Injury and Yield Responses of Peanuts to Chronic Doses of Ozone in Open-Top Field Chambers

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ABSTRACT

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Peanuts were exposed during 1979 and 1980 to concentrations of ozone (O_3) that spanned those that occur in ambient air of peanut production areas in the United States. The different concentrations were obtained by adding O_3 to the air of open-top field chambers for 7 hr per day from the seedling stage to harvest. Ozone at seasonal 7-hr per day concentrations (mean concentration for 7 hr per day during the seasonal exposure period) equal to, or greater than, the ambient concentration caused foliar injury and decreased shoot and root weight for both years. Seasonal 7-hr per day O_3 concentrations in ambient air at our field site near Raleigh, NC, were 0.052 and 0.056 ppm for 1979 (131 days) and 1980 (112 days), respectively. In 1979, marketable pod weight (yield) per plant at seasonal 7-hr per day O_3 concentrations of 0.049, 0.072, and 0.096 ppm was 0, 30, and 37% less, respectively, than for control plants in chambers that received charcoal-filtered air with a seasonal concentration of 0.026 ppm O_3. In 1980, yield at seasonal O_3 concentrations of 0.056, 0.076, 0.100, and 0.125 ppm was 14, 35, 52, and 72% less, respectively, than for the control treatment (0.025 ppm). Linear regression equations using data from 1979 and 1980 predicted yield losses of 17 and 21%, respectively, at a seasonal 7-hr per day mean O_3 concentration of 0.054 ppm.

Additional key words: air pollution.

Ozone (O_3) in the air is responsible for most pollutant-induced losses to agriculture in the United States (3). Current secondary National Ambient Air Quality Standards are based on interpretations of published research criteria (1); however, the source document contains little dose-response data from which one can assess the cost of O_3 pollution to agriculture.

Several recent reports (3,8,10) indicate that O_3 levels over most of the eastern United States during the growing season are in the range that can cause yield losses to important agricultural crops. Recent estimates for national crop losses caused by O_3 ranging from 2 to 5% (3) or from 13 to 18% (7) were derived from field studies conducted in open-top chambers. These are the only available estimates based on O_3 dose-yield response experiments. However, they should be considered preliminary because they used data from only one or two experiments for just a few of the most important field crops. Considering the magnitude of possible losses to agriculture, more dose-response data relating chronic O_3 exposures to crop yields are needed.

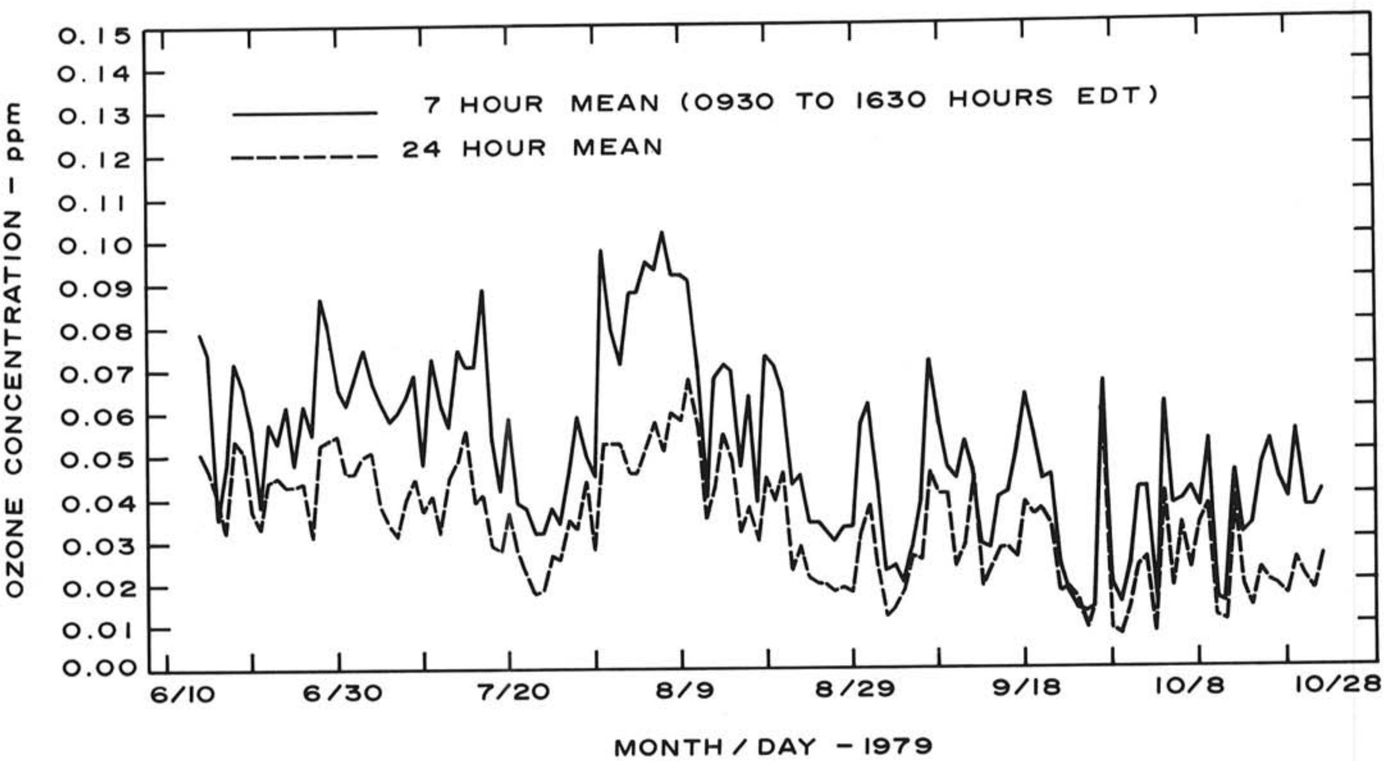
Approximately 1.73×10^9 kg (3.8 billion pounds) of peanuts are produced annually in the United States (13). With an average market value of 12 cents per kilogram (27 cents per pound), the 1981 crop was worth about $1 billion to producers. Our objective was to provide data to estimate the effects of seasonal O_3 concentrations on peanut yields.

MATERIALS AND METHODS

Seeds of peanut, *Arachis hypogaea* L. 'NC-6,' were treated with *Rhizobium* sp. inoculum and planted in sandy clay loam soil (Appling, clayey, kaolinitic, thermic, Typic Hapludults) on 17 May

1979 and on 22 May 1980. In 1979, seeds were planted by hand at 10-cm intervals in five 4.6-m rows spaced 0.6 m apart in each of 14 plots. In 1980, seeds were planted with a two-row planter in a 0.63-ha field with rows spaced 1.0 m apart. Plots were selected on the basis of even plant emergence, healthy plant appearance, and uniform topsoil depth and appearance within blocks. Plants were thinned to an average of one per 20 cm of row within 3 wk after emergence. Thrips were controlled with carbaryl 50W (5 g/L) and mites were controlled with cyhexatin 50W (1 g/3.8 L). Weeds were controlled by hand.

A thin layer of wheat straw was placed on the soil between rows to decrease soil compaction from irrigation with hand-held water-breaker nozzles. In 1979, plants were watered as appeared necessary to prevent wilting. Plants in all plots were watered the same amount. In 1980, soil tensiometers (Irrometer Company, Riverside, CA 92506) were placed in the soil at depths of 20 and 40



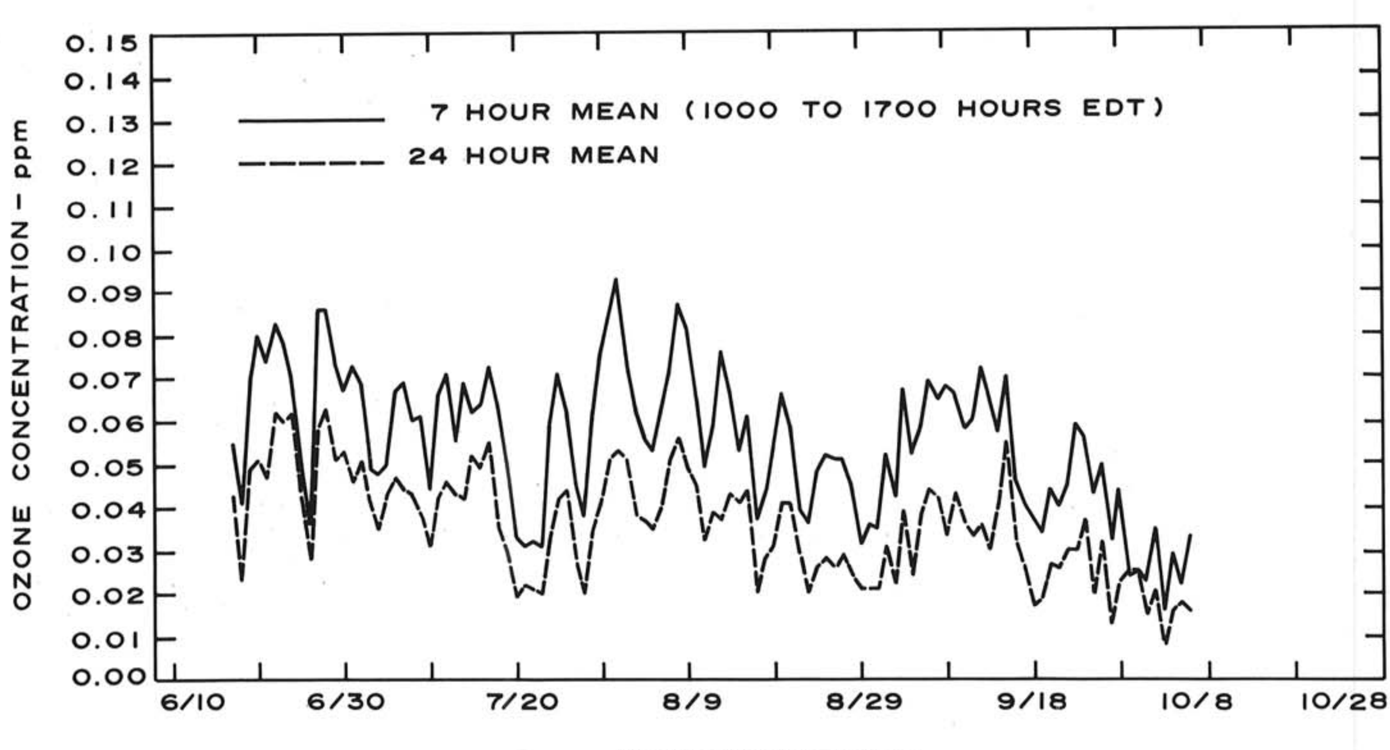


Fig. 1. Daily 7- and 24-hr/day mean ozone concentrations in ambient air 8 km south of Raleigh, NC, during the 1979 and 1980 experiments.

cm in each plot; plants in an entire block were irrigated when any tensiometer reading within a block exceeded 60% of scale; individual plots within the irrigated block received 1.00, 0.75, or 0.50 cm of water when the readings were >60%, 35 to 60%, or <35% of scale, respectively.

Different levels of O_3 were established within open-top field chambers that were 3 m diameter × 2.4 m tall (4). Dispensing and monitoring methods for O_3 in open-top chambers have been described previously (5). In 1979, chamber fans were run for 24 hr per day. In 1980, chamber fans were run only between 0600 and 2200 hours EDT to allow dew formation in the chambers.

A randomized complete block design was used in both years. In 1979, we selected five plots in each of two blocks; each plot consisted of four rows. There were four chamber treatments and one ambient air (AA) treatment in each block. In 1980, we selected six plots in each of four blocks; each plot consisted of two rows. There were five chamber treatments and one AA treatment per block. For both years, each block contained one charcoal-filtered-air (CF) chamber considered as the control and a series of nonfiltered-air (NF-1, NF-2, NF-3) chambers (particulate filter only). Ambient air plots were used only to measure chamber effects. This was done by comparing injury and yield in AA plots with that in NF-1 chambers in which the O_3 concentrations were similar to those in AA.

Constant, but different, amounts of O_3 were added to the fluctuating levels of O_3 in ambient air in the NF chambers for 7 hr/day, producing a series of seasonal 7-hr/day O_3 levels. The 1979 seasonal 7-hr/day mean O_3 concentrations during the period of O_3 addition (14 June–22 October) for the AA, CF, NF-1, NF-2, and NF-3 treatments were 0.052, 0.026, 0.049, 0.072, and 0.096 ppm, respectively. The 1980 seasonal 7-hr/day mean O_3 concentrations during the period of O_3 addition (17 June–6 October) for the AA, CF, NF-1, NF-2, NF-3, and NF-4 treatments were 0.056, 0.025, 0.056, 0.076, 0.100, and 0.125 ppm, respectively. In 1980, O_3 was not dispensed on days when rain was falling at 1000 hours and/or 1330 hours EDT (a total of 45.5 hr) and for 21 hr during the period from 13 to 16 July when the ozonizer failed.

Foliar injury was estimated as the percentage chlorosis and necrosis in 5% increments (0–100%) on all individual leaves on one main branch of four plants (one per quadrant) in each plot. Abscised leaves were rated as 100% injured. We did not attempt to differentiate between symptoms caused by O_3, normal senescence, or other factors. The branches were tagged and injury was estimated for the same branches for each of seven dates in 1979 and for each of four dates in 1980.

Plants were harvested on 23 October 1979 and on 7 October 1980. Sixteen plants per plot (eight from each of two rows) were tagged for treatment and position within chambers (one plant per position) and dug with a broad-tined fork. Plants within 75 cm of the chamber frame and plants in the two border rows in 1979 were not used. Soil was washed from the roots and pods, and pods >1 cm long were counted and weighed for each plant. Pods were air dried to 7.5% moisture content and those containing at least one mature seed were weighed. After removing the pods, shoots and roots were air dried for 28 days prior to weighing (1979) or were weighed at harvest (1980). Pods from each plot were graded for market quality and support price value according to standard marketing procedures.

Analyses of variance were performed on injury, growth, and yield data. Regression analyses were performed with seasonal 7-hr/day mean O_3 concentrations as the independent variable and marketable pod weight as the dependent variable. Data from AA plots were not used in regression analyses.

RESULTS

Ozone concentrations. The mean seasonal 7-hr/day O_3 concentration in ambient air (AA) was 0.052 ppm in 1979 and 0.056 ppm in 1980. Day-to-day concentration fluctuations (Fig. 1) were similar in magnitude to those observed in previous years.

In 1979, there were 12 days with 7-hr/day mean O_3 concentrations in AA above 0.08 ppm; eight of these were consecutive from 3 through 10 August (Fig. 1). In 1980, there were eight days with 7-hr means over 0.08 ppm, but only two of these were consecutive (Fig. 1). The daily 7-hr mean O_3 levels for any NF treatment can be estimated by subtracting the seasonal 7-hr AA mean from the seasonal 7-hr mean for the desired NF treatment and adding the difference to any daily 7-hr AA value shown (Fig. 1). For example, for 1980 data, a mean of 0.00, 0.020, 0.044, and 0.069 ppm was added to the NF-1, NF-2, NF-3, and NF-4 chambers, respectively. Adding these values to a given 7-hr per day AA mean will estimate daily 7-hr means for the NF-1, NF-2, NF-3, and NF-4 treatments, respectively.

The seasonal diurnal O_3 curves in AA were almost identical for each year; peak concentrations occurred between 1500 and 1600 hours EDT. Seasonal diurnal curves for the CF and various NF treatments during the 7-hr exposure period followed the AA curve for both years (Fig. 2).

Foliar injury. Symptoms included flecking and stippling on adaxial leaf surfaces and chlorosis. The flecks (tiny necrotic areas <1 mm in diameter) were white or beige and, depending on the concentration of O_3, covered part or all of the leaf surface and resembled a coating of coarse dust. Chlorosis was either interveinal or general and was often accompanied by upper surface stippling (purple spots <1 mm in diameter). Except for stippling, all of these symptoms were progressive, becoming more severe with increased exposure time and O_3 concentration. Leaves usually abscised before becoming completely chlorotic or necrotic. In the higher O_3 treatments (NF-3 and NF-4), only a few leaves were retained near the apex of each branch near the end of the season.

Analyses of variance showed that the O_3 effect on injury was highly significant for all measurement dates for both years. Injury was greater in all NF treatments than in the CF treatment for all dates in both years except at the 15- and 30-day estimates (Fig. 3). Percentage injury was greater for each successively higher NF treatment, but was similar for plants in the AA and NF-1 treatments except for the last estimate date in 1979 and the first and last estimate date in 1980 (Fig. 3).

Growth and yield. Ozone treatment resulted in significantly smaller shoot and root weights in both years (Table 1). In 1979, shoot weights at 0.049, 0.072, and 0.096 ppm O_3 were 12, 49, and 60% less, respectively, than that for the controls at 0.026 ppm O_3 (Table 2). The response to O_3 in 1980 was similar to that in 1979; shoot weight losses of 25, 52, 60, and 78% occurred at 0.056, 0.076,

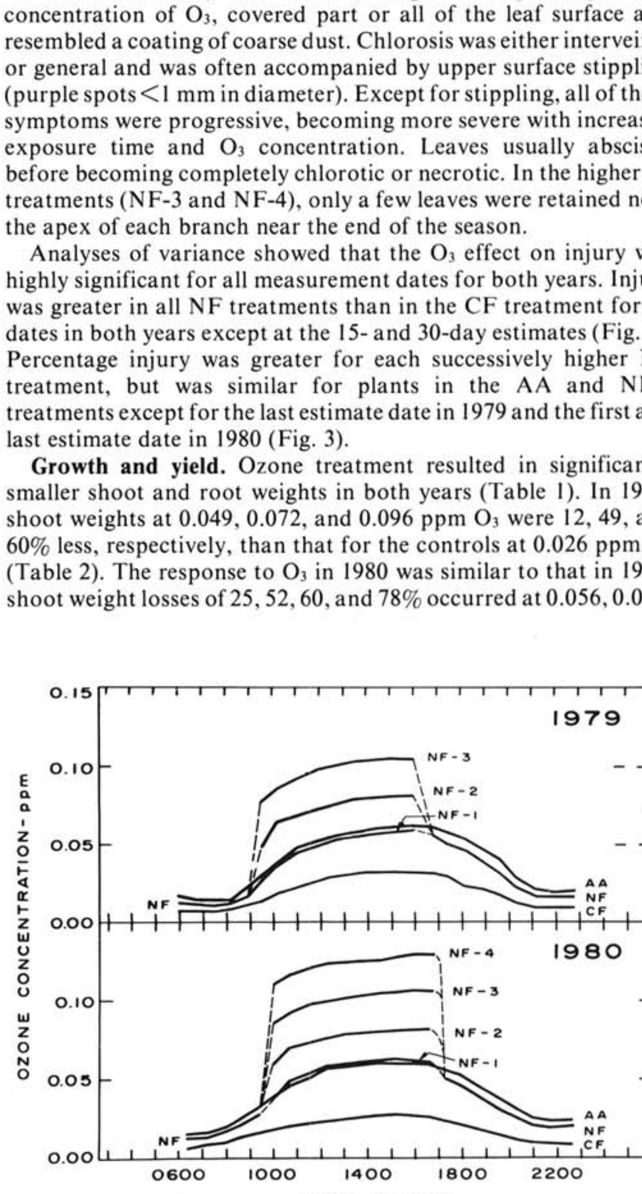


Fig. 2. Mean diurnal fluctuation in ozone concentrations for ambient air and chamber treatments during the 1979 and 1980 experiments. AA = ambient air (no chamber); CF = open-top chamber receiving charcoal-filtered air; NF = open-top chamber receiving nonfiltered air (particulate filter only); NF-1, NF-2, NF-3, and NF-4 = NF chambers receiving added ozone for 7 hr per day.

TABLE 1. Mean squares from analyses of variance for effects of chronic doses of ozone on growth and yield of peanuts in 1979 and 1980[a]

Source	Df 1979	Df 1980	Shoot weight per plant[b] 1979 (10^3)	Shoot weight per plant[b] 1980 (10^3)	Root weight per plant[b] 1979 (10^2)	Root weight per plant[b] 1980 (1^2)	Marketable pods per plant 1979 (10^2)	Marketable pods per plant 1980 (10^2)	Weight of marketable pods per plant 1979 (10^3)	Weight of marketable pods per plant 1980 (10^2)
Block	1	3	81	90	1	89	2	15	22	56
Ozone dose (O)	4	5	1,672**	6,027**	29*	2,533**	24[c]	1,300**	814[d]	2,947**
Error A	4	15	23	100	4	39	7	7	152	29
Position (P)	15	15	38	70	2*	16	2	17	64	43
O × P	60	75	27	46	1	21	2	14	65	37
Error B	75	269	32	48	1	20	1	13	58	28

[a] ** and * indicate statistical significance at $P = 0.01$ and $P = 0.05$, respectively.
[b] In 1979, shoots and roots were air dried for 28 days before being weighed. In 1980, shoots and roots were weighed at harvest.
[c] Prob $>F = 0.13$.
[d] Prob $>F = 0.07$.

TABLE 2. Effect of chronic doses of ozone (O_3) on growth and yield of peanuts in open-top field chambers during 1979 and 1980

Year	Treatment[a]	O_3 concn. seasonal 7-hr/day mean[a] (ppm)	Shoot weight per plant[b] (g)	Root weight per plant[b] (b)	Marketable pods per plant[c] (no.)	Marketable pod weight per plant (g)	Support price[d] ($/100 lb)
1979[e]	AA	0.052	81	4.8	48	82	22.56
	CF	0.026	80	4.9	47	93	22.62
	NF-1	0.049	71	4.4	44	94	22.84
	NF-2	0.072	41	3.2	32	66	23.94
	NF-3	0.096	32	2.8	30	59	23.48
1980[f]	AA	0.056	893	19.8	77	158	25.49
	CF	0.025	1,008	20.6	70	142	24.35
	NF-1	0.056	761	16.4	58	122	24.78
	NF-2	0.076	483	12.0	45	92	24.92
	NF-3	0.100	402	8.5	34	69	25.97
	NF-4	0.125	219	5.0	22	40	25.44

[a] AA = ambient air plot (no chamber); CF = open-top chamber receiving charcoal-filtered air; NF-1, NF-2, NF-3, and NF-4 = open-top chambers receiving nonfiltered air plus added ozone. Ozone was added to the inlet duct of NF chambers for 7 hr/day (from 0930 to 1630 hours EDT in 1979 and from 1000 to 1700 hours EDT in 1980) to produce the seasonal 7-hr/day mean concentrations shown.
[b] Shoots (with pods removed) and roots were air dried for 28 days prior to weighing in 1979 but were weighed at harvest without drying in 1980.
[c] Marketable pods are defined as pods containing at least one mature seed.
[d] The support price was determined by commercial grading procedures and support price levels in effect for each year (100 lb = 45.4 kg).
[e] Each value is the mean of 32 plants (eight plants in each of two rows, two blocks).
[f] Each value is the mean of 64 plants (eight plants in each of two rows, four blocks).

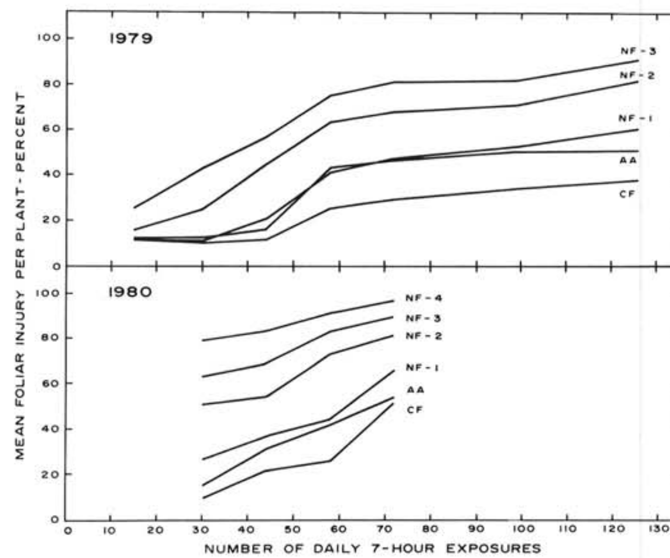


Fig. 3. Foliar injury of peanuts exposed to different levels of ozone in 1979 and 1980. Seasonal 7-hr/day ozone levels for 1979 were as follows: ambient air (AA) = 0.052 ppm; charcoal-filtered-air chamber (CF) = 0.026 ppm; nonfiltered-air chambers (NF-1, NF-2, and NF-3) = 0.049, 0.072, and 0.096 ppm, respectively. Seasonal values for 1980 were: AA = 0.056; CF = 0.025; NF-1, NF-2, NF-3, and NF-4 = 0.056, 0.076, 0.100, and 0.125 ppm, respectively.

0.100, and 0.125 ppm O_3, respectively. Root weight losses were slightly less than were shoot weight losses for both years. The only significant effect other than those caused by O_3 was a chamber position effect on root weight in 1979 (Table 1). However, there were no trends toward larger or smaller plants in one chamber position compared to another and this effect was not seen for other measures.

In 1979, the effects of O_3 on number and weight of marketable pods per plant were significant at $P = 0.13$ and $P = 0.07$, respectively; in 1980, the effects of O_3 were highly significant ($P = 0.01$) for both measures (Table 1). At each level of O_3, the percentage decrease in yield was less than the percentage decrease in shoot or root weight, indicating a capacity for peanuts to compensate for some growth loss. In 1979, observed marketable pod weights (yield) at 0.049, 0.072, and 0.096 ppm O_3 were 0, 30, and 37% less, respectively, than at 0.026 ppm (Table 2). In 1980, yields at 0.056, 0.076, 0.100, and 0.125 ppm O_3 were 14, 35, 52, and 72% less, respectively, than at 0.025 ppm O_3 (Table 2). Regression analyses showed highly significant linear relationships between the seasonal O_3 concentrations and yield for both years (Fig. 4).

DISCUSSION

Ozone at a given seasonal 7-hr per day mean concentration caused a greater decrease in peanut yield in 1980 than in 1979 (Table 2 and Fig. 4). The difference was not large at concentrations in the range of 0.05 to 0.06 ppm O_3, but was greater at higher concentrations. Cause for the different response was probably not related to timing of ambient pollution episodes during the season or to soil nutrient levels, as these were similar in both years. The different relative responses may have been due to differences in water relationships caused by differences in row width and amount of irrigation. Plants were more crowded in 1979 (83,000 plants per hectare) than in 1980 (50,000 plants per hectare). Wilting was not observed, but low soil moisture may have limited plant growth for both years, especially during late July or August. In 1979, only 4.3 cm of rain fell during the 30-day period from 27 July through 25 August; during this period plants were irrigated seven times with a total deposition of 2.1 cm of water. In 1980, 1.9 cm of rain fell from

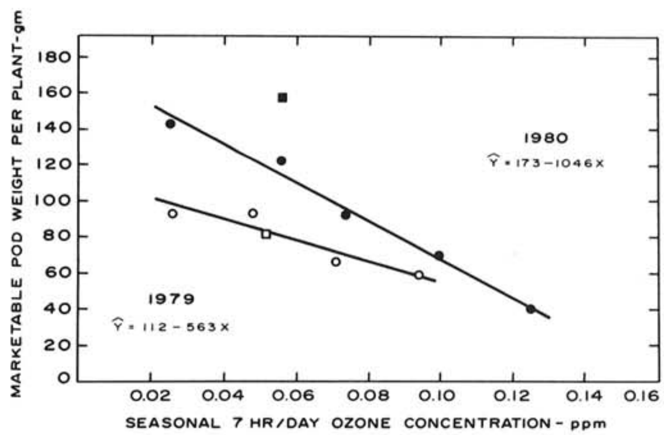


Fig. 4. Regression equations and regression lines showing the relationships between seasonal 7-hr/day ozone concentrations and predicted and observed yield of cultivar NC-6 peanut plants in 1979 and 1980. ○ and ● indicate observed treatment means in 1979 and 1980, respectively. □ and ■ indicate treatment mean for ambient air plots in 1979 and 1980, respectively. Ambient air data were not used in the regression analyses. R^2 values were 0.86 and 0.96 for 1979 and 1980 equations, respectively.

1 through 30 August; during this period plants were irrigated eight times with a total deposition of 6.0 cm of water. Thus, water stress was probably greater in 1979 than in 1980, even though yield per hectare was greater in 1979 than in 1980. Plants under water stress are known to be less sensitive to pollutants because of decreased rates of foliar gas exchange (2,6,9,11,12).

Comparisons between injury and yield in AA plots with that in chambers with a similar O_3 concentration (NF-1 chambers) provided a measure of chamber effects. In 1979, there was no apparent chamber effect measured by comparing the O_3 dose-yield response relationships for the AA and NF-1 treatments (Fig. 4). In 1980, however, mean pod weight per plant in the AA plots was 157.8 g compared to 122.4 g in the NF-1 plots (Table 2). The different results may have been due to turning fans off at night in 1980, but not in 1979, and to greater amounts of irrigation in 1980 than in 1979. Irrigation with water-breaker nozzles caused some temporary compaction of the plant canopy in both years. Canopy compaction reduces light intensity and increases moisture retention in the lower canopy. Canopy compaction was reduced more by air movement at night in 1979 when the fans were left on than in 1980 when they were not. Plants in the NF-1 treatment showed greater amounts of foliar injury than those in the AA plots in 1980, but not in 1979 (Fig. 3).

The regression analyses suggest a loss of peanut yield at levels of O_3 that occur each year in peanut production areas. Seasonal 7-hr per day O_3 concentrations at our field site have been in the 0.05 to 0.07 ppm O_3 range for the past 10 yr. The pervasive regional nature of oxidant air pollution suggests similar concentrations throughout most of the southeast. Yield losses were probably caused by O_3-induced foliar injury resulting in decreased photosynthesis and growth. However, ozone-induced injury symptoms in the AA or NF-1 treatment were limited to chlorosis and abscission, which can both result from normal senescence, and to slight flecking and stipple. These symptoms were very difficult to recognize without directly comparing leaves in the AA or NF-1 treatment with those in the CF treatment.

At a seasonal 7-hr per day mean of 0.054 ppm the linear regression equations for 1979 and 1980 data predicted a mean yield loss of 19% when the CF treatment (0.025 ppm) was considered as the control. However, these predictions resulted from tests with one peanut cultivar grown under nearly optimum (1980) or less-than-optimum moisture conditions (1979). Other cultivars may be more or less sensitive to O_3 than cultivar NC-6. Moisture stress commonly limits peanut production and this would likely decrease losses caused by O_3. Research seems warranted to determine effects of moisture stress on O_3 dose-yield response relationships, to define dose-response relationships for other peanut cultivars, and to determine whether sources of tolerance to O_3 exist.

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