). These findings support some other studies that suggest that rice is particularly sensitive to air pollution in the reproductive phase (Kobayashi and Okada, 1995). On the other hand, the higher sterility found in this particular study might be due to differing estimated AOT40 values experienced before and after heading. The daily estimated AOT40 value (estimated AOT 40 values divided by cumulative period) after panicle emergence evidently increased by 20% for MR84 and 43% for MR185, respectively (Table V), suggesting that the

TABLE III

Dry weight of plant parts of cultivar MR84 and MR185 at final harvest

Dry weight	Treatment		
	OP	NF	CF
cv. MR84			
Leaf blade (g)	12.0 ±0.27^{a}	13.0 ±0.17^{b}	12.6 ±0.15^{b}
Leaf sheath (g)	17.7 (+1.02, –0.97)	17.0 (+0.55, –0.53)	16.7 (+0.67, –0.65)
Stem (g)	10.2 ±0.25	10.1 ±0.19	10.5 ±0.12
Panicle (g)	38.1 ±1.18^{a}	40.7 ±0.96^{ab}	41.8 ±0.43^{b}
Shoot (g)	78.1 ±1.20	80.9 ±1.35	81.6 ±0.70
Root (g)	19.6 (+1.92, –1.75)^{a}	16.1 (+0.78, –0.75)^{b}	19.0 (+1.19, –1.12)^{a}
Total (g)	97.9 ±1.88	97.0 ±1.48	100.8 ±1.09
Root:Shoot ratio	0.25±0.009^{a}	0.20±0.005^{b}	0.23±0.006^{a}
cv. MR185			
Leaf blade (g)	10.4 ±0.31	10.2 ±0.14	10.8 ±0.22
Leaf sheath (g)	17.4 (+0.78, –0.74)^{a}	15.7 (+0.35, –0.34)^{b}	16.3 (+0.55, –0.54)^{b}
Stem (g)	9.3 ±0.17^{a}	8.5 ±0.09^{b}	9.4 ±0.23^{c}
Panicle (g)	42.7 (+2.43, –2.30)^{ab}	40.7 (+1.40, –1.35)^{a}	42.9 (+1.41, –1.37)^{b}
Shoot (g)	79.9 (+2.97, –2.87)^{a}	75.1 (+1.68, –1.65)^{b}	79.5 (+1.17, –1.15)^{a}
Root (g)	30.3 ±0.90^{a}	21.7 ±0.42^{b}	25.1 ±0.89^{c}
Total (g)	110.3 ±1.80^{a}	96.8 ±1.05^{b}	104.6 ±1.01^{c}
Root:Shoot ratio	0.38±0.014^{a}	0.29±0.005^{b}	0.31±0.012^{b}

Values are expressed as means ± s.e, where data transformation was implemented, 95% upper and lower confident limit are given instead of s.e. in parenthesis; Different letters indicate statistically significant difference at $p < 0.05$.

reproductive stage of cultivar MR185 experienced the highest cumulative average daily estimated AOT40 values.

In addition to the impacts on yield, O_3 appeared to have a range impacts on growth and to trigger early senescence in both rice cultivars. There were significant negative impacts on sink organs probably because the plants consumed more photosynthate for protecting against O_3 stress and less carbohydrate was stored in these organs. This was particularly true for sink organs with relatively lower sink activities, so that larger impacts were found in the root and stem dry weight than in other organs. Thus, there was a statistically significant decrease in root dry weight in the unfiltered air treatment (15.3% for MR84: $p < 0.01$ and 13.5% for MR185: $p < 0.01$) in There was also a significant reduction in stem dry weight for cultivar MR185 (9.6% : $p < 0.01$) which was rather higher than the panicle dry weight reduction of 5.1% ($p < 0.05$). No significant negative impacts were observed in

TABLE IV

Yield parameters of cultivars MR84 and MR185 at final harvest

	Treatment		
	OP	NF	CF
cv. MR84			
Total grain no. per plant	2061±60.5	2203±45.3	2193±24.2
Filled grain no. per plant	1759±59.0^{a}	1991±48.9^{ab}	2033±20.2^{b}
Unfilled grain no. per plant	302 (+99.9, –71.8)^{a}	212 (+37.5, –31.7)^{a}	160 (+23.1, –20.1)^{b}
% sterility per plant	14.4 (+4.81, –4.18)^{a}	9.7 (+1.76, –1.63)^{a}	7.3 (+0.92, –0.87)^{b}
Total grain no. per panicle	102±2.3^{a}	111±2.4^{b}	108±1.9^{ab}
Filled grain no. per panicle	86±3.8^{a}	100±2.8^{b}	100±1.7^{b}
Unfilled grain no. per panicle	14±2.0^{a}	11±0.7^{a}	8±0.5^{b}
% sterility per panicle	16.3 (+5.70, –4.94)^{a}	10.0 (+1.84, –1.70)^{a}	7.2 (+0.87, –0.83)^{b}
1000 grain weight (g)	20.0±0.42^{a}	18.7±0.13^{b}	18.9±0.07^{ab}
Yield per plant	35.1±1.27	37.3±0.98	38.5±0.32
Harvest index*	0.45 (+0.046, –0.045)	0.46 (+0.020, –0.020)	0.47 (+0.008, –0.008)
cv. MR185			
Total grain no. per plant	2492±70.8	2460±25.6	2451±38.1
Filled grain no. per plant	1994±56.3^{ab}	1927±20.0^{a}	2054±28.2^{b}
Unfilled grain no. per plant	498±36.8^{a}	533±19.7^{a}	397±21.8^{b}
% sterility per plant	19.8±1.24^{a}	21.6±0.68^{a}	16.1±0.78^{b}
Total grain no. per panicle	131±3.6	127±1.6	124±1.9
Filled grain no. per panicle	104 (+7.2, –6.7)	99 (+3.6, –3.5)	103 (+3.9, –3.7)
Unfilled grain no. per panicle	25 (+3.8, –3.3)^{a}	27 (+2.0, –1.9)^{a}	20 (+2.5, –2.2)^{b}
% sterility per panicle	20.9 (+3.08, –2.92)^{a}	22.4 (+1.54, –1.50)^{a}	16.5 (+1.87, –1.79)^{b}
1000 grain weight (g)	19.5±0.28	19.4±0.10	19.4±0.19
Yield per plant	38.7±0.96^{ab}	37.4±0.45^{a}	39.9±0.56^{b}
Harvest index*	0.48±0.009	0.50±0.003	0.50±0.006

Values are expressed as means ± s.e., where data transformation was implemented, 95% upper and lower confident limits are given instead of s.e. in parenthesis; Different letters indicate statistically significant difference at $p < 0.05$.

* Harvest Index = Yield/shoot dry weight.

the dry weight of leaf blade or leaf sheath for MR185, and for cultivar MR84, the only significant reductions were in root dry weight (Table III). The largest impact on root dry weight is consistent with previous studies from other regions

TABLE V

Different 8 hr mean, AOT40 and daily AOT40 values before and after heading of two Malaysian rice cultivars in the study

Cultivar	Growth stage	8 hr mean (ppb)	AOT40 (ppb hr)	Daily AOT40* (ppb hr d^{-1})
MR84	Before heading	32.5	2163.2	27.0
	After heading	32.5	843.5	32.4
MR185	Before heading	31.9	1754.8	25.4
	After hading	34.1	1238.7	36.4

* Daily ATO40 = daily average of AOT40 value calculated as total AOT40 value during the respective duration/number of days.

(Anbazhagan *et al.*, 1989b; Welfare *et al.*, 1996; Maggs and Ashmore, 1998; Jin *et al.*, 2001), and is presumably due to the fact that sink activity is known to be higher in shoot apices as compared to roots (Wada, 1995).

3.3. INFLUENCE OF CHAMBER EFFECTS

The main purpose of the design of the outside plots in the present study was to assess the extent of plant growth and chamber effects in order to elucidate the validity of the study for the field. The morphological parameters of the experimental chamber plants were very similar to published reference parameters of the same cultivars grown locally in the field (Table I) (Department of Agriculture, Malaysia, 1999). There was also little modification of plant growth as a result of the chambers themselves. However, some impact on plant growth was observed, presumably as a result of the reduced photon flux density in the chambers. The mean reduction in hourly photon flux density on measurement days was in the range 168.1–210.0 μmol m^{-2} s^{-1} (18.5–23.1%) (maximum 451.7–505.3 μmol m^{-2} s^{-1}), which was similar to other reported open top chamber studies (average 12% and up to 20% reduction) (Heagle *et al.*, 1988). Whilst the equipment was not available in the field to measure light saturation curves for the rice plants in this experiment, it would appear from an early study (Griffith, 1996) that the plants grown in the chambers may have experienced light intensities lower than the photosynthetic saturation level. The plants grown in the outside plots were visibly shorter and bushier, they had a significantly high average maximum tiller number (12.5–18.0%) and average maximum leaf number, although the latter was only found to be significant for MR185 (Table II). These plants also had a significantly greater root dry weight (17.8 and 28.4% more for MR84 and MR185, respectively) and 10% greater above ground dry weight for cultivar MR185 (Table III). Influences on yield parameters probably resulted from the above modified vegetative growth under conditions of reduced light intensity.

These modifications in plant growth are consistent with reduced light intensity (Inada, 1993), and this is supported by that the fact that there was very little difference in other micrometeorological parameters. There was a slight increase in mean hourly temperature inside the chambers as compared with the outside plot, (on average of 0.4–0.6 °C and the daily maximum difference by 1.6 –3.3 °C), and in relative humidity (on average by 2.1–2.5% hourly mean values, and the daily maximum difference by 4.7–5.8%). These differences were lower than reported for most other open top chamber studies (Heagle *et al.*, 1988).

4. Conclusion

Although air pollution impacts on vegetation have been studied across several regions, this study provides the first comprehensive experimental evidence of O_3 effects on rice plants from the Southeast Asian region. The results clearly indicate that at ozone concentrations even lower than the Malaysian air quality guidelines (60 ppb 8 hr mean) level, there can be a significant impact on the growth and yield of the popular local rice cultivars MR84 and MR185, due to an increase in grain sterility. The apparent difference in cultivar sensitivity, may be due in part to the higher daily ozone concentration found during the reproductive stage of cultivar MR185.

The evidence that ambient O_3 levels in a suburban area of Kuala Lumpur have consistently increased suggests an increasing threat to crops in this region, and points to the need to make a more comprehensive assessment of air pollution impacts on a range of local crops and cultivars in the region.

Acknowledgements

The authors gratefully acknowledge the support from Professor Dr. Muhammad bin Awang and the Department of Environmental Sciences in Universiti Putra Malaysia for providing the facilities to conduct this study. Warm thanks are also given to the staff in the Malaysian Agricultural Research and Development Institute, the Department of Agriculture of Malaysia and Department of Agriculture in Universiti Putra Malaysia for technical support and advice during the study.

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