Yield response of winter wheat to chronic doses of ozone[1]

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The relative sensitivity of 11 soft red winter wheat, *Triticum aestivum* L. cultivars, exposed as young plants to ambient levels of ozone (O_3) was determined. On the basis of the shoot dry weight response, the cultivar Holly was determined to be significantly more sensitive than Oasis or Coker 47-27; Blueboy II showed intermediate sensitivity. Plants of these four cultivars, grown in pots or in the ground, were exposed for 54 days in open-top field chambers to different O_3 concentrations added to existing levels of ambient oxidants for 7 h/day. The effects of O_3 on foliar injury, growth, and yield were determined. For the four cultivars combined, the threshold O_3 concentration (7 h/day seasonal mean) for significant injury and decreased growth and yield was between 0.06 and 0.10 ppm. For potted plants exposed to 0.10 and 0.13 ppm O_3, seed weight yields were 10 and 27% less, respectively, than for those grown in "charcoal-filtered-air" chambers (0.03 ppm O_3). For plants in the ground exposed to 0.10 and 0.13 ppm O_3, the yields were 16 and 33% less, respectively, than for those at 0.03 ppm O_3. The relative sensitivity of cultivars to O_3 as young plants could not be used to predict O_3 effects on seed yield.

Introduction

Estimates of crop yield losses caused by air pollutants are based primarily on visual estimates of foliar injury (Benedict et al. 1971; Feliciano 1971; Lacasse 1971; Lacasse and Weidensaul 1971; Millecan 1971; Naegele et al. 1972; Pell 1972; Pell and Brennan 1975). However, except for foliage crops, the relationships between leaf injury and yield loss is not well documented (Benedict et al. 1971). The effects of ambient oxidants on crop yields have been determined for only a few species. Recent reviews have emphasized the need for more research (Heck and Brandt 1977; Heck et al. 1977; Phillips and Runeckles 1974; United States Environmental Protection Agency 1978). No reports have been published on the effect on wheat yield of long-term exposure to ambient oxidants.

In greenhouse tests, wheat leaves were relatively sensitive to ozone (O_3), the principle phytotoxic component of ambient photochemical oxidants (Hill et al. 1961; Sechler and Davis 1964). In a field test, yields of winter wheat, *Triticum aestivum* L., "Arthur 71" and "Blueboy" were significantly decreased when plants were exposed to 0.20 ppm O_3 for 4 h/day for 7 days during anthesis (Shannon and Mulchi 1974). In another field test, wheat biomass was decreased from exposure to 0.08 to 0.10 ppm O_3 for 5 h/day but seed yields were not reported (Phillips and Runeckles 1974).

Our objectives were to determine threshold concentrations of O_3 in long-term (chronic) field exposures, required to significantly injure and decrease growth and yield of wheat cultivars. The relative sensitivity of seedlings of 11 wheat cultivars was determined, and 4 cultivars with varying degrees of sensitivity were selected for dose–response studies.

Materials and Methods

Cultivar Sensitivity

Eleven cultivars of soft red winter wheat (Table 1) were tested. Seeds were planted in 3.8-L pots containing a 1:1:1 mixture of sand : Metro-Mix 200[2] : soil (Appling series; clayey, kaolinitic, thermic, Typic Hapludults) on 6 August 1976. Metro-Mix 200 is a mixture of perlite, peat moss, vermiculite, and sand with added nutrients (W. R. Grace and Co., Cambridge, MA). Seedlings were thinned to three plants per pot on 16 August. Plants were watered as needed to prevent wilting. Insects were controlled with one application of malathion and carbaryl.

Five pots of each cultivar (15 plants) were placed randomly on the ground in each of two open-top field chambers (Heagle et al. 1973, 1979). Plants in one chamber were exposed continuously to charcoal-filtered air (CF); those in the other chamber were exposed continuously to nonfiltered air (NF). Ozone at 0.10 ppm (196 μg/m³) was added to existing ambient oxidant concentrations in the NF chamber for 7 h/day (0930 to 1630 hours eastern daylight time (EDT)) for 27 days, starting on 17 August. Ozone was dispensed to the inlet air stream of the NF chamber and was

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TABLE 1. Shoot weight response of 11 soft red winter wheat cultivars exposed in open-top field chambers to charcoal-filtered air (CF) or to nonfiltered air with O_3 added for 7 h/day (NF + O_3)[a]

Cultivar		Shoot dry weight[b]		
Name	C.I. No.	CF (g/plant)	NF + O_3 (g/plant)	Loss from control (%)
Ruler	17314	0.83	0.48	42
Holly	14579	0.64	0.41	36
McNair 4823	15290	0.59	0.39	34
Blueboy II	15281	0.72	0.52	28
Funk W-540	—	0.62	0.45	27
McNair 3001	—	0.61	0.46	25
Coker 68-15	15291	0.60	0.52	13
Oasis	15929	0.66	0.58	12
McNair 1813	15289	0.56	0.49	12
Arthur 81	15282	0.64	0.58	9
Coker 47-27	12563	0.61	0.56	8
LSD (P = 0.05)				23

[a]Plants were exposed for 27 days (11 to 38 days after planting). The mean 7 and 24 h/day O_3 concentrations in the CF treatment were 0.02 and 0.01 ppm, respectively; the comparative values for the NF + O_3 treatment were 0.15 and 0.06 ppm, respectively. At standard temperature and pressure, 1.0 ppm of O_3 = 1960 μg/m³.
[b]Each value is the mean of 15 plants (3 plants in each of 5 pots).

monitored at plant-canopy height in both chambers, using an automatic dispensing and monitoring system described previously (Heagle et al. 1979).

Plants were harvested on 15 September and shoot fresh and dry (70°C, 5 days) weights were measured. Analyses of variance were performed and significant differences between cultivars were identified using the LSD test when the F test was significant (P = 0.05).

Dose Response

Four cultivars were selected on the basis of their sensitivity to O_3 as seedlings and the availability of seed (Holly was more sensitive than Oasis and Coker 47-27 and Blueboy II were intermediate (Table 1)).

An 0.8-ha field was fertilized with (8–8–8, N–P–K) fertilizer at the rate of 113 kg/ha, 2 days before planting. Seeds were planted at the rate of 70 kg/ha on 2 November 1976, using a 12-row grain planter with a 17.5-cm row spacing. The hopper of the planter was partitioned to allow a separate cultivar to be planted in each of three rows. Three four-row strips contained one row of each cultivar in the same sequence.

On 3 November, seeds of each of four cultivars were planted in 3.8-L pots containing the same 1:1:1 mixture used in the cultivar sensitivity test. Potted plants were watered as needed and left outdoors on top of the soil over the winter.

On 15 March 1977, four blocks of field plots were selected on the basis of uniform plant appearance and physical soil characteristics within each block. Each block consisted of five 3 m × 2 m plots. Two blocks were located on Appling soil and two blocks were on Cecil (Typic Hapludults) soil. On 21 to 23 March, plants in the ground were thinned to one plant per 5 to 8 cm and plants in pots were thinned to two per pot. Fertilizer (10–10–10, N–P–K) was broadcast on 29 March at the rate of 321 kg/ha in field plots and 5 g per pot to potted plants. All plants were watered as needed to provide uniform soil moisture and to prevent wilting. Aphids were controlled with malathion on 21 April.

On 28 March, open-top field chambers, 3 m diameter by 2.4 m tall (Heagle et al. 1973, 1979), were placed over four of the five plots in each block. The fifth plot in each block remained in ambient air (AA) with no chamber. Plants in one chamber per block were exposed continuously to charcoal-filtered air (CF). Plants in the remaining three chambers were exposed continuously to nonfiltered (NF) air (particulate filter only). However, from 9 April to 31 May 1977, small constant O_3 concentrations were added to the existing ambient oxidant concentrations in the NF chambers for 7 h/day (0930 to 1630 hours EDT). Addition of 0.02 ppm O_3 (NF-1) resulted in 7-h O_3 curves that resembled ambient air curves by replacing the O_3 lost in the chamber air-handling system. Addition of 0.06 ppm of O_3 (NF-2) or 0.09 ppm of O_3 (NF-3) resulted in 7-h oxidant curves with O_3 concentrations averaging 0.04 and 0.07 ppm, respectively, above ambient.

The experimental design for potted plants resembled that for plants in the ground. Eight pots per cultivar were randomly placed on top of the soil in each of 12 open-top chambers (two pots in each of four chamber quadrants) and in three ambient air (AA) plots on 29 March. This provided three replicates of the five treatments previously described for plants in the ground.

When O_3 exposures began, plants in the ground had five to six leaves and a mean height of 28, 34, 45, and 41 cm in blocks one to four, respectively. Potted plants also had five to six leaves with a mean height of 28 cm. Plant height, growth stage, and foliar injury were recorded once each week for 6 weeks starting on 19 April . Injury (chlorosis and necrosis) was visually estimated in 5% increments (0–100%) on the four uppermost leaves of three plants per cultivar for each treatment in two blocks.

Plants in eight rows per chamber (one row of each cultivar in each half of the chamber) were harvested on 8 to 10 June. Each of the eight rows were subdivided into six 40-cm sections, from which a sample of four plants was harvested at random. Plants in the two outer and two center rows of each plot and those within 20–30 cm of row ends were used only as borders. All potted plants were harvested on 8 to 10 June and the two plants per pot were treated as one sample. The total shoot weight (stems, leaves, and heads) and number and weight of heads were determined at harvest. The heads were threshed by hand and seed weight per sample, weight of 100 seeds, and seed moisture content were measured.

Data from plants in the ground and from potted plants were analyzed separately. Analyses of variance were performed and LSD ($P = 0.05$) tests were used when warranted by significant F tests. Regression analyses were performed to determine relationships between percentage foliar injury and seed yield using the block × treatment × cultivar means.

Results

Cultivar Sensitivity

Foliar symptoms of O_3 injury included chlorosis and small white necrotic areas (flecking), as described previously (Hill et al. 1961). Cultivars differed greatly in their rate of tiller formation making it difficult to identify leaves of a similar physiological age. Therefore, detailed injury estimates were not made. Young leaves of Ruler, Holly, and Blueboy II had bifacial necrosis, but those of other cultivars did not. The interaction between O_3 treatment and cultivars was significant for shoot dry weight but not for shoot fresh weight although the cultivar trends for both weight measures were similar. Ozone decreased dry weight from 42- (Ruler) to 8% (Coker 47-27) (Table 1).

Dose Response

The daily 7-h (0930 to 1630 hours EDT) and 24-h mean O_3 concentrations in the ambient air at our field site near Raleigh, NC, is shown in Fig. 1. The mean 7 h/day ambient O_3 concentration exceeded 0.08 ppm daily from 12 through 20 May, the period during which wheat plants were in the watery ripe to milky ripe stage of development. The highest hourly mean ambient O_3 concentration (0.14 ppm) occurred on 18 May.

The mean diurnal changes in O_3 concentrations for the AA, CF, NF-1, NF-2, and NF-3 treatments are shown in Fig. 2. From 9 April through 31 May, the mean 7 h/day O_3 concentrations for the AA, CF, NF-1, NF-2, and NF-3 treatments were 0.06, 0.03, 0.06, 0.10, and 0.13 ppm, respectively. Differences in mean 7-h O_3 concentrations between replicates for a given treatment were less than 0.010 ppm.

Growth and Injury

Ozone did not affect the flowering date or maturity rate. Plant height was not significantly affected by O_3 in either growth medium except for the last measurement date when potted plants exposed to 0.13 ppm O_3 were 6 cm shorter than those exposed to 0.03 ppm O_3.

The overall injury trends were similar whether plants were grown in pots or in the ground (Table 2). Foliar injury (chlorosis and necrosis) increased rapidly for all O_3 treatments from 1 week before flowering (10 days after exposures began) to the mealy ripe stage (45 days after exposures began) (Fig. 3). Plants in the CF treatment showed chlorosis and necrosis (injury) due to natural senescence. Foliar injury at 0.10 (NF-2) and 0.13 ppm (NF-3) O_3 was significantly greater than that at 0.03 ppm (CF) O_3 on all but the last date when plants in all treatments were starting to mature. In both growth media, mean injury was slightly greater (not significantly) in the NF-1 and AA treatments than in the CF treatment (Table 2).

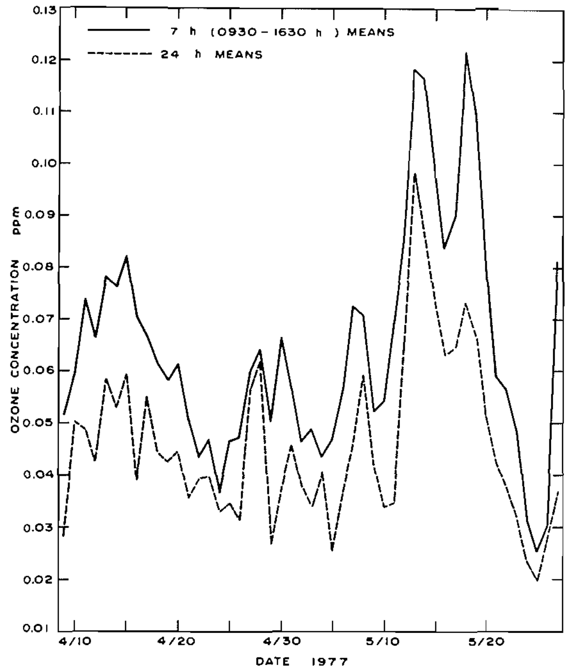

FIG. 1. Daily 7-h (0930 to 1630 hours EDT) and 24-h mean ozone concentrations in ambient air 4.8 km south of Raleigh, NC.

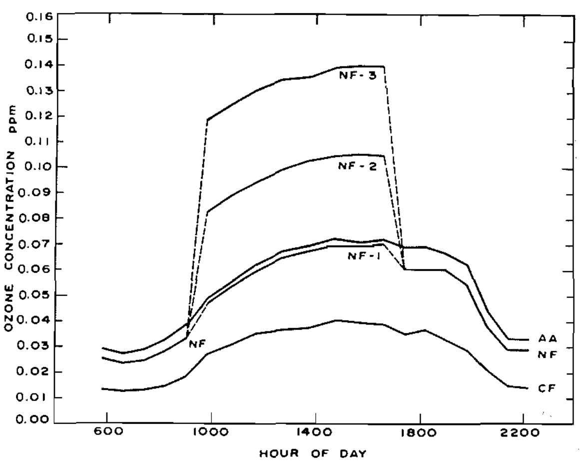

FIG. 2. Mean ozone concentrations from 9 April through 31 May 1977 at different hours of the day in ambient air (AA), charcoal-filtered-air chambers (CF), or in nonfiltered-air chambers with different concentrations of ozone added (NF-1, NF-2, NF-3) for 7 h/day.

TABLE 2. Effect of chronic doses of ozone on foliar injury, growth, and yield of winter wheat grown in pots or in the ground in open-top field chambers[a]

Growth medium[b]	Treatment	Ozone concn., seasonal 7 h/day mean[c] (ppm)	Foliar injury, 5-week mean[d] (%)	Shoot weight per plant (g)	Head weight per plant (g)	Seed weight per plant[e] (g)	100-seed weight[f] (g)
Pots[g]	AA	0.06	25	13.21	6.70	4.77	2.91
	CF	0.03	22	12.08	6.85	5.25	3.08
	NF-1	0.06	25	12.34	7.08	5.34	3.06
	NF-2	0.10	50	11.12	6.18	4.72	3.00
	NF-3	0.13	64	9.96	5.33	3.85	2.62
LSD (P = 0.05)			10.6	0.95	0.75	0.48	0.10
Ground[h]	AA	0.06	33	9.83	5.59	4.25	3.41
	CF	0.03	21	10.74	6.52	5.08	3.49
	NF-1	0.06	26	10.38	6.32	4.90	3.52
	NF-2	0.10	48	9.18	5.65	4.28	3.43
	NF-3	0.13	61	7.62	4.51	3.38	2.87
LSD (P = 0.05)			15.5	1.10	0.42	0.53	0.08

[a]Values show the combined effects for the cultivars Blueboy II, Coker 47-27, Holly, and Oasis.
[b]Data for each growth medium were analyzed separately.
[c]Ozone was added to the inlet duct of nonfiltered-air (NF) chambers for 7 h/day (0930 to 1630 hours EDT) to produce the seasonal 7 h/day mean concentrations shown.
[d]Each value is the mean percentage chlorosis and necrosis from 480 estimates (4 leaves, 3 plants, 4 cultivars, 2 blocks, 5 dates).
[e]Seed weight values reflect a seed moisture content of 12.8%.
[f]The 100-seed weight values for plants in pots are the mean of 36 samples (3 samples of 4 cultivars, from 3 blocks). Values for plants in the ground are the mean of 48 samples (3 samples, 4 cultivars, 4 blocks).
[g]Each value is the mean of 192 plants (4 cultivars, 2 plants in each of 8 pots, 3 blocks), except for foliar injury and 100-seed weight.
[h]Each value is the mean of 768 plants (4 cultivars, 4 plants per 6 samples, 2 rows, 4 blocks), except for foliar injury and 100-seed weight.

For potted plants, the cultivar × treatment interaction for foliar injury was not significant except on the fourth estimate date (data not shown). At this time, Coker 47-27 and Blueboy II were injured more at 0.10 ppm O_3 than were Holly and Oasis. There were no significant cultivar differences in the overall amount of foliar injury (mean injury at the first five estimate dates) for potted plants, although Holly was somewhat more injured than other cultivars at 0.06 ppm O_3 (NF-1) (Table 3).

For plants in the ground, the cultivar × treatment interaction was significant on the second, fourth, and fifth estimate dates (data not shown). On these dates, 0.10 ppm O_3 generally caused significantly more injury to Coker 47-27 than to Blueboy II. This difference is also reflected in the mean overall (5-week mean) injury for plants in the ground (Table 3).

Weight and Yield

The O_3 treatment and cultivar effects were highly significant for all weight parameters measured. For plants in chambers, the threshold O_3 concentrations (7 h/day seasonal mean) was the same (between 0.06 and 0.10 ppm) for all weight parameters measured for plants grown in both media (Table 2). Decreases in weight were slightly greater for plants in the ground than for potted plants. Yields (seed weight per plant) for plants in the ground at 0.10 and 0.13 ppm O_3 were 16 and 33% less, respectively, than yield at 0.03 ppm O_3; the comparative values for potted plants were 10 and 27% less, respectively (Table 2). Trends were similar for the other weight parameters measured. The percentage of yield decrease was slightly greater than the percentage of decrease in shoot weight (heads, leaves, and stalks) or head weight per plant.

The data suggest that yield decrease was caused by both decreased seed numbers and by decreased weight per seed (Table 2). For example, at 0.13 ppm O_3, the mean weight of 100 seeds was decreased by 16% but the seed yield per plant was decreased by 30% (means for plants in both media).

The relative cultivar response to O_3 was different for plants in the two media (Table 3). For potted plants, Holly yield at 0.10 and 0.13 ppm O_3 decreased more than that of most other cultivars. For plants in the ground, Coker 47-27 yield decreased more than that of other cultivars at all O_3 concentrations (Table 3).

Chamber position significantly affected the yield of plants grown in both media (data not shown). For potted plants, yields in the two northern chamber

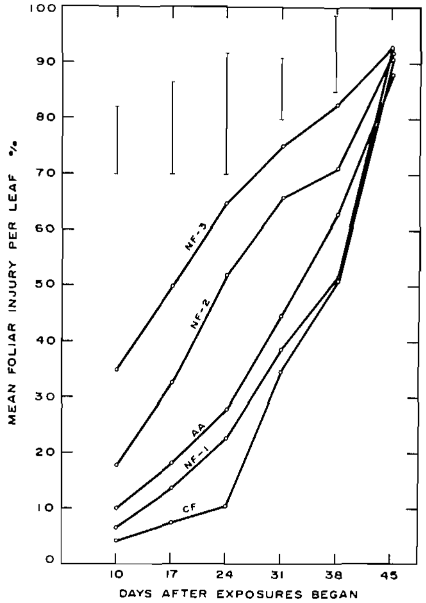

FIG. 3. Foliar injury (chlorosis and necrosis) on winter wheat grown in the ground at 10 to 45 days after exposures began. Plants were exposed to ambient air (AA, 0.06 ppm O_3), charcoal-filtered air in open-top chambers (CF, 0.03 ppm O_3), or to nonfiltered air (NF) in open-top chambers with different concentrations of O_3 added for 7 h/day ((NF-1, 0.06 ppm), (NF-2, 0.10 ppm), (NF-3, 0.13 ppm)). Each point is the mean injury on 96 leaves (4 cultivars, 3 plants, 4 youngest leaves per plant, 2 blocks). The confidence intervals are the LSD ($P = 0.05$) values for treatment.

quadrants were 4% less than those in the two southern quadrants but there were no significant quadrant × O_3 treatment interactions for any of the weight parameters measured. For plants in the ground, the sampling position × O_3 treatment interaction was significant (data not shown). For all treatments, the mean yield was 7% less for plants at the northern edge of the chambers than for those in other sampling positions. At 0.10 and 0.13 ppm O_3, yields of plants at the northernmost sampling position were 20 and 45% less, respectively, than those at 0.03 ppm O_3. For plants in all other sampling positions, the comparative values were 16 and 31%, respectively. There were no significant O_3 treatment × sampling position × cultivar interactions.

Correlations Between Injury and Yield

Linear regression analyses were performed using the block × cultivar × O_3 treatment means for seed weight per plant (yield), weekly mean foliar injury, and 6-week mean foliar injury (data not shown). For plants grown in both media, the correlations were highly significant for each weekly period and for the 6-week mean. For potted plants, correlation coefficients were −0.82, −0.74, −0.71, −0.67, −0.68, and −0.56 for the consecutive individual weekly injury means, respectively, and −0.75 for the overall (6-week mean) injury values; the regression equation for seed weight (y) and overall injury (x) was $y = 6.50 - 0.0367x$. For plants in the ground, correlation coefficients were −0.59, −0.59, −0.55, −0.53, −0.46, and −0.33 for the consecutive weekly means, respectively, and −0.51 for the overall injury values; the regression equation for seed weight (y) and overall injury (x) was $y = 5.78 - 0.0311x$.

Discussion

In this study, plants were treated by adding constant amounts of O_3 to nonfiltered air, rather than to filtered air. Thus, the daily O_3 dose was determined partly by daily and hourly changes in ambient O_3 concentrations. We chose this approach because of the complex nature of photochemical oxidant air pollution. Plant response to O_3 may be affected by other components in the photochemical oxidant complex but little information has been published on the subject. The use of filtered air would interfere with any possible interactions of this type. In most areas, oxidant concentrations change diurnally like those shown in Fig. 2, although concentrations differ daily (Fig. 1), depending on local and regional weather. Relationships between the effects of O_3 on plants at constant and changing levels have not been shown. Therefore, we added small constant amounts of O_3 to the existing oxidant complex.

Previous methods of describing ambient pollutant doses include seasonal means, weekly means, 24-h means, peak hourly means, number of hours above a given concentration, and percentage of time or number of hours above fixed concentration intervals. These methods do not adequately describe the dose biologically because pollutant dose – plant response curves are not linear and plants may respond differently to pollutants at different times during growth. None of these methods consider the timing of exposure at given concentrations in relation to plant growth stage or time of day. In our experience, the 7 h/day (0930 to 1630 hours EDT) and 24 h/day means, adequately characterize the dose biologically. At our field site, the 7 h/day (0930 to 1630 hours EDT) mean O_3 concentration rarely varied by more than ±0.02 ppm from the minimum or maximum concentration during the same period.

Yield reductions from plant exposure to O_3 may have been caused by foliar injury which decreased photosynthesis, resulting in slower growth and a

TABLE 3. Effect of chronic doses of ozone on foliar injury and seed yield of four winter wheat cultivars

Growth medium	Treatment	Ozone concn., 7 h/day mean (ppm)	Foliar injury (%)[a]				Seed weight per plant (g)[b]			
			Blueboy II	Coker 47-27	Holly	Oasis	Blueboy II	Coker 47-27	Holly	Oasis
Pots	AA	0.06	24	18	29	25	4.67	5.07	4.45	4.90
	CF	0.03	21	20	24	21	5.12	5.14	5.61	5.12
	NF-1	0.06	24	21	32	23	5.16	5.53	5.32	5.34
	NF-2	0.10	51	51	46	48	4.64	4.82	4.59	4.85
	NF-3	0.13	62	62	68	62	4.08	3.98	2.97	4.37
LDS ($P = 0.05$)				12.3				0.47		
Ground	AA	0.06	33	23	45	30	4.79	4.01	4.16	4.06
	CF	0.03	24	16	26	20	5.84	5.09	4.95	4.45
	NF-1	0.06	31	21	32	22	5.74	4.55	4.91	4.41
	NF-2	0.10	41	49	52	49	4.97	3.82	4.43	3.89
	NF-3	0.13	59	59	68	60	4.02	2.91	3.30	3.28
LSD ($P = 0.05$)				9.2				0.32		

[a]Each value is the mean overall percentage injury (5-week mean) calculated from 120 estimates (4 youngest leaves on 3 plants per cultivar in 2 blocks on 5 estimate dates).
[b]Each value for potted plants is the mean of 48 plants (2 plants in each of 8 pots in 3 blocks); each value for plants in the ground is the mean of 192 plants (4 plants for each of 6 samples in each of 2 rows in 4 blocks). Seed weight values reflect a moisture content of 12.8%. The LSD values ($P = 0.05$) are for cultivar × treatment.

decreased number and size of seeds. Injury was progressive, beginning on lower leaves and advancing, with continuing exposure, to younger leaves. Possibly environmental alterations caused by the open-top chambers affected the sensitivity of leaves to O_3 but we found that foliar injury of plants in ambient air (7 h/day seasonal mean of 0.06 ppm of O_3) usually did not differ significantly from that of plants in the NF-1 chambers with the same relative O_3 dose (Table 3). There are no reports of significant changes in sensitivity of plants to O_3 caused by environmental variations of the magnitude of differences between the chambers and the field (Heck and Brandt 1977; Heck et al. 1977). Light, measured in the photosynthetically active region (PAR) of wavelengths, averaged 12% less and temperature 0.7°C higher in the chambers than in ambient air (Heagle et al. 1979). The chambers did not affect relative humidity (Heagle et al. 1973) but mean air velocity in the chambers was less than in ambient air (Heagle et al. 1979).

The O_3 treatment × sampling position interaction for plants in the ground was probably caused by the smaller yield at the northernmost sampling position (about 25–65 cm from the chamber frame) in the 0.13 ppm O_3 treatment. Yield of plants at the northern sampling position was somewhat smaller than at most other positions in all chamber plots but the differences were not significant except at 0.13 ppm O_3. The effect may have been due to small differences in air velocity, light intensity, soil moisture, soil fertility, O_3 concentration, or a combination of these factors. Previous studies in open-top field chambers have shown no significant lateral variation in O_3 concentration in field corn (Heagle et al. 1979) or soybean canopies (unpublished data) but this possibility was not tested in the present study. If the wheat yield at the northernmost sampling position was not included, the mean loss at 0.13 ppm O_3 was 31 rather than 33%.

Drought stress is known to decrease plant sensitivity to gaseous pollutants (Heck et al. 1977). Our experiments were conducted during a relatively normal growing season and plants were watered to prevent wilting. Although different results might be obtained in seasons with extreme weather conditions, we feel that effects would be similar during most seasons with similar oxidant concentrations and adequate soil moisture.

Further refinements are needed concerning protocols for screening winter wheat cultivars for sensitivity to O_3. Neither the seedling test or the foliar injury of older plants were good predictors of the relative sensitivity of cultivars to yield loss caused by O_3. These results may be related to changes with age in relative foliar sensitivity of cultivars, to cultivar differences in relative tolerance to foliar injury, or to a combination of these factors. We do not understand why the relative yield loss of cultivars from exposure to O_3 was different in the two media; Holly was the most sensitive cultivar when plants were grown in pots and Coker 47-27 was the most sensitive cultivar when plants were grown in the ground. Much remains to be discovered about how the methods of culture and exposure affect the response of plants to air pollutants.

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