Effect of Ozone on Yield of Sweet Corn

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ABSTRACT

Sweet corn, *Zea mays* L. 'Golden Midget' and 'White Midget', were exposed to 0, 5, or 10 pphm ozone for 6 hr/day, from emergence to harvest, in field exposure chambers. Golden Midget was more sensitive to ozone than White Midget as indicated by the amount of visible injury and by reduction in growth and yield. Fresh weight of ears, number of kernels, and dry weight of kernels on plants receiving 10 pphm ozone were significantly reduced (5% level) with respect to the controls in Golden Midget but not in White Midget. Since the ozone levels used in this experiment were lower than those commonly found in the air surrounding many urban areas, the results suggest that measurable yield losses in corn due to air pollution may be greater than was previously recognized.

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Additional key words: air pollution, field exposures.

Photochemical oxidants are the most important and widespread forms of air pollution affecting agriculture in the United States. Injurious effects of ozone (O_3), regarded as the most important phytotoxic component of the photochemical oxidant complex, have been extensively reviewed (3, 8, 11, 13). Most published reports, however, relate only to symptomatic or physiological responses produced by experimental laboratory exposures or by ambient pollutants in the field.

In California, ambient oxidants have been shown to adversely affect Kentia palms (18), citrus (14, 16), grapes (15), and a variety of herbaceous species (10). In the Eastern United States, ambient oxidants have affected spinach (2), tobacco (9), and carnation (6). Greenhouse studies showed that O_3 levels of 5 to 10 pphm adversely affected tobacco (12), radish (17), white pine (5), and geranium (7).

Recent reports indicate that the growth and yield of sweet corn are affected by oxidant air pollution. Cameron et al. (1) observed ambient oxidant injury to field-grown sweet corn in California. They reported varietal differences in sensitivity and indicated that yield was reduced as a result of decreased seed set. W. A. Feder (*personal communication*) exposed potted dwarf sweet corn to low levels of O_3 in the greenhouse, and showed that growth and yields were reduced.

No reports exist on the effects of prescribed levels of O_3 on growth and yield of corn or on other important crop species under field conditions. Therefore, we exposed two cultivars of midget sweet corn to O_3 concentrations that occur in the air surrounding many urban areas to determine effects on growth and yield.

MATERIALS AND METHODS.—Seeds of two cultivars of midget hybrid sweet corn (*Zea mays* L. 'Golden Midget' and 'White Midget') were sown in sandy clay-loam soil on 18 June 1970. A 2.44-m row of each variety was planted in each of 20 2.44-m^2 plots. Seeds were spaced 10 cm apart in the row, and rows were spaced 120 cm apart. Soil moisture was maintained close to field capacity, and weeds were controlled by hand cultivation. Insects were controlled with Carbaryl (1-napthyl methylcarbamate) or malathion [S-(1,2-bis[ethoxycarbony]ethyl)0,0-dimethyl phosphorodithioate] as needed.

The plots were arranged in a randomized block design with four treatments in each of five blocks (20 plots) as follows: (i) an open plot; (ii) three plots enclosed by chambers in which the air was filtered by activated charcoal. Plants in the enclosed plots were exposed to O_3 at 0, 5, and 10 pphm (0, 99, or 198 $\mu g/m^3$ at 760 mm Hg and 25 C) for 6 hr daily from 8 AM to 2 PM EST from emergence to harvest.

The O_3 concentrations were measured with 10 Mast oxidant sensors. We have found that Mast sensors are never 100% efficient; both efficiencies and airflow rates vary widely from instrument to instrument. Therefore, individual Mast efficiencies were determined by calibration with the 2% neutral KI standard method (19), and airflow rates were routinely measured to provide correction factors for each instrument. If efficiencies and airflow rates of the Mast sensors are not considered, the sensed O_3

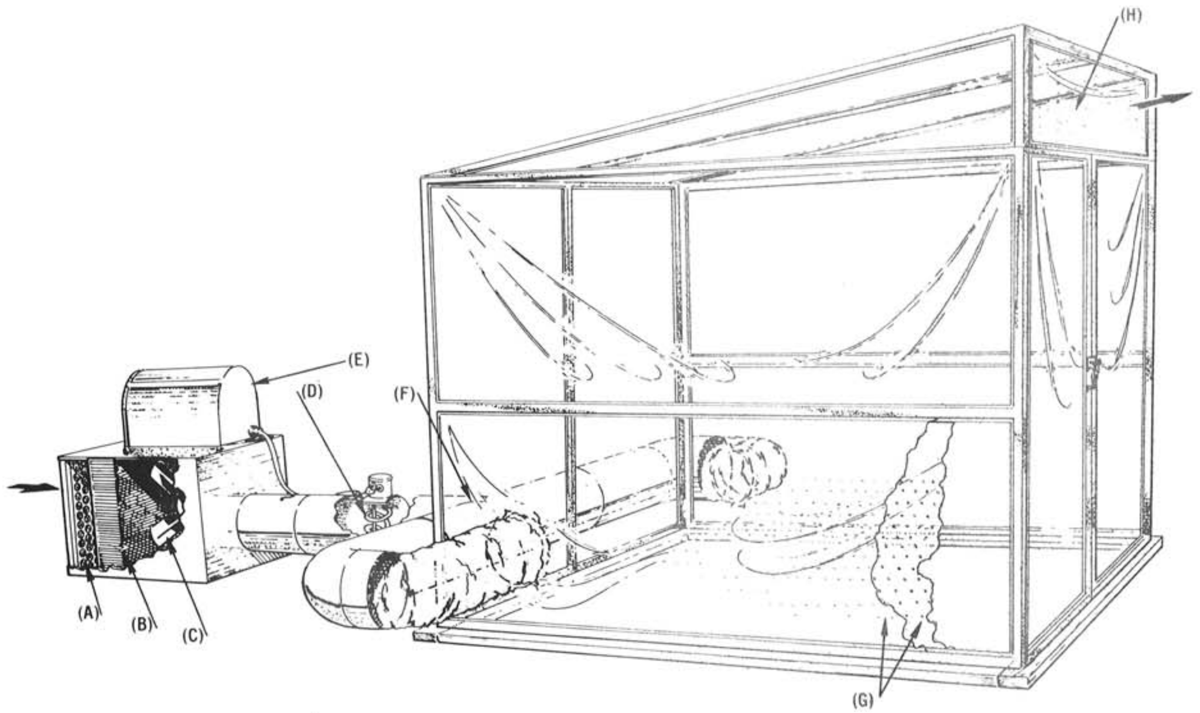

Fig. 1. Portable field exposure chamber system. (A) Particulate filter; (B) activated-charcoal filter; (C) axial fan; (D) ultraviolet lamp; (E) mailbox used to house the ultraviolet lamp transformer and the variable autotransformer; (F) galvanized steel duct; (G) double-layered, clear Teflon duct with perforated inner layer; (H) perforated exit panel.

concentrations may be as much as 40 to 50% below the actual concentration.

The exposure chambers (Fig. 1) were 2.44 m^2 and 1.94 m high at the back and 2.25 m high at the front. They consisted of an aluminum frame covered with 2 mil clear Teflon film (modified on one surface to permit the use of adhesives), an air handling system, and an O_3 generation section. Ambient air first passed through a particulate filter (Fig. 1-A), an activated charcoal filter to remove oxidant pollutants (Fig. 1-B), and was then forced by an axial fan (Fig. 1-C) through the O_3-generating area. Ozone was generated by an ultraviolet lamp (Fig. 1-D) in the air stream. The level of O_3 generated was controlled by a variable autotransformer in the primary circuit of the ultraviolet lamp transformer, both of which were housed in a large mailbox (Fig. 1-E). The ozonated air stream was then divided (Fig. 1-F) and introduced into two double-layered, clear Teflon panels (Fig. 1-G) on each side of the chamber. The inner layer of each panel was perforated to allow the ozonated air to flow into and through the chamber and then out through a perforated panel at the top (Fig. 1-H). The control chambers were identical to the exposure chambers, but did not contain O_3 generators.

The clear Teflon film was used as a covering because it is chemically nonreactive, about 95% transparent in the visible region, and transmits a broader band of radiant energy frequencies than any other commonly used chamber covering. Teflon allows light transmittance of 50, 85, and 95% at the light wavelengths of 200, 300, and 600 nm, respectively. At wavelengths from 400 to almost 600 nm, 95% of the light is transmitted, whereas at 700 nm, only about 50% of the light is transmitted. Beyond wavelengths of 700 nm, the transmittance decreases irregularly.

Air flows through the chambers at a rate of about 331 liters/sec (700 cubic ft/min) or 1.7 air changes/min. Shaded iron-constantan thermocouples continuously monitored chamber and ambient temperatures. The temperature differential between the chamber air and the ambient air reached a maximum of about 5 C for several hours on hot cloudless days, but was typically 1.5 to 3 C during the day. No differences were found at night.

Alternate plants were cut at ground level when the corn was approximately half-mature (33 and 40 days after planting for Golden Midget and White Midget, respectively). Growth variables measured included plant fresh weight, height, and tassel fresh weight. The percentage of injured leaf area on the six oldest leaves of each plant was estimated. The remaining plants were harvested at maturity (67 and 74 days after planting for Golden Midget and White Midget, respectively) and whole-plant fresh weight, root fresh weight, and ear fresh weight per plant (husks removed) were measured. The percentage of leaf area injured on the six youngest leaves of each plant was estimated. The ears from individual plants were then dried at 50 C for 5 days before the yield variables, including the number of ears with kernels per plant, percentage ear fill per plant (sum of the estimated percentage kernel set on individual ears), number of kernels per plant, and oven-dry weight (70 C for 2 days) of kernels per plant were determined. Analyses of variance were performed separately on each variety owing to varietal differences in variability. Treatment separations were identified using Tukey's method (4) at the 5% level of significance.

RESULTS.—At the beginning of each daily exposure, the O_3 concentrations within each chamber were 1-2 pphm lower than the daily 6-hr average. Concentrations rose slowly during the day owing to changing environmental conditions, and were 1-2 pphm above the daily 6-hr average at the end of exposures. The average 6-hr O_3 concentration in the low O_3 treatment ranged from 4.1 to 5.1 pphm, with an over-all average in the five plots of 4.7 pphm. Averages in the high O_3 treatments ranged from 9.3 to 10.2 pphm with an over-all average of 9.6 pphm. We will refer to the lower concentration as 5 pphm and the higher as 10 pphm.

Several field problems occurred that made analysis of the data difficult. Variability in plant size and appearance was great, especially in White Midget. Discussions with corn geneticists have confirmed that the midget corn varieties are likely to be more genetically variable than are most other commercial hybrids. Variability in both cultivars was increased due to edaphic factors, primarily soil moisture and soil type. An infestation by the lesser corn stalk borer, *Elasmopalpus lignosellus* (Zeller), killed or stunted some plants. These were not included in growth or yield measurements. The White Midget plants exposed to 10 pphm O_3 in block one were located on a low spot in the chamber, grew poorly owing to excessive water, and therefore were discarded. An epidemic of the southern corn leaf blight, *Helminthosporium maydis* Nisikado & Miyake, occurred in the open plots and severely stunted or killed most plants. Plants in the open plots were therefore discarded. No leaf blight occurred in the enclosed plots, probably because the filters excluded the spores.

TABLE 1. Summary of the significant levels of ozone effects in the first harvest as shown by the analyses of variance

Variety	Effect	Leaf injury (%)	Ht (cm)	Fresh wt (g)	Tassel fresh wt (g)
Golden Midget	Blocks	**[a]	**	*[b]	–[c]
	Treatment	**	–	–	–
	Blocks × treatment	–	–	–	–
White Midget	Blocks	–	*	–	–
	Treatment	**	–	–	*
	Blocks × treatment	–	*	*	–

[a] ** = significant at the .01 level.

[b] * = significant at the .05 level.

[c] – = no significant effects.

TABLE 2. Injury and growth responses of sweet corn to chronic ozone exposures at first harvest

Response measured	Ozone (pphm)	Varietal response[a] Golden Midget	White Midget
Leaf injury (%)[b]	0	17 h	40 h
	5	23 h	40 h
	10	48 i	57 i
Plant height (cm)	0	97 h	92 h
	5	93 h	87 h
	10	89 h	96 h
Plant fresh wt (g)	0	198 h	276 h
	5	203 h	251 h
	10	164 h	356 h
Tassel fresh wt (g)	0	14 h	14 hi
	5	13 h	12 i
	10	14 h	15 h

[a] Each figure is the mean of 19-25 plants. Means within each response grouping followed by the same letter are not significantly different at the .05 level according to Tukey's method.

[b] The average percentage injury on the six oldest leaves.

First harvest.—A summary of the significant levels of O_3 effects on percentage leaf injury, plant height, plant fresh weight, and tassel fresh weight, as indicated by the analyses of variance, is presented in Table 1. The mean responses of the cultivars to O_3 with respect to the above parameters are shown in Table 2.

The percentage injury values include O_3-induced injury and necrosis resembling natural senescence. Ozone injury appeared as small white or tan adaxial necrotic spots plus early chlorosis and senescence on the lower leaves. More than twice as much injury appeared on the lower leaves of Golden Midget exposed to 10 pphm as on the plants exposed to 5 or 0 pphm. Significantly more injury occurred on White Midget at 10 pphm than at 0 or 5 pphm, but the injury resembled symptoms of early senescence. No classical O_3 injury symptoms were seen on White Midget.

Growth reductions were not proportional to injury. Golden Midget plants were shorter and weighed less after exposure, but the effects were not statistically significant. No differences in Golden Midget tassel weight were found.

In White Midget, no growth reductions due to O_3 were found (Tables 1, 2). The high values for growth variables in White Midget at 10 pphm O_3 were due to unusually large plants in one plot.

Final harvest.—A summary of the significant levels of O_3 effects on percentage leaf injury, growth, and yield measurements, as indicated by the analyses of variance, is presented in Table 3. The significant mean

TABLE 3. Summary of the significant levels of ozone effects in the final harvest as shown by the analyses of variance

			Growth variables			Yield variables				
Variety	Effect	Leaf injury (%)	Plant ht (cm)	Plant fresh wt (g)	Root fresh wt (g)	Ear fresh wt (g)	Ears with kernels	Ear fill (%)	No. kernels	Kernel dry wt (g)
Golden Midget	Blocks	–	–	–	**[a]	–	*[b]	–	*	*
	Treatment	**	–	–	–	*	*	*	**	**
	B × T[c]	–	–	–	*	–	–	–	–	–
White Midget	Blocks	–	**	–	*	–	–	**	**	**
	Treatment	–	*	**	*	**	–	–	–	*
	B × T[c]	–	–	**	**	**	**	**	**	**

[a] ** = significant at the .01 level.
[b] * = significant at the .05 level.
[c] Block × treatment.
[d] – = no significant effects.

treatment responses of the cultivars with respect to the above parameters when no block × treatment interaction occurred are shown in Table 4.

Significantly more injury occurred on the upper six leaves of Golden Midget than on White Midget. The three growth variables of plant height and plant and root weight in Golden Midget were not affected by O_3. However, every yield variable of Golden Midget associated with seed set was significantly reduced by exposure to 10 pphm O_3 (Tables 3, 4). All yield variables of Golden Midget on plants exposed to 5 pphm were less but never significantly different from the controls (Table 4). A block × treatment interaction with respect to Golden Midget root fresh weight was found. When the treatment-block means for Golden Midget root fresh weight were compared, no treatment differences were found in any of the blocks, and treatment ranking was highly variable from block to block.

In White Midget, O_3 did not significantly reduce any of the plant growth or yield variables measured. Where significant effects occurred (Table 3), they reflected unusually large plants in a single plot.

DISCUSSION.—This is the first report of yield loss in a field-grown agronomic crop due to long-term, low-level O_3 exposure in field chambers. The yield reductions reported here are relevant, since they resulted from daily O_3 doses often surpassed in the ambient air surrounding large urban areas.

At present, the use of field chambers is the only method of exposing plants to controlled gaseous pollutant concentrations for long time periods. Different results might be obtained if plants were exposed under completely natural conditions. The possibility does exist that plant sensitivity to O_3 could be altered by environmental changes induced by field chambers. The chamber air was slightly warmer than ambient air during the day and had a constant wind velocity of about 0.05 km/hr (0.03 mph); and a small portion of the light spectrum was excluded by the chamber. Chamber humidity was equal to ambient humidity, and chamber temperatures were occasionally 5 C above ambient on hot sunny days. To our knowledge, this field chamber design provides an air atmosphere which approximates ambient conditions more closely than

TABLE 4. Significant injury, growth, and yield responses of sweet corn to chronic ozone exposures at final harvest where no block × treatment interactions occurred[a]

Variety	Response measured	Ozone (pphm)	Response value[b]
Golden Midget	Leaf injury (%)[c]	0	21 h
		5	35 i
		10	46 j
	Ear fresh wt (g)	0	183 h
		5	153 hi
		10	128 i
	Ears with kernels	0	5.5 h
		5	4.6 h
		10	4.1 h
	Percentage ear fill[d]	0	220 h
		5	219 h
		10	157 i
	Number of kernels	0	373 h
		5	350 h
		10	228 i
	Kernel dry wt (g)	0	43.6 h
		5	39.7 h
		10	23.8 i
White Midget	Plant ht (cm)	0	160 h
		5	165 h
		10	166 h

[a] Values included in this table showed a significant treatment effect without a block × treatment interaction according to the analyses of variance in Table 3.

[b] Each value is the mean of 29-41 plants. Means in each response grouping followed by the same letter are not significantly different at the .05 level of confidence according to Tukey's method.

[c] The average percentage injury on the six youngest leaves.

[d] The sum of the estimated percentage kernel set on individual ears per plant.

other chambers previously described. To date, research of environmental effects on plant sensitivity to O_3 has provided no evidence indicating that the chamber-caused environmental variations mentioned above would alter plant sensitivity to O_3.

It is interesting to note the relationships of the two varieties with respect to percentage leaf injury, plant fresh weight, and the yield variables directly associated with seed set and subsequent seed development. In Golden Midget, percentage leaf injury increased significantly with each O_3 concentration, and average plant fresh weight decreased, although not significantly. All yield measurements associated with successful seed set in this cultivar were significantly lower among plants exposed to O_3. In White Midget, no classical O_3 injury was observed, and plant weights were not reduced by O_3. However, average percentage ear fill, kernels per plant, and kernel dry weight were less in the O_3 treatments, but the differences were not significant. This evidence suggests that in some cultivars, reproductive processes necessary for successful seed set are more sensitive to low-level O_3 exposures than are vegetative growth processes.

Our data support the evidence of others (1, W. A. Feder, *personal communication*) who have also indicated yield loss in corn due to oxidant air pollutants. If the values obtained in this and previous research are valid under completely natural growing conditions, the yield loss in sensitive corn varieties grown in polluted areas may be greater than previously believed.

Additional research with individual pollutants and with mixtures of pollutants, at realistic concentrations, is clearly needed to identify more accurately the impact of air pollutants on cultivated crops as well as on natural vegetation.

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