# Thresholds for Injury, Growth, and Yield Loss Caused by Ozone on Field Corn Hybrids

A. S. Heagle, R. B. Philbeck, and W. M. Knott

Plant pathologist and agricultural engineer, Southern Region, Science and Education Administration, US Department of Agriculture, Plant Pathology Department, North Carolina State University, Raleigh 27650; and research associate, Botany Department, North Carolina State University.

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## ABSTRACT

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A commercial field corn (*Zea mays* L.) hybrid 'Coker 16' was exposed to four chronic doses of ozone ($O_3$) in open-top field chambers from 25 days after planting until maturity. The different doses were obtained by adding different but constant concentrations of $O_3$ to the naturally varying ambient concentrations for 7 hr/day (from 0930 to 1630 hours). The threshold $O_3$ concentrations causing foliar injury (between 0.02 and 0.07 ppm) were lower than concentrations required to decrease kernel yield (between 0.11 and 0.15 ppm). These thresholds were the same whether plants were grown in pots or in the ground. In the greenhouse, the sensitivity of Coker 16 to growth effects caused by chronic $O_3$ exposures was intermediate to that of two open-pedigree hybrids. In the field, both open-pedigree hybrids were more sensitive than Coker 16. Exposure to a mean $O_3$ concentration of 0.15 ppm for 7 hr/day decreased kernel yield of the open-pedigree hybrids by 37–40%, but that of Coker 16 was decreased by only 12%.

Chronic doses of ozone ($O_3$) can injure foliage and decrease yield of important crop species (5,6,11,13–15). Yield of sweet corn, *Zea mays* L. 'Golden Midget', grown in field chambers was decreased by daily 7-hr exposures to 0.10 ppm of $O_3$ (0.10 ppm of $O_3$ = 196 $\mu g/m^3$ at 25 C and 760 mm Hg) but not by 0.05 ppm (6). Yield of sweet corn was decreased substantially by exposure of plants to ambient oxidants in open-top field chambers in California (14) and by exposure in a greenhouse to 0.20 or 0.35 ppm of $O_3$ (11). Cameron (2) and Cameron and Taylor (3) showed that sweet corn had high heritability for response to foliar injury from ambient oxidants in California. There are no reports of the effects of ambient oxidants or chronic doses of $O_3$ on field corn.

Fertility levels and growth media greatly affect the sensitivity of plants to $O_3$. Interactions between the different nutrient elements and sensitivity seem complex (1,8), but the exact relationships have not been shown (10). Greenhouse studies with potted pinto bean and tobacco showed that foliar sensitivity to oxidants is greater in plants growing in artificial media such as vermiculite or a mixture of peat and perlite than in plants growing in soil (9,12). However, foliar injury of tobacco caused by ambient oxidants in the field was four to five times less for potted plants grown in a mixture of peat, perlite, and soil than for plants grown in the ground (4). No studies have compared the effects of $O_3$ on yield of plants grown in different growth media.

Previous field studies on the effects of ambient oxidants have been limited to determining the effects of one dose, usually comparing plants grown in carbon-filtered (CF) air with plants grown in air that was not filtered (NF). The relative impact of different doses and the threshold doses for effects on injury, growth, and yield cannot be determined from such studies.

The present research was conducted with field corn to (i) identify the range of sensitivity to $O_3$ of several hybrids in a greenhouse, (ii) determine threshold doses of $O_3$ that cause injury and decreased growth and yield of a commercial hybrid grown in pots or in the ground in field chambers, and (iii) relate the injury and growth effects of $O_3$ in the greenhouse to effects of $O_3$ on yield in the field.



## MATERIALS AND METHODS

**Greenhouse study.**—Five open-pedigree and six commercial field corn hybrids (Table 1) were tested for relative sensitivity to $O_3$. Seeds were planted on 2 February 1976 in 4-liter pots, containing a 1:1:1 ratio (by volume) of sand:sandy-loam soil:Pro-Mix BX. Pro-Mix BX contains peat and perlite with nutrients (Premier Brands, Inc., New York, NY 10017). Plants were thinned to one plant per pot and fertilized 7 days after planting with 2 g of fertilizer (14-4-6, N-P-K). Eight plants per hybrid were exposed to $O_3$ or carbon-filtered air in two field chambers (6) installed in a greenhouse. Plants were exposed to $O_3$ for 7 hr (from 0900 to 1600 hours) for 21 days, starting 14 days after planting. Ozone was generated by ultraviolet light. Concentrations of $O_3$ in chambers were monitored continuously during exposure with a chemiluminescence $O_3$ analyzer (Model 8410A, Monitor Labs Inc., San Diego, CA 92121) calibrated to a 1% neutral buffered KI standard. The mean hourly $O_3$ concentrations during the 21-day exposure ranged from 0.06 to 0.18 ppm. The mean 7-hr $O_3$ concentration was 0.12 ppm (daily range, 0.08–0.17 ppm). Temperature and relative humidity in the greenhouse and exposure chambers ranged from 20 to 25 C and 35 to 70%, respectively. No supplemental lighting was used. One day after exposures ended, we estimated visible foliar injury on individual leaves in 5% increments (0–100%). Fresh weight of the stem and leaves (shoots) were measured. Dry weights of shoots were measured after drying for 2 days at 60 C.

**Field studies.**—*Threshold doses of ozone and effect of plant growth media.*—Seeds of Coker 16 cultivar were sown with a four-row planter on 6 May 1976 in rows spaced 95 cm in a 1.2 ha field of sandy-clay and sandy-loam soil (Cecil and Appling, Typic Hapludults; clayey, kaolinitic, thermic). Fertilizer (14-0-14, N-P-K) was banded along each row at 500 kg/ha at planting. Ammonium nit-

TABLE 1. Injury and growth response of 11 field corn hybrids to chronic doses of ozone in a greenhouse[a]

| Hybrid | Foliar injury[b] (Leaves nos. 5,6,7,8) (%) | Shoot fresh weight[c] Control (g) | Shoot fresh weight[c] Exposed (% loss)[d] |
|---|---|---|---|
| Open pedigree | | | |
| (FR 37 × H 84) × Va 26 | 24 ij | 98.8 | 37 kl |
| FR 632 × H 94 | 33 kl | 74.3 | 30 j |
| FR 632 × FR 619 (OP-1) | 34 kl | 55.8 | 2 h |
| B 73 × MO 17 | 37 l | 61.4 | 28 ij |
| H 95 × FR 64A (OP-2) | 45 m | 71.7 | 63 n |
| Commercial | | | |
| Pioneer 3368A | 18 h | 73.2 | 27 i |
| DeKalb XL43 | 23 hi | 75.3 | 29 ij |
| Coker 16 | 23 hi | 86.3 | 35 k |
| Funk G 4646 | 23 hi | 73.0 | 41 m |
| McNair × 170 | 25 ij | 83.7 | 39 lm |
| DeKalb XL78 | 29 jk | 72.7 | 38 l |
| LSD ($P = 0.05$) = | 5.3 | | 2.8 |

[a] Plants were exposed to carbon-filtered air (control) or to carbon-filtered air plus ozone (mean concentration of 0.12 ppm for 7 hr/day for 21 days, starting 14 days after planting).

[b] These leaves were chosen because no chlorosis or necrosis was present on homologous leaves of control plants. Each value is the mean of 32 leaves (four leaves on each of eight plants per cultivar). Means followed by different letters are significantly different (LSD, $P = 0.05$).

[c] Each value is the mean of eight plants per cultivar. Means followed by different letters are significantly different (LSD, $P = 0.05$).

[d] Percent loss is defined as 100 − (exposed wt/control wt) 100.

rate was applied in a strip along each row at 336 kg/ha, 34 days after planting.

Seeds also were planted on 6 May in 15-liter plastic pots containing a 1:1:1 ratio (by volume) of sandy-loam soil (Appling): sand:Pro-Mix BX. Plants were thinned to one plant per pot 21 days after planting. Each plant was fertilized with 6 g of fertilizer (14-4-6, N-P-K) 24 days after planting and with 5 g of ammonium nitrate 34 days after planting.

Each plot (of a total of 25 in five blocks) initially consisted of two 2.75-m rows of corn. Plants in alternate halves of each row were removed to make room for plants in four 15-L pots. Pots were partially buried leaving the top 5–10 cm uncovered The plants growing in the ground were thinned to about one per each 15 cm of row, leaving seven to eight plants in each of the two alternate 1.38-m rows per plot. Plants were watered to prevent wilting. Corn plants growing adjacent to plots were not disturbed. Weeds were controlled by hand. Insects were controlled with carbaryl (1-napthyl methylcarbamate) or malathion (S-[1, 2-bis(ethoxycarbony)ethyl] 0,0-dimethyl phosphorodithioate) as needed.

Five treatments (one treatment per plot) were randomized in each of the five blocks. One treatment was ambient air (AA) with no chamber. A cylindrical (3-m diameter) open-top field chamber (4,7) was placed over each of the four remaining plots in each block, 22 days after planting. Plants in one chamber per block received CF air continuously. Plants in three chambers per block were exposed continuously throughout the summer to NF air (particulate filter only). Starting 25 days after planting, however, small constant concentrations of $O_3$ were added for 7 hr/day (0930 to 1630 hours). The added $O_3$ resulted in three different $O_3$ curves that followed the daily fluctuations of ambient oxidant concentrations (Fig. 1). One

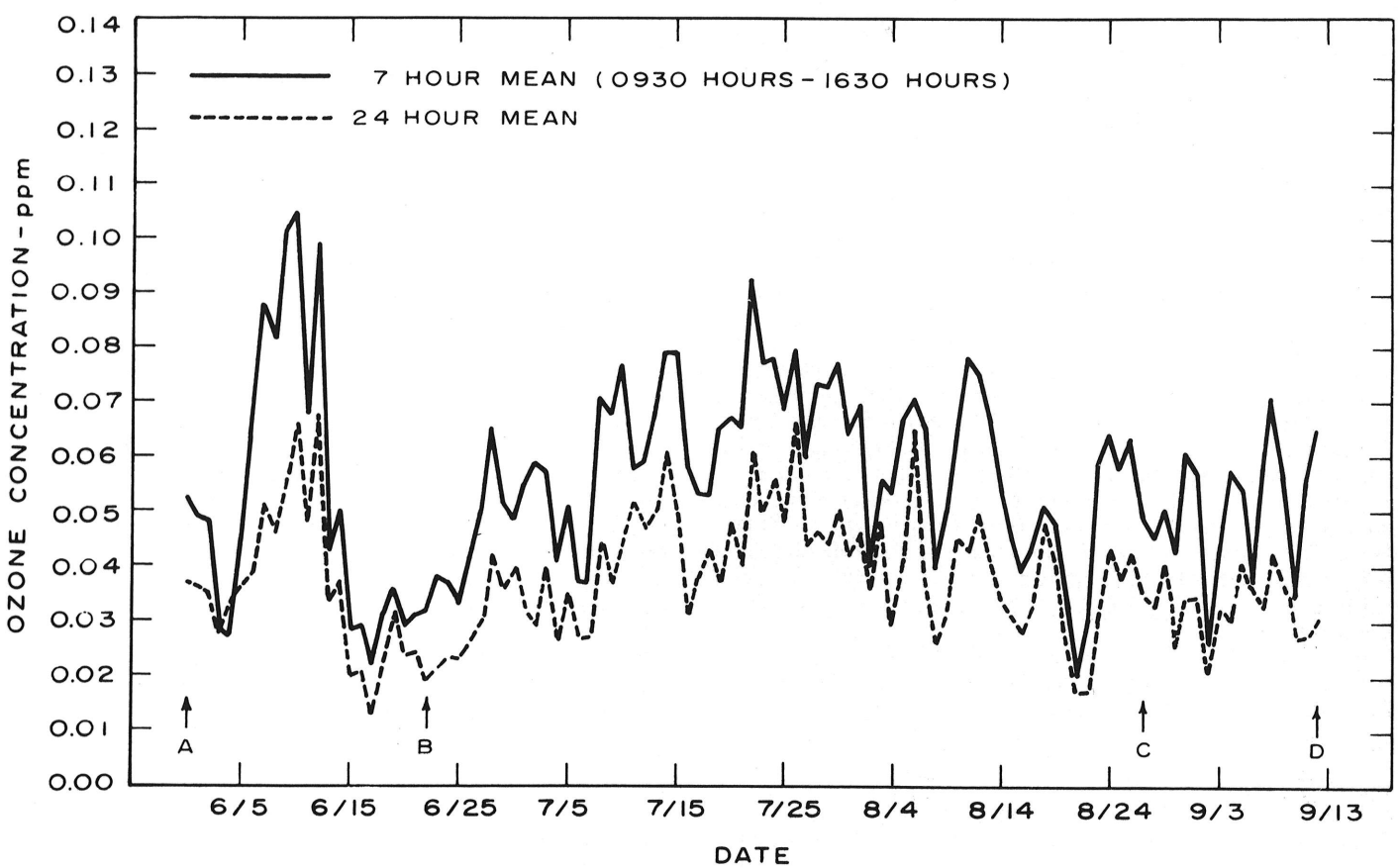


**Fig. 1.** Daily 24 and 7 hour (0930 to 1630 hour) mean ozone concentrations in ambient air 4.8 km south of Raleigh, North Carolina. Ozone was added for 7 hr/day to ambient air in unfiltered-air chambers from 31 May through 27 August (A–C) in the threshold-dose study and from 22 June through 12 September (B–D) in the three-hybrid study.

dose (NF-1) was near ambient concentrations and was obtained by adding 0.02 ppm of $O_3$ to chamber concentrations, thus making up for the $O_3$ lost in the chamber air-handling system. Two higher doses were obtained by adding 0.06 ppm (NF-2) or 0.10 ppm (NF-3) of $O_3$. Ozone was added to the NF-1, NF-2, and NF-3 chambers for 7 hr/day for 88 days (31 May through 27 August).

Ozone was produced and dispensed as described previously (7). Ozone concentrations were monitored from the center of the chamber at midplant canopy height as described previously (7).

Plant height and leaf emergence were measured, and estimates of visible foliar chlorosis and necrosis (injury) on individual leaves were made once each week for 10 consecutive weeks, starting 8 days after exposures began. Eight plants growing in the ground (four in each row) and the eight plants in pots in each plot were labeled to show plant position before harvest. Plants in the ground adjacent to the chamber wall or pots were not used in measuring effects. Plants were harvested 115 days after planting, when leaves of plants in all treatments were brown and a black layer had formed in the kernels. Plant height and fresh weight of ears, with husks and without husks, were measured. Ears were dried to 12.5% moisture content and weighed. The total kernel weight and the weight of 100 kernels per plant were measured. Stovers were dried in the field for 42 days (10–25% moisture content) and weighed.

*Response of three hybrids.*—Plants of Coker 16 cultivar sown on 6 May were removed, and seeds of two open-pedigree hybrids, FR 632 × FR 619 (OP-1) resistant and H 95 × FR 64A (OP-2) sensitive, and Coker 16 intermediate sensitivity were planted on 24 May. Seeds were spaced 15 cm apart in seven 45-cm subrows in two 2.75-m rows in each of three plots in three blocks. The positions of hybrids were randomized in each subrow. Four seeds were planted at each position but plants were thinned to one after 12 days. Plants were fertilized with 336 kg/ha of ammonium nitrate and 336 kg/ha of 10-10-10, N-P-K, 18 and 25 days, respectively, after planting. Coker 16 corn growing in adjacent rows was maintained.

Open-top field chambers were installed on two plots per block 25 days after planting. Plants in one chamber received CF air for 24 hr each day. Those in the other chamber received unfiltered air for 24 hr/day with 0.10 ppm $O_3$ added (NF-4) for 7 hr/day for 82 days, starting on 22 June and continuing through 12 September (29–111 days after planting).

TABLE 2. Mean ozone concentrations for 7 hr per day (0930 to 1630 hours) and 24 hr per day in field studies designed to determine threshold doses of ozone for significant effects on field corn hybrids

| Treatment | Ozone concentrations in: | | | |
|---|---|---|---|---|
| | Threshold-dose study[a] | | Three-hybrid study[b] | |
| | 7 hr/day (ppm) | 24 hr/day (ppm) | 7 hr/day (ppm) | 24 hr/day (ppm) |
| Ambient air | 0.06 | 0.04 | 0.06 | 0.04 |
| Carbon-filtered air | 0.02 | 0.01 | 0.02 | 0.01 |
| Air (not filtered) + $O_3$ | | | | |
| NF-1[c] | 0.07 | 0.04 | ... | ... |
| NF-2[c] | 0.11 | 0.05 | ... | ... |
| NF-3[c] | 0.15 | 0.06 | ... | ... |
| NF-4[c] | ... | ... | 0.15 | 0.06 |

[a] Threshold doses of $O_3$ for effects on injury, growth, and yield of Coker 16 cultivar grown in pots or in the ground were determined. Mean concentrations per treatment cover the period from 31 May through 27 August 1976. At 25 C and 760 mm of Hg, 0.10 ppm of $O_3$ = 196 $\mu g/m^3$.

[b] The effects of $O_3$ on injury, growth, and yield were determined for two open-pedigree hybrids and for Coker 16. Mean concentrations per treatment for 22 June through 12 September.

[c] Ozone was added to ambient concentrations in chambers for 7 hr per day (0930 to 1630 hours). Concentrations in unfiltered air chambers when $O_3$ was not added = ambient air × 0.87.

## RESULTS

**Greenhouse study.**—Foliar symptoms of $O_3$ exposure ranged from interveinal chlorosis and surface necrosis to white bifacial necrosis on all 11 hybrids.

Among the open-pedigree hybrids, H 95 × FR 64A (OP-2) was more sensitive and (FR 37 × H 84) × Va 26 more resistant to $O_3$ injury than others (Table 1). Overall, the commercial hybrids were injured less than were the open-pedigree hybrids. DeKalb XL 78 was comparatively sensitive but Pioneer 3368A was relatively resistant.

The correlation coefficient between shoot fresh and shoot dry weights was 0.97. Therefore, Table 1 shows only shoot fresh weights. Of the open-pedigree hybrids, shoot weight of FR 632 × Fr 619 (OP-1) was 2% less because of $O_3$ and shoot weight of OP-2 was 63% less than the control (Table 1). The range of $O_3$ effects on shoot weight was less among the commercial hybrids than among the

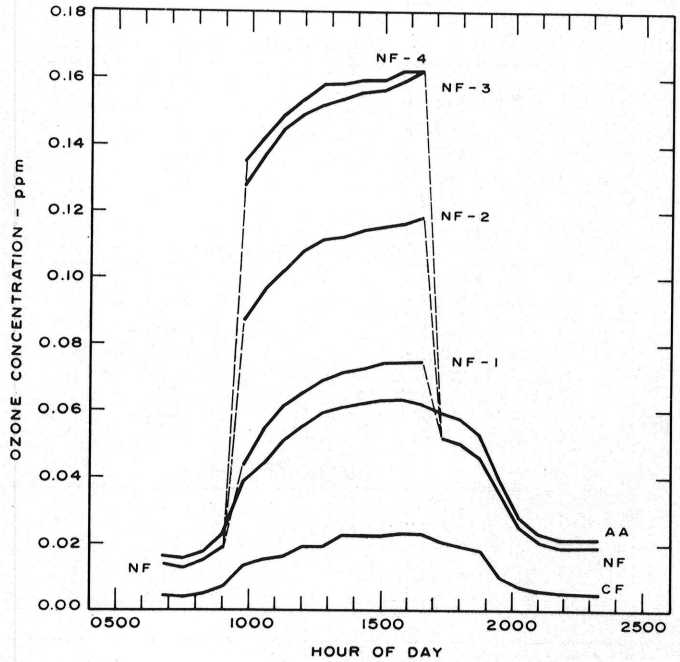


**Fig. 2.** Mean ozone concentrations at different times of the day in ambient air (AA), carbon-filtered air chambers (CF), or chambers in which air was not filtered but in which different concentrations of ozone were added (NF-1, NF-2, NF-3, NF-4) for 7 hr/day. Each point is the mean from 31 May through 27 August 1976 except for NF-4, which is the mean from 22 June through 12 September 1976.

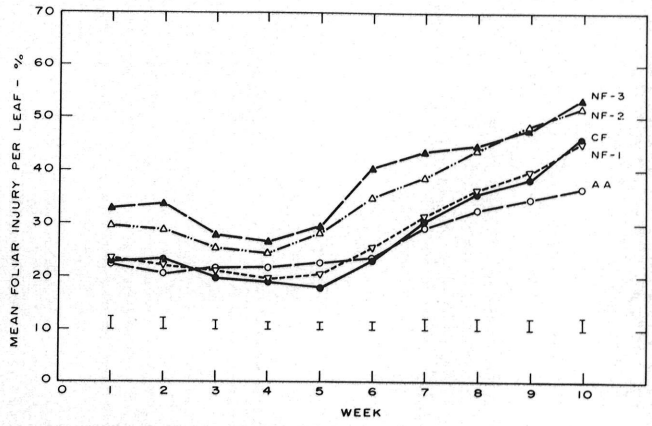


**Fig. 3.** Foliar injury at 10 weekly intervals on cultivar Coker 16 corn grown in ambient air (AA), carbon-filtered air chambers (CF), or chambers in which air was not filtered but in which different concentrations of ozone were added for 7 hr/day (NF-1, NF-2, NF-3). Each point is the mean injury per leaf on 24 plants (three plants in two growth media in each of four blocks). Confidence intervals shown are the LSD ($P = 0.05$) values for treatment × growth media.

open-pedigree hybrids. Shoot weight of Pioneer 3368A was decreased less (27%) and that of Funk G 4646 more (41%) than that of most other commercial hybrids tested (Table 1).

**Field studies.**—*Ozone concentrations.*—Daily fluctuations in the ambient $O_3$ concentrations were plotted as daily 7-hr and 24-hr means (Fig. 1). Except for several rainy days, the 7-hr mean $O_3$ concentration greatly exceeded the 24-hr mean $O_3$ concentration, as would be expected by the diurnal pattern of $O_3$ concentrations (Fig. 2). The overall mean 7- and 24-hr $O_3$ concentrations in AA and those for the various chamber treatments are shown in Table 2. The daily 7-hr mean concentrations for the NF-1, NF-2, NF-3, or NF-4 treatments can be easily determined by adding 0.01, 0.05, 0.09, or 0.09 ppm, respectively, to the daily 7-hr AA means (Fig. 1). The daily 24-hr mean $O_3$ concentrations for the various NF treatments also can be calculated from a common $O_3$ dose (87% of AA) for all NF treatments during the 17-hr period when $O_3$ was not added. For example, the calculation to determine a given 24-hr mean for NF-1 is:

$$\text{24-hr mean for NF-1} = \frac{7\ (\text{7-hr NF-1}) + 17\ (\text{NF 17})}{24}$$

NF 17 is the common 17-hr daily mean for all NF treatments, therefore:

$$\text{NF 17} = \frac{24\ \text{hr AA} - 7\ \text{hr AA}\ (7/24)}{17/24} \times 0.87$$

*Threshold doses of ozone and effects of plant-growth media.*—Symptoms of foliar injury in the field resembled those from greenhouse exposures to $O_3$. The initial symptom was a faint interveinal chlorosis that gradually increased with continuing exposure, often culminating in complete chlorosis.

The percentage injury of plants in pots and in the ground was similar and the percentages were combined for each $O_3$ treatment (Fig. 3). The decreased injury between weeks 2 and 4 was probably due to rapid growth, as well as to relatively low $O_3$ concentrations. The difference in foliar injury between plants in the CF treatment (0.02 ppm) and plants in each of the other chamber treatments is an indication of the amount of injury caused by $O_3$ rather than by normal senescence. The threshold $O_3$ concentration for significant foliar injury of Coker 16 was between 0.07 (NF-1) and 0.11 ppm (NF-2) (Fig. 3). Chlorosis and necrosis of foliage were greater in chambers at 0.07 (NF-1) or 0.02 (CF) ppm $O_3$ than that in the AA (0.06 ppm) treatment from weeks 8 to 10 (Fig. 3).

There were no significant $O_3$ treatment × media interactions for any of the growth or yield measures taken. Plants in chambers were slightly taller than those in the AA treatment (Table 3). Plants near the center of the chambers were slightly taller with slightly greater kernel weight than those nearer the chamber walls, but these differences were not statistically significant. No $O_3$ treatment × chamber position interactions significantly affected growth. The threshold $O_3$ dose for decreased height and weight of stovers was higher for potted plants than for plants grown in the ground (Table

TABLE 3. Growth and yield of cultivar Coker 16 field corn grown in pots or ground in ambient air with no chamber or in open-top field chambers and exposed continuously to charcoal-filtered air or unfiltered air with three levels of $O_3$ added for 7 hr/day

| Treatment[a] | 7-hr daily mean $O_3$ concentration[b] (ppm) | Growth media[c] | |
|---|---|---|---|
| | | Pots | Ground |
| | | Plant height (cm) | |
| AA | 0.06 | 287 j | 312 k |
| CF | 0.02 | 318 h | 343 h |
| NF-1 | 0.07 | 315 h | 333 i |
| NF-2 | 0.11 | 315 h | 338 i |
| NF-3 | 0.15 | 305 i | 323 j |
| | LSD ($P = 0.05$) = | 6.8 | 4.8 |
| | | Weight of stover (g)[d] | |
| AA | 0.06 | 203 i | 194 j |
| CF | 0.02 | 244 h | 257 h |
| NF-1 | 0.07 | 237 h | 217 i |
| NF-2 | 0.11 | 193 i | 196 j |
| NF-3 | 0.15 | 142 j | 133 k |
| | LSD ($P = 0.05$) = | 21.2 | 18.9 |
| | | Weight of kernels (g/plant)[e] | |
| AA | 0.06 | 234.9 h | 221.3 j |
| CF | 0.02 | 240.1 h | 239.1 hi |
| NF-1 | 0.07 | 243.3 h | 245.9 h |
| NF-2 | 0.11 | 239.1 h | 229.7 ij |
| NF-3 | 0.15 | 209.8 i | 201.5 k |
| | LSD ($P = 0.05$) = | 11.0 | 15.5 |
| | | Weight (g/100 kernels)[e] | |
| AA | 0.06 | 32.3 h | 32.2 h |
| CF | 0.02 | 32.3 h | 31.2 h |
| NF-1 | 0.07 | 32.5 h | 31.8 h |
| NF-2 | 0.11 | 32.7 h | 31.0 h |
| NF-2 | 0.15 | 29.9 i | 28.3 i |
| | LSD ($P = 0.05$) = | 1.2 | 1.2 |

[a] AA = ambient air; CF = charcoal-filtered air; NF-1, NF-2, NF-3 = air, not filtered, with three levels of $O_3$ added.

[b] Each value is the mean of 40 plants (eight plants in each of five blocks). Ozone was added to the inlet duct of unfiltered air (NF) chambers for 7 hr/day to produce the 7-hr mean concentrations as shown.

[c] Data for each growth media were analyzed separately. Means for a given response measure and growth media followed by different letters are significantly different according to the LSD ($P = 0.05$) values (treatment).

[d] The moisture content of stovers ranged from 10 to 25%.

[e] The values for kernel weights were adjusted to reflect a moisture content of 15.5%.

TABLE 4. Growth and yield of three field corn hybrids grown in ambient air with no chambers, in charcoal-filtered air in open-top chambers, or in unfiltered-air in open-top chambers with $O_3$ added for 7 hr/day[a]

| Treatment[b] | 7-hr daily mean $O_3$ concentration (ppm) | Effect on hybrid:[c] Coker 16 | OP-1 | OP-2 |
|---|---|---|---|---|
| | | Plant height (cm) | | |
| AA | 0.06 | 285 hi | 256 j | 227 l |
| CF | 0.02 | 292 h | 259 j | 233 kl |
| NF-4 | 0.15 | 283 i | 240 k | 212 m |
| | LSD ($P = 0.05$) = 7.11 | | | |
| | | Weight of stover (g)[d] | | |
| AA | 0.06 | 295 h | 90 j | 80 jk |
| CF | 0.02 | 301 h | 90 j | 100 j |
| NF-4 | 0.15 | 136 i | 56 k | 53 k |
| | LSD ($P = 0.05$) = 27.7 | | | |
| | | Weight of kernels (g/plant)[e] | | |
| AA | 0.06 | 213.5 h | 126.3 jk | 119.6 k |
| CF | 0.02 | 214.5 h | 130.5 jk | 136.1 j |
| NF-4 | 0.15 | 188.9 i | 81.9 l | 82.1 l |
| | LSD ($P = 0.05$) = 15.2 | | | |
| | | Weight (g/100 kernels)[e] | | |
| AA | 0.06 | 33.5 h | 30.5 i | 25.7 k |
| CF | 0.02 | 34.7 h | 30.4 i | 27.7 j |
| NF-4 | 0.15 | 29.6 i | 22.7 j | 19.4 l |
| | LSD ($P = 0.05$) = 1.75 | | | |

[a] 0.08 ppm ozone was added to ambient concentration in unfiltered-air chambers for 7 hr/day (0930 to 1430 hours). Ozone concentrations shown are means for (0930 to 1630 hours).
[b] AA = ambient air; CF = charcoal-filtered air; NF-4 = air, not filtered, with $O_3$ added.
[c] Each value is the mean of 24 plants (eight plants in each of three blocks). Means followed by different letters within a response measure are significantly different according to the LSD ($P = 0.05$) values (treatment × hybrid).
[d] The moisture content of stovers ranged from 10 to 25%.
[e] The values were corrected to reflect a moisture content of 15.5%.

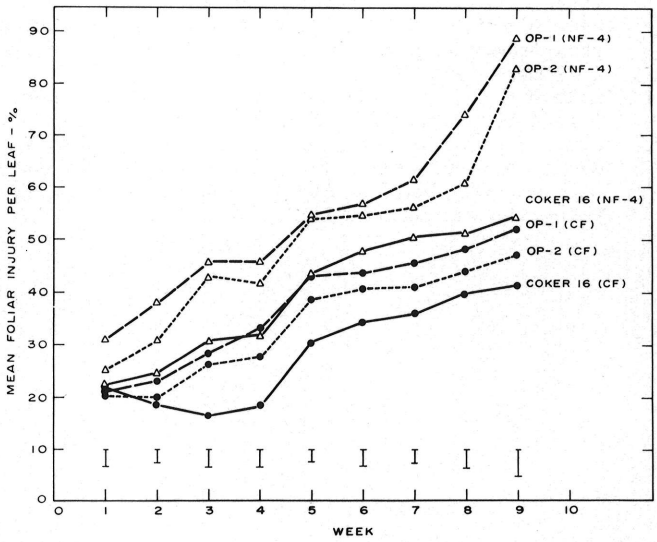


**Fig. 4.** Percentage injury per leaf on three field corn hybrids grown in carbon-filtered air (CF) or in chambers in which air was not filtered and 0.10 ppm ozone was added for 7 hr/day (NF-4) over a 9-wk period. Each point is the mean of 12 plants (four plants in each of three blocks). Confidence intervals shown are the LSD ($P = 0.05$) values for treatment × hybrid.

3), but the interaction was not significant statistically.

Yields tended to decrease at a higher $O_3$ level for potted plants than for plants in the ground (Table 3), but there was no significant $O_3$ concentration × media interaction. Kernel weight per plant at 0.15 ppm of $O_3$ was 30 g less than that at 0.02 ppm for potted plants and 38 g less for plants in the ground. At 0.15 ppm, kernel size was decreased by 7–9% compared with a 13–16% decrease for kernel weight per plant, showing that $O_3$ also caused a decrease in numbers of kernels.

A block × $O_3$ treatment interaction for yield of potted plants was caused partially by block-to-block fluctuations at 0.07 ppm of $O_3$ where the yield ranged from 7% greater to 13% less than that at 0.02 ppm. Block-to-block fluctuations were smaller at 0.11 ppm. For all blocks, however, the weights of kernels per plant at 0.15 ppm were less (9–19%) than those at 0.02 ppm. There were no differences in $O_3$ concentrations that accounted for these fluctuations.

Block × $O_3$ treatment effects also occurred for growth and yield of plants grown in the ground, primarily due to variation at 0.02 ppm where plants were unusually small in block 3 and unusually large in block 2. In all blocks, growth and yield of plants at 0.15 ppm was less than that at 0.02 ppm.

*Response of three hybrids.*—Injury symptoms were similar to those in the threshold-dose study except for bifacial necrosis, which occurred on some leaves of both open-pedigree hybrids after several weeks of exposure in the NF-4 treatment.

Injury of all hybrids was significantly greater at 0.15 (NF-4) than that at 0.02 (CF) ppm $O_3$ on all dates, except that injury was similar in both treatments for Coker 16 after week 1 (Fig. 4). The two open-pedigree hybrids were more severely injured than Coker 16 after weeks 1, 2, 8, and 9. But during intermediate weeks, foliar injury of all hybrids was similar; about 15% greater at 0.15 ppm than at 0.02 ppm of $O_3$. Percentage injury of the open-pedigree hybrids was similar (<5% different), except after week 8 when OP-1 was more severely injured than OP-2.

Plants of all hybrids were shorter and the stovers weighed less at 0.15 ppm than at 0.02 ppm in all blocks (Table 4). A block × $O_3$ treatment interaction for plant height and weight of stovers was caused primarily by greater effects of $O_3$ on all hybrids in block 1 than in other blocks.

The weight of kernels per plant at 0.15 ppm was 12, 37, and 40% less than that at 0.02 ppm for Coker 16, OP-1, and OP-2, respectively; the weight of 100 kernels was decreased by 15, 25, and 30% for Coker 16, OP-1, and OP-2, respectively (Table 4). These values indicated that yield decreases of Coker 16 were caused by decreased kernel sizes rather than by numbers. However, with the open-

pedigree hybrids, decreased kernel numbers as well as size apparently caused yield decreases.

## DISCUSSION

Ozone concentrations in ambient air at our field site near Raleigh depended mainly on regional weather patterns and were representative of most of the southeastern United States. The daily concentration curve was predictable, based on previous hourly concentrations during a given day, assuming no abrupt change in intensity of sunlight. Hourly fluctuations in $O_3$ concentrations usually were less than 0.02 ppm. The daily 7-hr ambient $O_3$ means (Fig. 1), were generally within 0.04 ppm of the daily minimum and maximum concentrations during daylight hours.

Threshold doses of $O_3$ for injury expression and effects on growth were much lower than threshold doses for decreased kernel yield, demonstrating that field corn can withstand some injury with no loss of yield. The correlation between injury, growth, and yield effects across treatments often was low. The magnitude of the differences between treatments in the amounts of foliar injury and effects on stover weight was a poor indication of the magnitude of the effects on kernel weight. For example, at 0.11 ppm of $O_3$, the percentage of foliar injury averaged about 7% greater than that at 0.02 ppm, stover weight was decreased by 23%, and yield was decreased by only 2%. At 0.15 ppm, foliar injury was 10% greater than at 0.02 ppm of $O_3$, stover weight was decreased by 45%, and yield was decreased by 15%.

Differences in plant injury, growth, and yield in AA at 0.06 ppm of $O_3$ (24-hr mean = 0.04) and in chambers at 0.07 ppm (24-hr mean = 0.04) (Table 3) provided an estimate of the chamber effects, assuming that small dose difference between 0930 and 1630 hours was not a factor. The causes for these differences are not known but are probably related to small differences in climate (4,7). Although the chambers can affect plant growth, there are no reports that changes in light, wind speed, or temperature, of the magnitude caused by the chambers, can affect sensitivity to $O_3$. We found no significant $O_3$ treatment × chamber position interaction affecting injury, growth, or yield. More research is needed to determine interactions between various environmental factors and plant response to chronic doses of $O_3$.

Threshold doses for injury, growth, and yield of the open-pedigree hybrids were not determined, but our results indicate that all thresholds would be lower for the two open-pedigree hybrids tested than for Coker 16. The effects of $O_3$ on injury rather than growth under greenhouse conditions were a better indicator of the reaction under field conditions. It is not known why growth of OP-1 was severely affected in the field but not in the greenhouse.

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