Special Topics

Effects of Growth Medium and Fertilizer Rate on the Yield Response of Soybeans Exposed to Chronic Doses of Ozone

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ABSTRACT

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The objectives were to determine whether wide variation in fertilizer rates or type of growth medium would affect the response of soybeans, *Glycine max* 'Davis,' exposed to chronic doses of ozone (O_3) in open-top field chambers. Responses to O_3 were compared for plants grown in the ground or in pots containing an artificial growth medium. In 1977, the yield of plants grown in pots containing soil, sand, and a mixture of perlite, peat moss, and vermiculite was greater than that of plants grown in the ground; in 1978, the reverse was true. However, the percentage yield loss caused by O_3 was not affected by the growth medium either year. Separate tests were made for potted plants that received different levels of fertilizer. At moderate fertilizer rates, the yield response to different doses of O_3 was not significantly affected by fertilizer rate for either year. In 1978, plants with no fertilizer added were severely stunted and even relatively high doses of O_3 did not further decrease yield. The results suggest that plant response to O_3 will be fairly uniform over a range of substrate types and fertilizer rates when edaphic conditions are adequate to insure normal plant growth.

Photochemical oxidants, primarily ozone (O_3), cause foliar injury and crop yield loss in many areas of the United States. Estimates of annual national losses obtained by using empirical predictions based on foliar injury or subjective estimates by experienced observers have ranged from $125 million (2) to over $600 million (11). To improve the credibility of loss estimates, information is needed on the yield of plants exposed to realistic levels of O_3 pollution. Data currently available were obtained in the field where uncontrolled climatic and edaphic factors can greatly affect plant growth and yield and also plant response to O_3 (10,11). Researchers need to know how much change in plant response to pollution can be caused by alterations in climatic and edaphic factors. With such knowledge, we will have a better idea of the degree of precision needed in controlling or understanding variables shown to affect response.

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Climatic factors, which can not be controlled in the field, are relatively uniform for all pollutant treatments at a given location. Edaphic conditions, however, may vary at a given location and thus may vary between pollutant treatments depending on the relative soil homogeneity, slope, drainage, tillage practices, and other factors. Uniformity of edaphic conditions can be partially insured through careful plot selection, fertilization, and irrigation. These practices may not be adequate when experiments require large areas or when the effects of ambient oxidants are being compared at different sites. In such cases, edaphic uniformity can be obtained only by using pots or microplots containing a uniform growth medium.

Relatively little is known of the interactions between plant response to O_3 and physical or chemical characteristics of plant growth media (10,11). Pinto bean plants were more severely injured by oxidants when grown in vermiculite than in soil, and a peat-perlite mixture than in vermiculite (17). However, soybeans were injured more by O_3 when grown in soil than in peat-perlite (5).

The authors of a recent review (11) conclude that "the importance of soil fertility in the response of plants to oxidants is not understood." Some reports indicated that increases in one or more fertilizer element caused increased sensitivity (3,12,15,16); other reports indicated the opposite (1,4). Optimal fertilizer rates have resulted in greater (5,13) or less (14) sensitivity.

Because there were no guidelines for the degree of variability in edaphic factors acceptable to air pollution effects research, our objectives were to determine whether the type of growth medium or fertilizer rate would significantly affect the injury, growth, and yield response of soybeans due to chronic O_3 exposures in open-top field chambers.

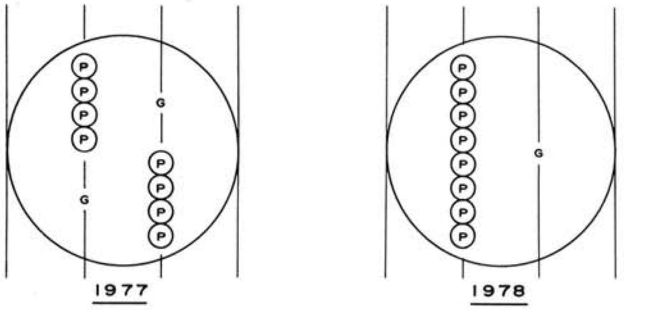

Fig. 1. Plot design to measure the effects of chronic doses of O_3 on soybean plants grown in 15-L pots (P) or in the ground (G). The positions of P and G plants were as shown for two blocks and were the opposite of that shown for the remaining two blocks.

MATERIALS AND METHODS

These studies were performed during 1977 and 1978 at the North Carolina State University Research Unit #2 located 8 km south of Raleigh. Seeds of soybean, *Glycine max* (L.) Merr. 'Davis' were

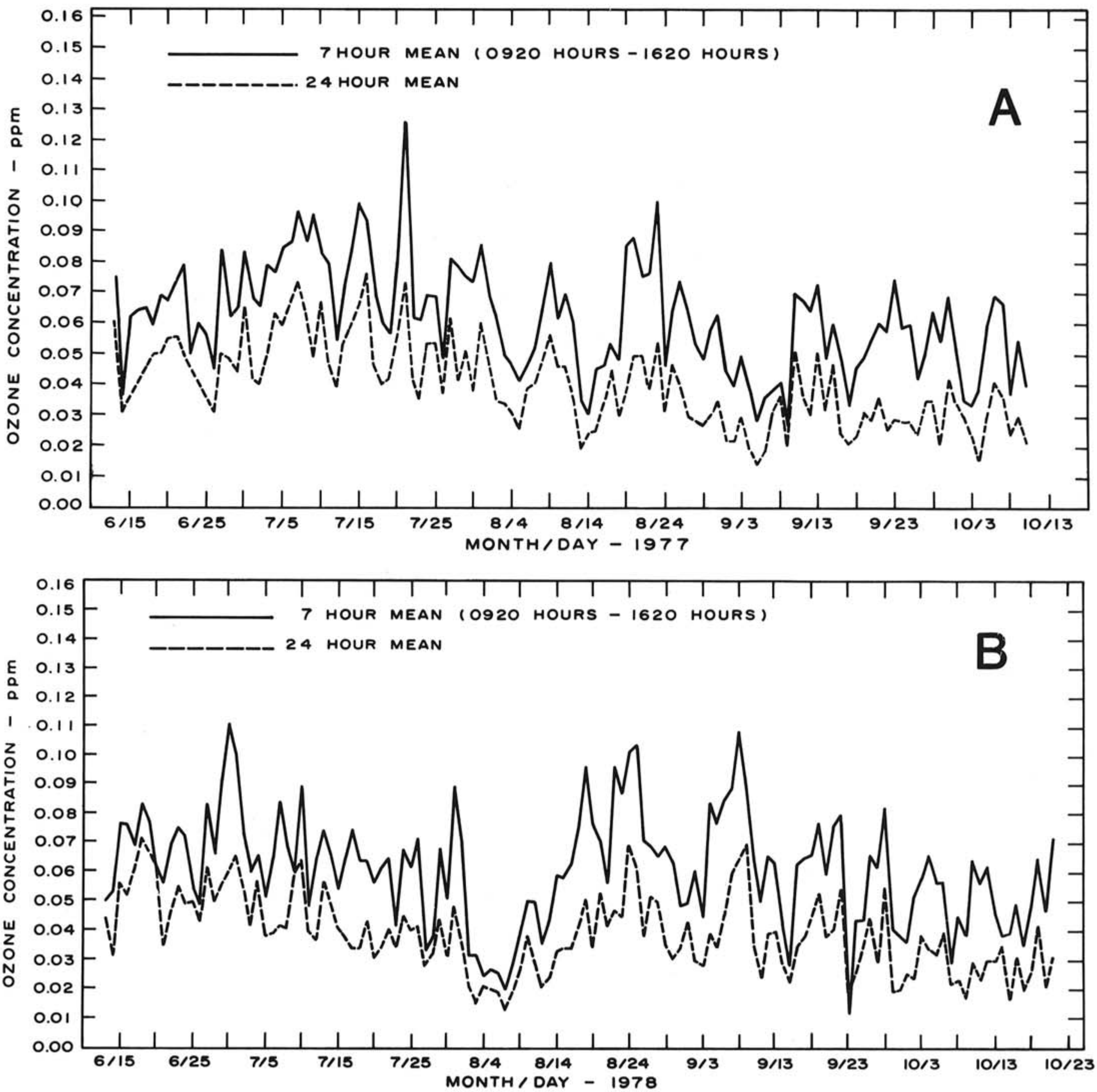

Fig. 2. Ambient concentration of O_3 for 7 hr (from 0920 to 1620 hours) or 24 hr per day **A,** from 13 June through 10 October 1977 and **B,** from 13 June through 21 October 1978.

sown in the ground (Appling series, clayey, kaolinitic, thermic, Typic Hapludults) in rows spaced 1 m apart or in 15-L pots. All plants were watered as needed to prevent wilting. Plants were thinned within 3 wk after planting to provide uniform stands for all treatments. Insects and mites were controlled by treating all plants with foliar sprays of carbaryl or dicofol as needed.

Cylindrical (3 m diameter) open-top field chambers (6) were used to provide different levels of O_3. Chambers equipped with charcoal filters (CF) were used for the control treatments. Chambers with particulate filters (NF) only were used to expose plants to ambient or elevated concentrations of O_3 (NF + O_3). Small, constant concentrations of O_3 were added to the inlet duct of NF chambers for 7 hr/day (from 0920 to 1620 hours EDT). The added O_3 plus ambient O_3 produced concentration curves that followed the daily fluctuations of ambient O_3 concentrations. The methods of dispensing and monitoring O_3 in the open-top field chambers used in this research have been published (8).

Plants were harvested at maturity. Shoot weight, number of filled pods, pod weight, and seed weight per plant were determined. Analyses of variance were performed for all data and LSDs were determined. Specific materials and methods for two separate experiments are presented below.

Growth medium. This experiment was designed to measure the effects of O_3 on plants growing in media with widely differing physical characteristics. Seeds were planted in 15-L pots and in the ground on 24 May 1977 and 5 June 1978. The growth medium in pots was a mixture of Appling top-soil, sand, and Metro-mix 200 (2:1:1, v/v). Metro-mix 200 is a mixture of perlite, peat moss, and vermiculite with added nutrients (W. R. Grace and Co., Cambridge, MA 02140). Seedlings in pots were thinned to two per pot in 1977 and to three per pot in 1978. In both years, seedlings in the ground were thinned to one plant per 15 cm of row. Plants in pots were fertilized with 1 L of a solution containing 15 g of a complete fertilizer (6-25-15, N-P-K, plus micronutrients) per 3.8 L of water on 16 and 21 June, 7 and 28 July, and 19 August in 1977, and on 23 and 30 June and 11 August in 1978. Plants in the ground were fertilized with 0-10-30 (N-P-K) at 44.8 kg/ha on 15 April 1977, and with the complete fertilizer (15 g/3.8 L) at the rate of 4 L per meter of row on 11 August 1978.

Eight chambers were used to provide two O_3 treatments (CF and NF + O_3) in each of four randomized blocks. Plants in pots and growing in the ground were contained in each chamber. Plots were selected 3 wk after planting on the basis of uniform soil characteristics and appearance of plants planted in the ground within each block. Each plot consisted of two 2.75-m rows. In 1977, plants in alternate halves of each plot row were removed to make room for four pots in each half row (Fig. 1). Pots were partially buried with ~10 cm remaining above ground. In 1978, eight pots were placed in an entire row; plants in the ground remained undisturbed (Fig. 1). Field chambers (4) were installed on 13 June 1977 and 21 June 1978. Plants in one chamber per block were exposed continuously to charcoal-filtered air. Plants in the other chamber in each block were exposed continuously to nonfiltered air. Ozone was added to the inlet duct of nonfiltered-air chambers (NF-2) for 7 hr/day from 17 June through 10 October in 1977 and from 28 June through 21 October in 1978. The additions raised the seasonal 7 hr per day mean O_3 concentrations in the NF-2 chambers by 0.054 ppm above ambient O_3 levels in 1977 and by a mean of 0.037 ppm above ambient O_3 levels in 1978. Two plants from each pot and 16 plants in the ground were harvested on 17 and 10 November in 1977 and 1978, respectively.

Fertilizer rate. In this experiment, four fertilizer rates were obtained by using solutions containing 0.0, 7.5, 15.0, or 22.5 g of complete fertilizer (6-25-15, N-P-K plus micronutrients) per 3.8 L of water. Seeds were planted on 25 May in 15-L pots containing the medium described previously; seedlings were thinned to five per pot 2 wk after emergence. One liter of the solution was applied to each pot on 9 and 16 June, 7 and 28 July, and 19 August in 1977, and on 13, 20, and 23 June, 21 July, and 2 and 23 August in 1978.

Eight chambers were used to provide four O_3 levels with two replicates each. Four pots for each of the four fertilizer treatments were placed in a 4 × 4 Latin square arrangement in each chamber. The Latin-square design (fertilizer rate positions) was uniform for the four O_3 treatments of a single replicate, but differed between replicates.

Plants were exposed daily to four O_3 levels from 17 June through 10 October in 1977 and from 19 June through 12 October in 1978. Plants in one chamber per replicate were exposed continuously to charcoal-filtered air. Plants in three chambers per replicate were exposed continuously to nonfiltered air (NF-1, NF-2, and NF-3) with different, but constant, concentrations of O_3 added to the inlet duct for 7 hr per day (from 0920 hours to 1620 hours). In 1977, the additions raised the seasonal 7 hr per day mean O_3 concentration in the NF-1, NF-2, and NF-3 chambers by 0.007, 0.053, and 0.093 ppm, respectively, above ambient O_3 levels. In 1978, the seasonal mean O_3 concentrations in the NF-1, NF-2, and NF-3 chambers were raised by 0.005, 0.039, and 0.071 ppm, respectively.

One plant was sampled from each pot at 4, 5, and 6 wk after exposure began; shoot fresh weights were determined, and the percentage of foliar injury (chlorosis and necrosis) for individual trifoliate leaves was estimated visually in 5% increments (0–100%). The remaining two plants per pot were harvested after maturity on 17 November in 1977 and 31 October in 1978.

RESULTS

Ozone concentrations. The ambient O_3 concentrations during the 1977 and 1978 experiments were plotted as daily 7-hr (from 0920 to 1620 hours) and 24-hr means (Fig. 2). Seasonal mean O_3 concentrations (Table 1) and diurnal patterns of O_3 concentrations (Fig. 3) in ambient air (AA) were similar for both years. The same was true for O_3 concentrations in chambers with CF. Daily additions of O_3 to ambient O_3 in NF chambers resulted in the mean seasonal 7-hr O_3 concentrations shown in Table 1 and

TABLE 1. Mean O_3 concentrations for 7 hr per day (from 0920 to 1620 hours EDT) and 24 hr per day in field studies to determine the effects of substrate type and fertilizer rate on soybean response to O_3

	Growth medium experiment				Fertilizer study			
	7-hr O_3 addition period		24-hr		7-hr O_3 addition period		24-hr	
Treatment	1977	1978	1977	1978	1977	1978	1977	1978
Ambient air	0.062[a]	0.061[b]	0.041[a]	0.039[b]	0.062[a]	0.061[b]	0.041[a]	0.040[c]
Charcoal-filtered air	0.025	0.023	0.017	0.015	0.025	0.024	0.017	0.015
Nonfiltered air + O_3[d]								
NF-1	...	...			0.069	0.066		
NF-2	0.116	0.098			0.115	0.100		
NF-3	...	...			0.155	0.132		

[a]Mean concentrations from 17 June through 10 October 1977.

[b]Mean concentrations from 28 June through 21 October 1978.

[c]Mean concentrations from 19 June through 12 October 1978.

[d]Ozone was added to ambient air in nonfiltered (NF)-air chambers for 7 hr per day (from 0920 to 1620 hours). Concentrations in nonfiltered-air chambers when O_3 was not added were approximately equal to concentrations in ambient air × 0.87.

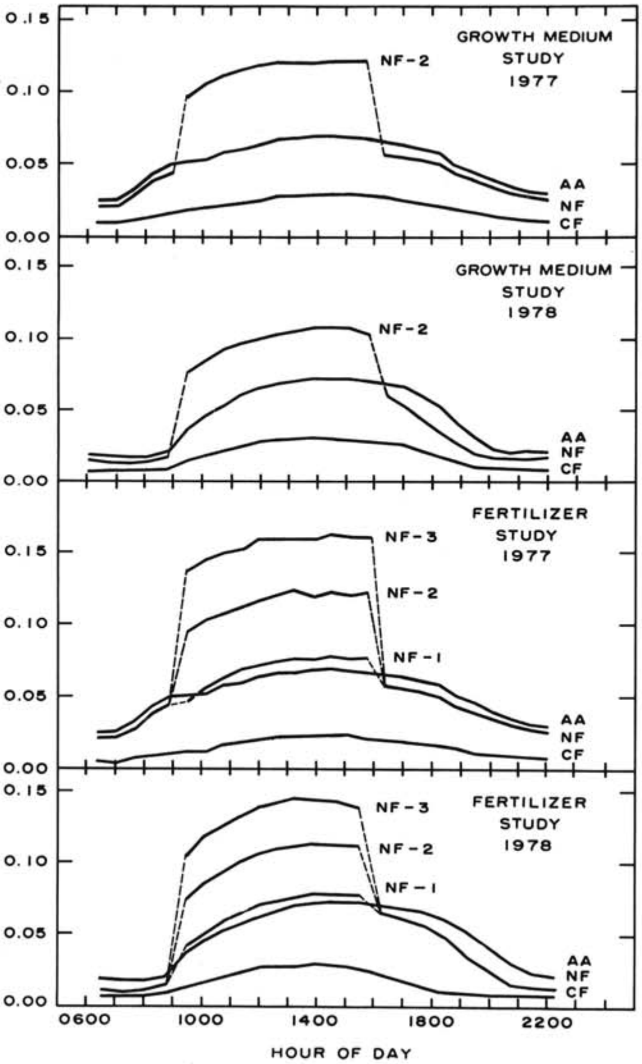

Fig. 3. Diurnal fluctuations in O_3 concentrations in ambient air (AA), chambers with charcoal filters (CF) and in nonfiltered-air chambers (NF) with different concentrations of O_3 added for 7 hr per day (NF-1, NF-2, NF-3). Means for the growth medium study are for the periods 17 June through 10 October in 1977, and 28 June through 21 October in 1978. Means for the fertilizer study are for the periods 17 June through 10 October in 1977, and 19 June through 12 October in 1978.

Fig. 3.

Growth medium. The degree that roots of potted plants entered the ground was not measured quantitatively. Observations of several pots at harvest showed no evidence of roots entering the ground. There were significant effects of growth medium and O_3 on plant growth and yield, but these effects did not change plant response to O_3. In 1977, plants in pots (two per pot) were 18% heavier (shoot weight), produced 22% more pods, and had 22% greater seed weight (yield) per plant than plants in the ground (Table 2). In 1978, the reverse was true; plants in pots (three per pot) were 9% smaller, produced 15% fewer pods, and had 15% less yield than plants in the ground. In spite of these effects of growth medium, the relative effect of O_3 on growth and yield was the same whether plants were grown in pots or in the ground in both years. In 1977, yield of potted plants at 0.116 ppm of O_3 was 53% of that at 0.025 ppm; the value for plants in the ground was 52% (Table 2). In 1978, exposure to 0.098 ppm of O_3 caused yield decreases of 28% in both growth medias (Table 2).

Fertilizer rate. Leaves were significantly injured by O_3; the effects of fertilizer rate on the foliar injury response measured at 4, 5, and 6 wk after exposures began are shown in Fig. 4. Statistically significant $O_3 \times$ fertilizer rate interactions for foliar injury occurred primarily because of results at the 0.0-g fertilizer rate (1977 and 1978) and to a lesser degree because of results at the 7.5-g fertilizer rate (1977). The $O_3 \times$ fertilizer rate interaction was somewhat different for each year, but was consistent at each sampling date for a given year. Therefore, the combined foliar injury (means) for

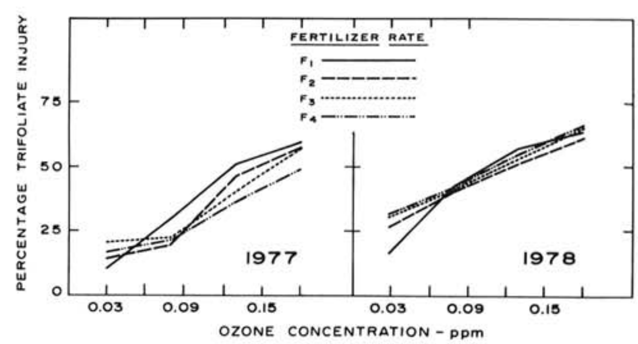

Fig. 4. Effects of O_3 on foliar injury of soybean (Davis) grown at different fertilizer rates and exposed to different doses of O_3 in open top field chambers. Each point is the mean injury per leaf on eight plants for each of three sampling dates (4, 5, and 6 wk after exposures began). Fertilizer rates F_1, F_2, F_3, and F_4 are equal to 0.0, 7.5, 15.0, and 22.5 g of a soluble complete fertilizer (6-25-15, N-P-K plus micronutrients) per 3.8 L of water.

TABLE 2. Response of cultivar Davis soybean plants to O_3 when grown in 15-L pots containing an artificial growth medium or in the ground in 1977 and 1978

		Response per year per O_3 treatment[a]					
		1977			1978		
Measure	Growth medium[b]	CF chambers-0.025 ppm O_3[c]	NF chambers-0.116 ppm O_3[d]	Loss[e] (%)	CF chambers-0.023 ppm O_3[c]	NF chambers-0.098 ppm O_3[d]	Loss[e] (%)
Pods per plant (no.)	Pots	215	153**	29	160	149	7
	Ground	168	119**	29	190	172	9
Seeds per plant (no.)	Pots	466	323**	31	361	313	13
	Ground	371	248**	33	428	376	12
Seed weight per plant (g)	Pots	80.3	42.8**	47	60.2	43.6**	28
	Ground	62.7	32.8**	48	71.1	51.2**	28

[a] Seasonal mean 7 hr/day (from 0920 to 1620 hours EDT) O_3 concentrations from 17 June through 10 October 1977 and from 28 June through 21 October 1978. Each value is the mean of 19 plants.

[b] The growth medium effect was statistically significant for all measures ($P = 0.01$ in 1977; $P = 0.05$ in 1978).

[c] Seasonal mean 7 hr/day O_3 level (ppm) in charcoal filtered-air chambers (CF).

[d] Seasonal mean 7 hr/day O_3 level (ppm) in nonfiltered-air chambers with O_3 added for 7 hr/day. ** = significantly less ($P = 0.01$) than corresponding values measured in charcoal filtered-air chambers.

[e] Percent loss is defined as $1 - (NF/CF)100$.

three sampling dates are shown in Fig. 4. In 1977, the $O_3 \times$ fertilizer rate interaction occurred mainly because plants in the 0.0-gram fertilizer treatment were injured less in the CF chambers than those at higher fertilizer rates. However, for all NF + O_3 levels, plants at 0.0 grams of fertilizer were more severely injured (LSD, $P = 0.05$) than those at higher fertilizer rates (Fig. 4). In 1978, the $O_3 \times$ fertilizer rate interaction occurred because plants in the 0.0 gram fertilizer treatment were less injured (LSD, $P = 0.05$) in the CF treatment than were those that had received fertilizer; in the other O_3 treatments, foliar injury was similar at all fertilizer rates (Fig. 4).

Fertilizer rate significantly affected plant growth for the 4-, 5-, and 6-wk samples in both years; each increment of fertilizer rate generally caused a corresponding growth increment. There were, however, no significant interactions between fertilizer rate and O_3 treatment for shoot weight. Plants in the two highest O_3 treatments were usually smaller than CF plants, but the differences were not significant except for the 4-wk samples in 1978. At this time, plant shoot fresh weights were 72, 74, 58, and 55 g in the 0.024, 0.066, 0.100, and 0.132-ppm O_3 treatments, respectively.

Exposure to O_3 resulted in decreased final shoot weight, number and weight of pods, and seed weight (yield) per plant (Fig. 5). For all treatments, seed and pod weights were affected more than shoot weight or number of pods. Fertilizer significantly increased yield in both years; the gains were generally incremental with increased fertilizer in 1977, but this relationship was not as clearly defined in 1978 (Fig. 5).

In 1977, the yield decline with increased O_3 was similar at all fertilizer rates (Fig. 5). There was no significant fertilizer rate $\times$ O_3 interaction, but the effects of O_3 tended to be greater at the 0.0-g rate than at the 7.5, 15.0, and 22.5-g fertilizer levels. For example, at 0.115 ppm of O_3, the yields for plants in the 0.0, 7.5, 15.0, and 22.5-g fertilizer treatments were 53, 36, 35, and 35% less, respectively, than yields at 0.025 ppm; at 0.155 ppm these values were 66, 56, 48, and 42% (Fig. 5).

In 1978, plants in the 0.0-g fertilizer treatments grew and yielded poorly in all O_3 treatments (Fig. 5). Soil analyses after harvest showed that phosphorus (11 mg/100 cm^3) was probably the limiting factor; phosphorus at about 70 mg/100 cm^3 is recommended for good soybean growth. However, with one exception, the effects of O_3 were similar for plants in the other fertilizer treatments; at 0.100 ppm O_3, the yield for plants in the 7.5-, 15.0-, and 22.5-g treatments were 30, 30, and 2% less, respectively, than yield at 0.024 ppm; at 0.132 ppm O_3, these values were 36, 40, and 39% (Fig. 5). The apparent anomaly for plants in the 22.5-g treatment at 0.100 ppm O_3 was due to unexplained high mean seed weight per plant (129 g) for four plants (each in separate pots) compared to a mean of 72 g for the remaining 12 plants. This anomaly, and the lack of an O_3 effect for plants at 0.0 g of fertilizer, probably were the main causes for a nonsignificant F-test ($P = 0.12$) for the O_3 effect in 1978.

DISCUSSION

In the growth medium study, plants in pots and in the ground were fertilized and irrigated to provide good growth and yield. However, the roots of potted plants were partially pot-bound at harvest for both years. Plant density in pots was varied so that potted plants yielded more (1977) or less (1978) than plants in the ground. However, the percentage of yield loss caused by O_3 was almost identical in both growth media each year. Previous field studies have shown similar results; the injury and yield responses of field corn (7) and of winter wheat (9) to chronic doses of O_3 were similar whether plants were grown in pots (soil:sand:Metro-mix) or in the ground. The yield response of winter wheat to O_3 was similar when plants were grown in Appling sandy clay loam soil or in Cecil clayey loam soil (9).

In the fertilizer-rate study, differences in growth and yield for nonfertilized plants for the 2-yr period was probably related to the low content of P (24 mg/100 cm^3) of soil used in the potting mixture in 1978. At harvest, the P contents of the potting media were 11, 30, 66, and 92 mg/100 cm^3, respectively, for the 0.0-, 7.5-, 15.0-, and 22.5-g fertilizer rates. In 1978, the nutrient stress of plants in the low

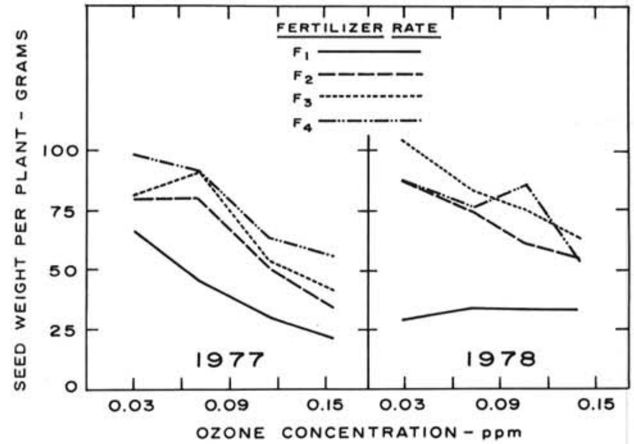

Fig. 5. Effects of O_3 on seed weight of soybean (Davis) grown at different fertilizer rates and exposed to different doses of O_3 in open top field chambers. Each point is the mean of 16 plants (two plants per pot, four pots per block, two blocks). The LSDs ($P = 0.05$) for O_3 effects were 11.9 and 21.1 in 1977 and 1978, respectively. Fertilizer rates F_1, F_2, F_3, and F_4 are equal to 0.0, 7.5, 15.0, and 22.5 g of a soluble complete fertilizer (6-25-15, N-P-K plus micronutrients) per 3.8 L of water.

fertilizer treatment resulted in limited growth. Plants limited in this way did not respond to additional stress imposed by O_3. However, for both years, the yield response to O_3 was similar for plants treated with intermediate fertilizer rates. Thus, we have not attempted to identify the cause for the variable response of plants with no fertilizer added. The present results resemble those of a greenhouse study in which 0.60 ppm of O_3 for 1.5 hr caused similar decreases in shoot weight of soybean when plants were fertilized at either of two intermediate rates; plant responses at low or high fertilizer rates were generally less than at intermediate rates (5).

The results of this and previous work suggest that physical or nutritional characteristics of growth substrates will not cause major changes in the magnitude of plant response to chronic doses of O_3 when requirements for normal plant growth are met. Further work seems warranted to determine whether similar results will occur for other plant species or other pollutants.

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