Final Report For ARB Agreement A3-047-33

THE EFFECTS OF OZONE AND SULFUR DIOXIDE ON COTTON GROWTH AND QUALITY

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16. Abstract (Limit: 200 words)

In a two year study, two varieties of cotton, Acala SJ-2 and Acala SJC-1, were exposed to SO_2 and ambient oxidants alone and in combination using open top field chambers. Two levels of SO_2, 0.05 ppm and 0.10 ppm were applied for six hours per day, four days per week. SO_2 at 0.10 ppm reduced yields of SJ-2 cotton in both ambient and filtered air. SO_2 at 0.10 ppm in combination with ambient oxidants reduced yield of SJC-1 cotton by 16% in the second year. SO_2 in filtered air did not reduce SJC-1 cotton yield. No changes in cotton quality were observed. Poor growing conditions during the first year and a severe infestation of verticillium, a soil borne fungal disease, during the second year may have obscured the impact of air pollution on yields.

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Prepared for California Air Resources Board

FINAL REPORT ON ARB CONTRACT A3-047-33

January 15, 1985

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ABSTRACT

Experiments were conducted for two years (1983 and 1984) to determine the impact of ambient oxidants and realistic concentrations of SO_2, both alone and in combination on two varieties of Acala-type cotton. Cotton is by far the most important field crop grown in the San Joaquin Valley, accounting for returns annually of over 1.5 billion dollars to the economy of the region.

Acala SJ-2, the most commonly grown variety in the San Joaquin Valley, accounting for 79% of the planted acreage, and SJC-1, a promising new variety, were planted in 12 foot square plots enclosed by open top, plastic covered, force ventilated chambers. Anhydrous SO_2 in amounts necessary to produce concentrations of .05 and .10 ppm SO_2 by volume was metered into the air streams ahead of the blowers six hours per day four days per week during the growing season (June through September). The treatments used in these experiments were as follows:

1. Filtered air chambers
   (all air passed through activated carbon filters)
2. Ambient air chambers
   (no filters)
3. Filtered air plus .05 ppm SO_2
   (six hours per day, four days per week)
4. Filtered air plus .10 ppm SO_2
   (six hours per day, four days per week)
5. Ambient air plus .05 ppm SO_2
   (six hours per day, four days per week)
6. Ambient air plus .10 ppm SO_2
   (six hours per day, four days per week)
7. Outside plots
   (same size but no chamber walls).

Care was taken to keep other growing conditions as nearly alike in all chambers as possible. Temperature, humidity, light intensity and soil fertility were uniform from plot to plot. In 1984, the second season,

damaging levels of Verticillium, a soil-borne fungal disease was rampant in some but not all plots. This disease attacks the mature cotton plant during the period of boll development, usually stopping or significantly reducing normal maturation of bolls, thereby reducing or masking the potential impact of other environmental factors, such as air pollution, on yields.

Yields of raw cotton (lint and seed) indicated significant reductions due to the higher SO_2 concentration (1.0 ppm) with variety SJ-2 both in ambient and filtered air. With variety SJC-1 there was no significant impact of SO_2 in 1983 but in 1984 the combination of oxidants (ambient air) plus SO_2 produced a significant reduction.

There were no significant effects of the treatments used on lint to seed ratio, fiber length, diameter (micronaire), strength, elasticity or uniformity.

Results of these experiments indicate that cotton, especially the SJ-2 variety, when exposed to concentrations of .10 ppm or more SO_2 for prolonged periods will probably suffer significant reductions in yields, and therefore result in reduced financial returns to the farmer.

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This report was submitted in fulfullment of Air Resources Board Contract Number A3-047-33, The Effects of Ozone and SO_2 on SJ-2 and SJC-1 Cotton Growth and Quality, by the University of California under the sponsorship of the California Air Resources Board. Work was completed as of January 15, 1985.

DISCLAIMER STATEMENT

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commerical products, their source or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products.

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SUMMARY AND CONCLUSIONS

The most significant result of this experiment was an adverse effect of SO_2 on SJ-2 cotton, the primary cotton variety in the San Joaquin Valley. SO_2 at a level of 0.10 ppm maintained six hours per day, four days per week reduced boll set approximately 20% and raw cotton yields 22.5% in this experiment. The combination of ambient oxidants and .10 ppm SO_2 (Treatment 6) also resulted in 16% lower raw cotton yields by cotton variety SJC-1 compared with ambient oxidants only (Treatment 2). Addition of .10 ppm SO_2 to carbon filtered air had no significant effect, however, an indication of possible synergism.

Verticillium infection became rampant in the cotton plots in 1984. The 1983 growing season was a poor one for cotton due to a wet, cold spring followed by a warm summer. The weather in 1984 was ideal for growing cotton, but potential response to pollution stress was limited by the disease factor. The test plots have been fumigated twice with a mixture of chloropicrin and methyl bromide to remedy the situation in future experiments.

It can be concluded from these experiments that SO_2 concentrations in the range of .10 ppm for six or more hours per day over a prolonged period will have a detrimental effect on cotton yields, in addition to effects, if any, that ambient oxidants might have. This information should be of interest to cotton growers and air pollution control agencies in Kern and Kings Counties who are faced with both oxidant and SO_2 air pollution.

RECOMMENDATIONS

1. California cotton acreage should be protected by preventing exposure to SO_2 concentrations of the length and magnitude found detrimental in this study (0.1 ppm for six hours, four days per week) during growth, flowering and boll development stages.

2. When this study was initiated (1982) it was the opinion of most cotton breeders and growers that Acala SJC-1 would replace the old variety Acala SJ-2 within a few years. This has not been the case, and will probably not happen. Other more promising varieties are in the testing stage at present. When and if one or several of these displace SJ-2 as the dominant variety(ies) planted in the San Joaquin Valley, experiments should be conducted to evaluate air pollution sensitivity(ies) relative to SJ-2.

3. Results of this experiment indicate a significant negative response by Acala cotton to prolonged exposure to SO_2 at a concentration of 0.1 ppm. The present California ambient air quality standards, primarily based on human health considerations, would not be exceeded by six hour episodes averaging 0.1 ppm - it would require in excess of twelve hour daily episodes (twice the length of our exposures) averaging 0.1 ppm to exceed the 24-hour standard of 0.05 ppm (in the presence of oxidant and particulate matter). With the diurnal wind patterns present in the San Joaquin Valley, as well as most other major agricultural areas of California, continuous SO_2 exposure for more than twelve hours is very unlikely. Lowering the standard to 0.05 ppm for six instead of 24 hours would provide the protection indicated as being necessary to protect crops such as cotton.

INTRODUCTION

Cotton is the most important field crop grown in the San Joaquin Valley with an annual return to the growers of over one billion dollars. An additional one-half billion dollars in revenue is generated within the valley by ginning and processing the cotton lint, seed, and by-products.

Due to climatic limitations, Acala-type cotton is grown principally on the great central valley floor between Merced to the north and the Tehachapi Mountains to the south. Long fiber or "Pima" type cotton is grown in the desert valleys of eastern Riverside and Imperial Counties.

Previous air pollution studies with cotton (Brewer 1973, 1979 and Temple 1985) had demonstrated that cotton was sensitive to oxidant-type air pollution and that some varieties were considerably more sensitive than others. In general the eastern varieties were the most sensitive followed by the California Acala varieties 1, 2, 3, 4 and 5 in order of decreasing sensitivity. Ambient oxidants at Parlier were found to reduce SJ-1 yields approximately 30%, SJ-2 approximately 18% and SJ-5, the last of the "SJ" series, less than 5%. The effect of ozone on a new "C" series of Acala cotton bred for California by the California Planting Cotton Seed Distributors (CPCSD) was not known previously and its determination was one of the objectives of this study. To the author's knowledge there is no information available concerning the SO_2 sensitivity of any of the Acala varieties. At the present time (1984) approximately 79% of the San Joaquin Valley cotton acreage is planted to SJ-2, 8% to SJ-5 and 13% to SJC-1 or its commercial equivalent, Germains Acala 510.

Most of the cotton grown in the San Joaquin Valley is exposed to ambient oxidant concentrations exceeding .08 ppm (8 pphm) on most of the days between blossom set (mid-June) and boll development (late September). Generally cotton growing on the east side of the valley is exposed to higher concentrations of

ozone than that grown on the west side. In some parts of the valley, primarily areas of Kings, Fresno and Kern Counties, cotton is grown near oil-producing facilities known to release some SO_2. Secondary oil recovery accomplished by burning crude oil to heat steam which is injected in one of several adjoining wells to enhance the production of its neighbors is suspected of being a significant source of SO_2.

OBJECTIVES

The objectives of this study were as follows:

1. To compare ozone sensitivity of Acala SJC-1 cotton with that of SJ-2.
2. To determine the response of both SJ-2 and SJC-1 cotton to three concentrations of SO_2 in the atmosphere.

EXPERIMENTAL PROCEDURE

Treated seed of two cotton varieties, Acala SJ-2 and Acala SJC-1 were direct seeded into prepared raised beds enclosed by open top plastic growth chambers. Figure 1 shows a layout of the cotton rows in relation to the blower and air ducts. In half the replications variety SJ-2 was planted in the easternmost three rows; SJC-1 to the west. In the other half of the replications the planting order was reversed with SJC-1 to the east and SJ-2 on the west. The blowers are on the north side of the twelve foot square chambers. The plot locations in 1983 and 1984 are shown in Figure 2.

Air Treatments

Six different air treatments were used in this experiment with cotton. Table 1 lists these treatments together with the approximate ozone and SO_2 concentrations maintained during the growing season. Treatment 7 which was

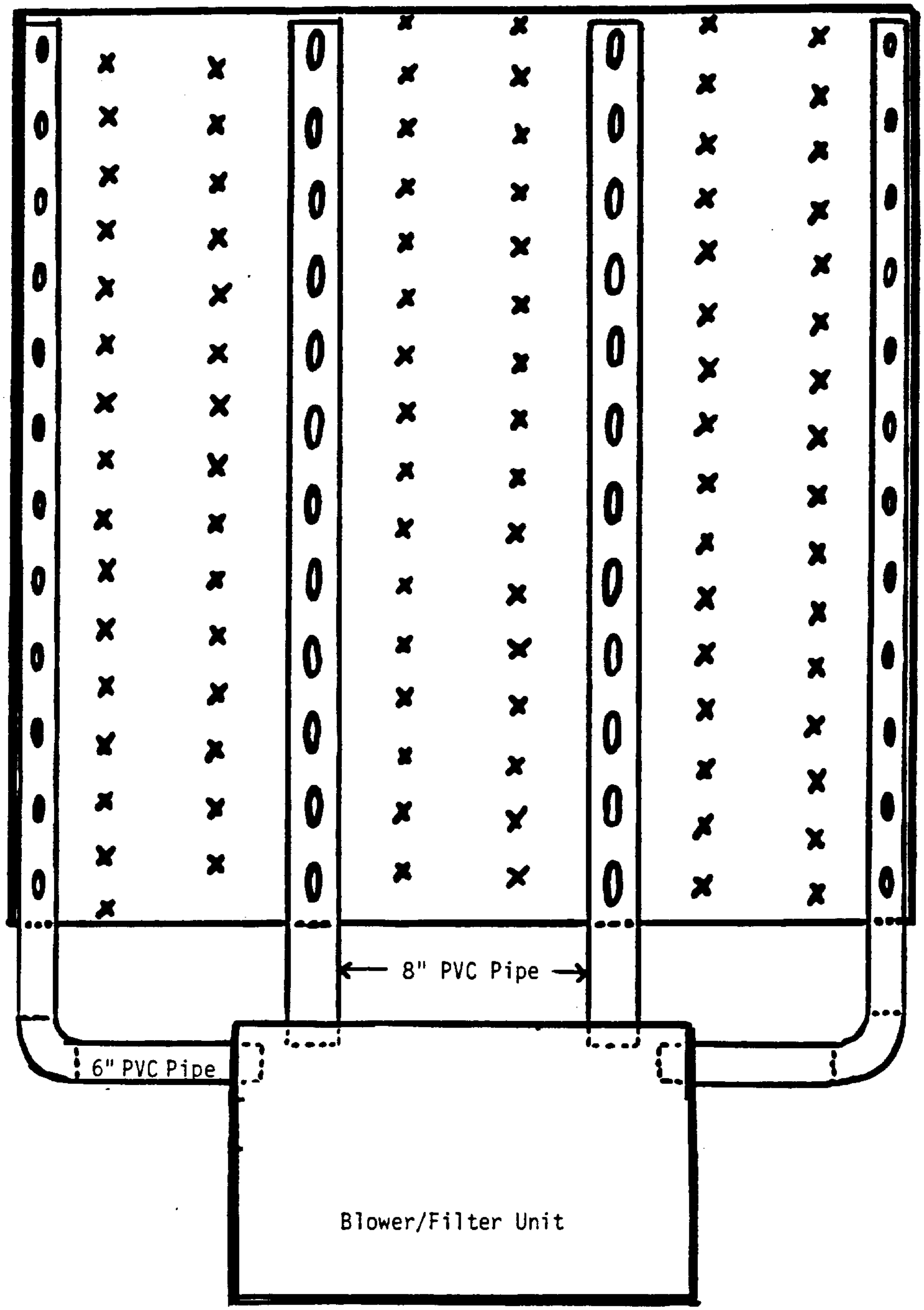


Figure 1. Layout of individual cotton rows in relation to air ducts.

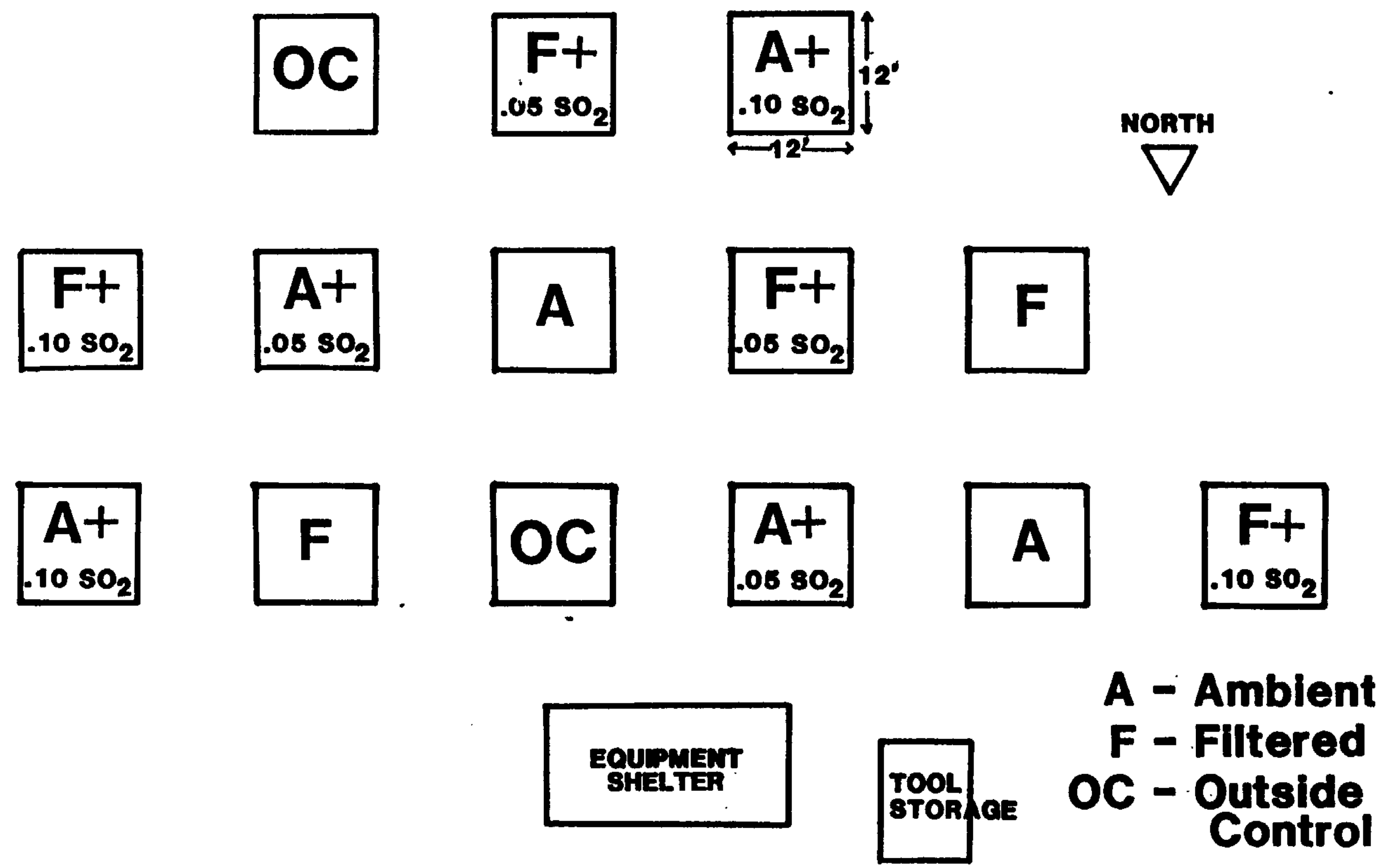


Figure 2. **1983-84 PLOT LOCATIONS FOR SJ2 AND SJC1 COTTON**

essentially the same as treatment 2 except there was no chamber enclosure, was used to provide a measure of the "chamber" effect. The more negligible the chamber effect, the greater confidence one has in applying chamber data to field conditions.

Table 1. Ozone and SO_2 concentrations applied to cotton, 1983 and 1984.*

Treatment	Description	O_3 Conc.	SO_2 Conc.**
1	Filtered Air	20-25% of Ambient	None added***
2	Ambient Air	95% of Ambient	None added***
3	Filtered Air + Low SO_2	20-25% of Ambient	.05 ppm
4	Filtered Air + Moderate SO_2	20-25% of Ambient	.10 ppm
5	Ambient Air + Low SO_2	95% of Ambient	.05 ppm
6	Ambient Air + Moderate SO_2	95% of Ambient	.10 ppm
7	Outside Control Plot	100% of Ambient	None added***

* Actual pollutant doses are shown in Table 2, page 8.

** SO_2 supplied four days per week, six hours per day June 10 to October 1, 1983 and from July 6 to September 20, 1984.

*** Never have we detected a measurable amount of SO_2 in ambient air at Kearney. The threshold of sensitivity with our instruments is approximately .005 ppm.

Growth Chamber

The plastic covered open top chambers used in these experiments are igloo-shaped, having twelve foot square bases and ten foot circular openings nine feet above the plot surface. Treated or nontreated air is introduced through perforated, partially submerged air ducts at a rate calculated to change the enclosed chamber volume (1100 ft^2) twice each minute. The chambers are constructed of a light weight welded steel frame covered by 10 mil clear polyvinyl film. Air flow was provided by motor-driven forward-curve blowers individually adjusted to provide the same volume of air to all chambers. Air

flow was measured within the chambers with a hot wire anemometer and blower-filter performance was monitored by inclined oil tube manometers. Manometers are excellent indicators of reduced air flow due to defective motors, loose belts or plugged air filters.

Cultural Practices and Growing Conditions

All cultural practices were kept as similar to commercial operations as was possible within the limitations of the growth chambers. Uniform nutrient availability was provided by differential addition N, P or K fertilizer materials based on results of soil analyses. Since S (sulfur) is a plant nutrient and was being studied as an air pollutant, a generous application of gypsum ($CaSO_4$) was made to all plots to assure adequate sulfate availability and thereby remove the possibility of a positive response to S introduced into the system via the air.

Uniform irrigation was provided by low pressure porous dual wall drip tubing laid hole-down between the rows of cotton on the raised beds. Initial irrigation timing was based on pressure bomb Leaf Moisture Tension measurements as prescribed by Grimes (1978).

Air and soil temperatures within the chambers were monitored continuously using copper constantan (Type T) thermocouples and were found to vary little from comparable locations in outdoor plots. Relative humidity and light intensities (PAR) were measured periodically to insure that conditions were uniform from chamber to chamber and not too different from outside conditions. Frequent scrubbing of the plastic chamber walls with a soft sponge dipped in a special detergent helped keep the plastic transparent and minimized dust, buildup due to "static cling."

Anhydrous SO_2 (sulfur dioxide), in amounts required to maintain the designated concentrations (.05 or 0.1 ppm) was metered into the air stream

ahead of the motorized blowers to assure complete mixing. Actual SO_2 concentrations in the chambers were monitored with a TECO SO_2 analyzer and recorded on a roll chart potentiometric recorder. Similarly, ozone concentrations were continuously monitored with a Daisibi ozone analyzer and recorded with a second potentiometric recorder. Tables 2 and 3 contain SO_2

Table 2. SO_2 dose to which cotton was exposed in 1983 and 1984. Dose is expressed in pphm-hrs (parts per hundred million hours).

Treatment	Description	1983	1984
1	Filtered	0	0
2	Ambient	0	0
3	Filtered +.05 SO_2	2,098	1,476
4	Filtered +.10 SO_2	4,350	2,997
5	Ambient +.05 SO_2	2,098	1,476
6	Ambient +.10 SO_2	4,350	2,997
7	Outside Plot	0	0

Table 3. Ozone dose to which cotton was exposed in 1983 and 1984. Dose is expressed in PPHM hrs above thresholds of .5, 5 and 10 pphm.

Treatment	Description	1983			1984		
		>.5	>5	>10	>.5	>5	>10
1	Filtered	4755	739	24	4865	1098	51
2	Ambient	11810	3610	218	12350	3907	306
3	Filtered +.05 SO_2	4755	739	24	4865	1098	51
4	Filtered +.10 SO_2	4755	739	24	4865	1098	51
5	Ambient +.05 SO_2	11810	3610	218	12350	3907	306
6	Ambient +.10 SO_2	11810	3610	218	12350	3907	306
7	Outside Plot	13360	4146	264	13610	4392	360

and O_3 (ozone) doses to which the cotton plants were exposed in both the 1983 and 1984 growing seasons. Monthly ozone doses and peak hourly ambient ozone concentrations for 1983 and 1984 are presented in Appendixes A, B, and C, respectively. Typical daily SO_2 and O_3 concentration profiles are shown in Appendixes D, E and F. For the most part daily maximum ozone concentrations ranged between 0.05 and 0.10 ppm during most of the cotton growing season, with infrequent maximums below 0.1 or above 0.15 ppm. In no instance did the recorded ambient ozone concentration exceed 0.2 ppm.

Two environmental factors which had significant impact on the results of this two year study were:

1. A cold, wet spring and early summer in 1983 which resulted in slow seed germination with subsequent poor cotton growth.
2. The appearance of severe Verticillium fungus infestations in some, but not all of the experimental plots in 1984.

Cotton is a hot weather crop. Cotton seed requires a minimum soil temperature of 60°F (15.6°C) to germinate and the young, developing plants require warm days (and nights) to grow properly. Cool, wet weather such as the central valley experienced in April, May and early June of 1983 would therefore have a significant impact on the season's crop and thereby influence the response of that crop to other environmental factors including air pollution.

The verticillium fungus (*Verticillium dahliae*) found here in the central San Joaquin Valley is very ubiquitous and able to flourish on crops such as cotton and tomatoes. Planting to grains such as wheat, oats or barley have been found to reduce the fungal population, probably because the soil is often left dry a significant part of the season. Irrigated crops such as alfalfa and sugar beets also depress the populations somewhat, but to a lesser degree. Our plots were established in an area where cotton had been grown continuously for four years (1972 through 1976) and then again in 1978. There were no appreciable

expressions of verticillium in any of these cotton plantings. In 1983 some of the SJ-2 plants exhibited symptoms of verticillium infection, but it was not considered a significant factor that season. In 1984 the manifestations of the disease were a very significant factor, especially on the SJ-2 variety.

Typically, cotton plants display symptoms of the disease (discolored stems, necrotic leaves and apical dieback) in mid-August or early September which is during the period of boll development. If the cotton plant is severely afflicted and dies, boll development ceases; if the infection is less severe, the plant may survive but be stunted in growth with boll development reduced somewhat. The new Acala variety SJC-1 is much more resistant to verticillium attack than is the older Acala variety SJ-2. In 1984 up to 30% of the SJ-2 plants in some but not all of the experimental plots were seriously affected by the disease. Most of the SJC-1 plantings were relatively free of the disease, although as many as 20% of the plants in several plots exhibited symptoms of chronic infestation (red streaked stems and terminal dieback).

All of the yield and product quality data obtained in this study was subjected to a standard (Fisher, 1954) analysis of variance. If the treatment factor was significant (probability >20 to 1, confidence level .05) the data was then subjected to Duncan's multiple range test for differences among treatment means.

RESULTS AND DISCUSSION

Plant Responses

As was the case in previous air pollution experiments with cotton, the most pronounced visible symptom of air pollution was accelerated senescence of the upper leaves which begins as a slight interveinal chlorosis and progresses to a general bronzing or purpling of the leaf surfaces. A color

print of these symptoms was included in the Final Report for ARB Agreement A7-119-30, page 17. Symptoms of excess sulfur accumulation developed in plots receiving the high (0.1 ppm) SO_2 treatment. These symptoms were mainly those commonly associated with salt accumulation -- namely chlorosis and then marginal necrosis of older bottom leaves. There were no classic symptoms of acute SO_2 injury of the type commonly observed on deciduous vegetation (see Malhotra and Blauel, 1980, p. 25 or Linzon, 1969, Chapter VIII in Vegetation Damage). It has been the observation of many workers that foliar toxicity symptoms due to high sulfate concentrations in the substrate (root uptake) are similar to those associated with exposure to atmospheres containing sub-acute concentrations of SO_2. In both cases the sulfate accumulates faster than it can be reduced to the less toxic sulfide forms (Eaton, et al., 1971).

Raw and Processed Cotton Yields

Table 4 contains raw cotton yield data for the years 1983 and 1984. Table 5 contains corresponding boll count data. Although the ambient plots averaged approximately 10% less bolls and raw cotton than did the filtered plots, these differences were not quite statistically significant at the 95% level of probability using all of the yield data from the SO_2 as well as ambient and filtered plots in the analysis of variance. If only the ambient and filtered plot data for 1983 and 1984 are pulled out (Appendix G) and combined with comparable 1978 data, we find that the filtered plots significantly outproduced the ambient plots with statistical confidence of .05. The yearly yield differences were a reflection of the cool spring and summer of 1983 and the high incidence of verticillium infection in 1984. The low variance found for (filtered vs. ambient) x years indicates consistency over all the years for the filtered versus ambient comparison. A combination of red[illegible] response due to unfavorable growing conditions and reduced number of

Table 4. Raw cotton (fiber and seeds) yields from three row subplots (grams per 50 plant plot, two plots per treatment). Treatment means not showing the same subscript were found to be significantly different at .05 level using Duncan's Multiple Range test.

Treat-ment	Description	1983 Yields SJ-2	1983 Yields SJC-1	1984 Yields SJ-2	1984 Yields SJC-1	Two Year Total SJ-2	Two Year Total SJC-1
1	Filtered Air	2372_a	1624_a	$^V2190_a$	1868_a	4561_a	3492_a
2	Ambient Air	2168_{ab}	1848_a	2002_a	2185_b	4170_{ab}	4033_b
3	Filtered +.05 SO_2	2045_b	1613_a	$^V2098_a$	2322_b	4142_{ab}	3935_{ab}
4	Filtered +.10 SO_2	1835_c	1677_a	$^V2164_a$	2147_{ab}	3999_b	3824_{ab}
5	Ambient +.05 SO_2	2063_b	1886_a	$^V2192_a$	2139_{ab}	4255_{ab}	4025_b
6	Ambient +.10 SO_2	$^V1588_c$	1612_a	$^V2028_a$	1784_a	3616_b	3396_a
7	Outside Plot	2892_d	2634_b	$^V2351_b$	2682_c	5243_c	5316_c
<u>Variable Means</u>	(Average of four plots)						
A	Filtered plots (except .10 SO_2)	2208_a	1618	2144	2095	4351_a	3713_a
B	Ambient plots (except .10 SO_2)	2115_a	1867	2097	2162	4212_a	4029_b
C	Moderate (.10) SO_2	1711_b	1644	2096	1965	3807_b	3609_a

^{V} More than 20% of plants in at least one plot affected by Verticillium.

Table 5. Boll counts, 1983 and 1984, recorded as bolls per plot (approximately 50 plants per plot, two plots). Treatment means not showing the same subscript were found to be significanly different as .05 level using Duncan's Multiple Range test.

Treat-ment	Description	1983 Yields		1984 Yields		Two Year Total	
		SJ-2	SJC-1	SJ-2	SJC-1	SJ-2	SJC-1
1	Filtered Air	381_a	294_a	432	370	813	664
2	Ambient Air	348_{ab}	308_a	416	430	764	738
3	Filtered +.05 SO_2	327_{ab}	265_a	434	405	761	670
4	Filtered +.10 SO_2	302_b	282_a	430	439	732	721
5	Ambient +.05 SO_2	366_{ab}	321_a	456	411	822	732
6	Ambient +.10 SO_2	268_b	269_a	467	398	735	667
7	Outside Plot	430_c	426_b	454	489	884	915
Variable Means	(Average of four plots)						
A	Filtered Plots (except .10 SO_2)	354_a	279	433	387	787	667
B	Ambient Plots (except .10 SO_2)	357_a	314	436	420	793	735
C	Moderate (.10) SO_2	285_b	275	448	418	733	694

treatment replications was therefore responsible for the apparent discrepancies between the 1978 findings and the 1983 or 1984 results, both as regards magnitude of response and statistical significance.

The higher SO_2 treatment (.10 ppm six hours per day, four days per week) had a significant impact on SJ-2 variety in 1983, but the picture was so clouded by Verticillium in 1984 that no firm conclusions could be made. Variety SJC-1 did not respond to SO_2 in filtered air, but significantly lower yields were obtained in 1984 with the .10 ppm concentration of SO_2 in ambient air (Treatment 6). Combining Treatment 1 and 3 (filtered and filtered plus low SO_2) yields (A) and comparing these with combinations of Treatments 2 and 5 (ambient and ambient plus low SO_2) and Treatments 4 and 6 (filtered plus

moderate SO_2 and ambient plus moderate SO_2) doubles the data points and gives a better measure of the individual effects. The higher concentration of SO_2 (.10 ppm) reduced SJ-2 boll set by 20% and yields by approximately the same amount. There was no indication that either ambient oxidants or the introduction of SO_2 had any significant impact on variety SJC-1 boll set. Raw cotton yields for SCJ-1 were approximately 8% and 10% higher in the ambient as compared with filtered or moderate SO_2 plots, respectively.

The significant differences in both boll set and raw cotton yields found between ambient enclosed plots and outside plots in this study were probably the result of forced ventilation on Verticillium development. The high rate of air exchange necessary to prevent significant temperature increase during midday causes slight (1 to 2°F) temperature depression due to increased evaporative cooling at night. Low night temperatures favor Verticillium development. In most previous studies with cotton grown in chambers where Verticillium was not a problem. Yields of outside plots were approximately equal to or less than yields of chamber enclosed plots.

Lint Quality and Cotton Seed Production

The raw cotton picked from the various test plots in 1983 and 1984 was ginned at the USDA Cotton Research Station at Shafter, California. The lint fractions were also subjected to standardized quality analysis. Included in these tests were lint to seed ratio, lint length, micronaire (fineness of lint), fiber strength, fiber elasticity and fiber uniformity index. The criteria tested and a brief explanation of their significance follows:

1. Lint to Seed Ratio - Weight of lint divided by weight of seed.
2. 50% Span Length - The length in inches in the test specimen spanned by 50% of the fibers - a test of fiber strength.
3. Micronaire - The fineness of the lint measured by a micronaire machine and expressed in standard micronaire units which for cotton ranges from 3 for very fine to 5 for very coarse.

4. T_1 - Fiber strength measured by a stilometer with a bundle of fibers held between two jaws separated by 1.8 inch. Strength is expressed in grams per grex.

5. E_1 - The elongation of the fibers when tested for strength in the T_1 test expressed as a percentage. An indication of elasticity.

6. Uniformity Index or Ratio - A measure of the uniformity of fiber lengths determined by dividing 50% span length by 2.5% span length and multiplying by 100.

Table 6 lists the lint/seed ratios for the two years. There were no significant differences in lint/seed ratio which could be attributed to differences in air quality.

Table 6. Lint/Seed Ratio for 1983 and 1984 pickings.

Treatment	Description	1983* SJ-2	1983* SJC-1	1984* SJ-2	1984* SJC-1
1	Filtered	.600	.569	.546	.556
2	Ambient	.600	.566	.554	.571
3	Filtered +.05 SO_2	.610	.578	.566	.563
4	Filtered +.10 SO_2	.593	.577	.553	.566
5	Ambient +.05 SO_2	.574	.565	.556	.564
6	Ambient +.10 SO_2	.567	.557	.559	.566
7	Outside Plot	.603	.599	.546	.574

* None of the treatment means were found to be significantly different at the .05 level using an analysis of variance.

Other important criteria of cotton fibers include span length (Table 7) micronaire (Table 8), fiber strength and elongation (Table 9) and uniformity index or ratio (Table 10).

The fiber lengths in 1984 were slightly longer than in 1983, a result of a better growing season for cotton, but there were no significant differences in fiber length attributable to differences in air quality.

Table 7. 50% span length of cotton produced in the various air treatments. This test is a measure in inches of the length spanned by 50% of the fibers.

Treatment	Description	1983* SJ-2	1983* SJC-1	1984* SJ-2	1984* SJC-1
1	Filtered	.53	.52	.58	.60
2	Ambient	.53	.54	.58	.59
3	Filtered +.05 SO_2	.53	.53	.58	.56
4	Filtered +.10 SO_2	.55	.54	.58	.60
5	Ambient +.05 SO_2	.52	.55	.58	.60
6	Ambient +.10 SO_2	.52	.52	.56	.58
7	Outside Plots	.51	.53	.54	.58

* None of the means were significantly different at .05 level using an analysis of variance.

Table 8. Micronaire (fineness) measurements for the 1983 and 1984 cotton crops. These units range from 3 for very fine to 5 for very coarse.

Treatment	Description	1983* SJ-2	1983* SJC-1	1984* SJ-2	1984* SJC-1
1	Filtered	4.45	4.55	4.20	4.29
2	Ambient	4.60	4.05	4.36	4.48
3	Filtered +.05 SO_2	4.65	4.45	4.30	4.42
4	Filtered +.10 SO_2	4.45	4.45	4.28	4.25
5	Ambient +.05 SO_2	4.75	4.40	3.95	4.35
6	Ambient +.10 SO_2	4.25	4.05	4.09	4.20
7	Outside Plot	4.65	4.25	4.44	4.44

* Statistical analyses of variance indicated no significant differences between means.

Table 9. Fiber Strength (T_1) and Elasticity (E_1) values for 1983 and 1984 cotton lint samples. Both characteristics are determined by a stiometer on which a uniform bundle of fibers are clamped between two jaws and subjected to increasing strain until separation occurs.

		Fiber Strength (T_1)				Elasticity (E_1)			
		1983*		1984*		1983*		1984*	
Treatment	Description	SJ-2	SJC-1	SJ-2	SJC-1	SJ-2	SJC-1	SJ-2	SJC-1
1	Filtered	27.0	26.0	25.8	29.0	8.2	8.2	7.3	7.2
2	Ambient	25.9	27.3	25.6	27.0	7.9	8.2	7.3	6.8
3	Filtered +.05 SO_2	25.6	27.5	26.4	26.6	8.0	7.5	6.7	6.6
4	Filtered +.10 SO_2	24.4	27.8	26.8	25.8	8.5	8.1	6.8	7.2
5	Ambient +.05 SO_2	25.6	28.8	27.2	26.3	8.1	8.0	6.5	6.8
6	Ambient +.10 SO_2	25.0	27.7	26.0	26.6	8.3	8.1	6.5	6.8
7	Outside Plot	24.8	26.7	25.4	26.2	8.1	8.5	7.0	6.9

* Analysis of variance indicated no significant differences among means for any given variety for any one year.

Table 10. Uniformity ratios (expressed as quotient of 50% span divided by 2.5% span) for 1983 and 1984.

Treatment	Description	1983* SJ-2	1983* SJC-1	1984* SJ-2	1984* SJC-1
1	Filtered	45	46	48	49
2	Ambient	47	47	48	48
3	Filtered +.05 SO_2	47	46	48	47
4	Filtered +.10 SO_2	49	49	49	50
5	Ambient +.05 SO_2	49	47	48	50
6	Ambient +.10 SO_2	46	45	47	48
7	Outside Plot	46	48	46	48

* None of these means were significantly different at .05 level using an analysis of variance.

REFERENCES CITED

1. Brewer, Robert F. and G. Ferry. 1974. Effects of Air Pollution on Cotton in the San Joaquin Valley. California Agric. 28(6):6-7.

2. Brewer, Robert F. 1979. The Effects of Present and Potential Air Pollution on San Joaquin Valley Cotton, Final Report for ARB Agreement A7-119-30. June 15, 1979. 41 pages.

3. Temple, Patrick T., O. Clifton Taylor and Lawrence F. Benoit. 1985. Cotton yield responses to oxone as mediated by soil moisture and evapotranspiration. J. Environ. Qual. 14:55-60.

4. Grimes, D. W., W. L. Dickens and H. Yamada. 1978. Early-season Water Management for Cotton. Agronomy Journal Vol. 70:1009-1012. Nov.-Dec. 1978.

5. Duncan, David B. 1955. Multiple Range and Multiple F Tests. Biometrics, 11:1-42.

6. Fisher, R. A. 1954. Statistical methods for research workers. Hafner Pablo. 356 p.

7. Malhotra, S. S. and R. A. Blauel. 1980. Diagnosis of Air Pollutant and Natural Stress Symptoms on Forest Vegetation in Western Canada. Information Report NOR-X_ 228. Northern Forest Research Centre, Canadian Forestry Service, Environment Canada, Edmonton, Alberta, Canada. p. 24.

8. Linzon, Samuel N. 1969. Symptomology of sulfur dioxide injury on vegetation, in <u>Vegetation Damage</u>, Handbook of effects assessment, edited by N. Lacasse and W. Moroz, Pennsylvania State University, Chapter VIII, 13 pages.

9. Eaton, F. M., W. R. Olmstead and O. C. Taylor. 1971. Salt injury to Plants with special reference to cations versus anions and ion activities. Plant and Soil 35:533-547.

APPENDIXES

Appendix A

Ozone dosages - Cotton (pphm-hrs)

		1983						
Threshold	Treatment	May	June	July	August	September	October	Total
0.5 pphm	Filtered Chamber	2040	845	610	520	405	335	4755
	Ambient Chamber	2040	1960	2310	2270	1920	1310	11810
	Outside Ambient	2040	2270	2580	2560	2310	1600	13360
5 pphm	Filtered Chamber	444	177	46	53	19	0	739
	Ambient Chamber	444	699	809	802	498	358	3610
	Outside Ambient	444	808	917	989	628	451	4146
10 pphm	Filtered Chamber	18	6	0	0	0	0	24
	Ambient Chamber	18	34	62	73	19	12	218
	Outside Ambient	18	44	72	80	33	17	264

		1984						
Threshold	Treatment	May	June	July	August	September	October	Total
0.5 pphm	Filtered Chamber	2270	985	615	575	420	-	4865
	Ambient Chamber	2270	2290	2945	2815	2030	-	12350
	Outside Ambient	2270	2490	3285	3175	2390	-	13610
5 pphm	Filtered Chamber	596	276	76	88	62	-	1098
	Ambient Chamber	596	816	895	874	726	-	3907
	Outside Ambient	596	888	1072	991	8457	-	4392
10 pphm	Filtered Chamber	40	11	0	0	0	-	51
	Ambient Chamber	40	58	84	84	40	-	306
	Outside Ambient	40	74	91	93	62	-	360

Appendix B

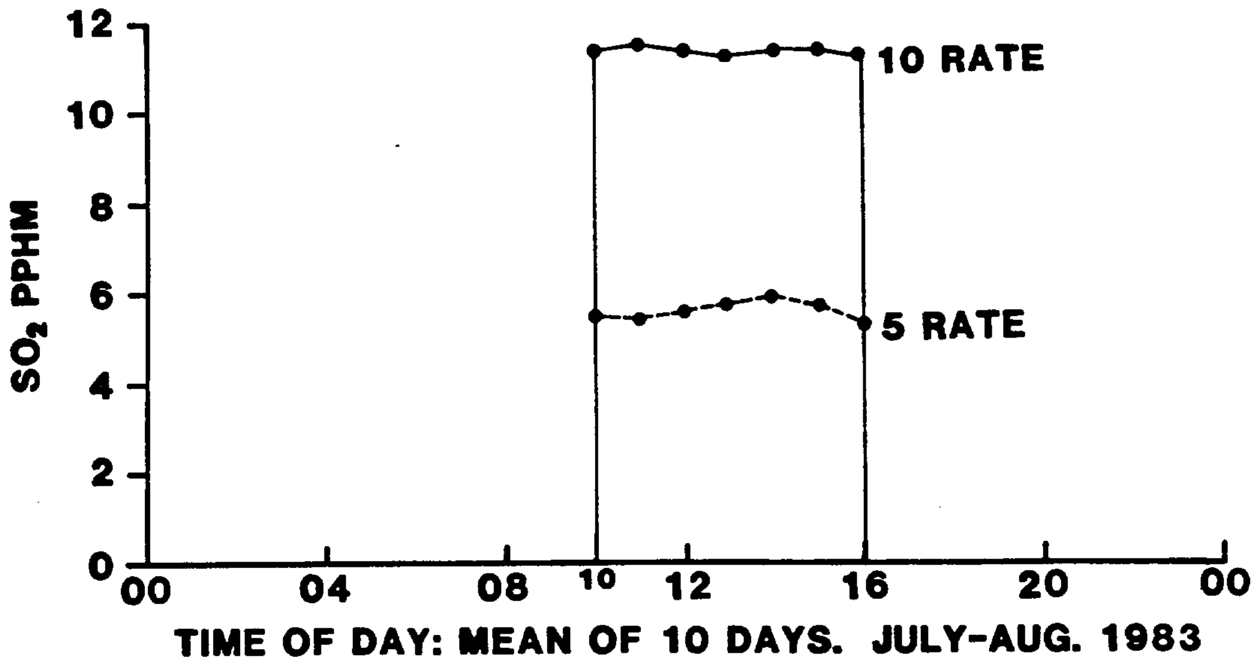
Peak hourly ambient ozone concentrations, Parlier, CA, 1983.
Concentrations are expressed as parts per hundred million (pphm)

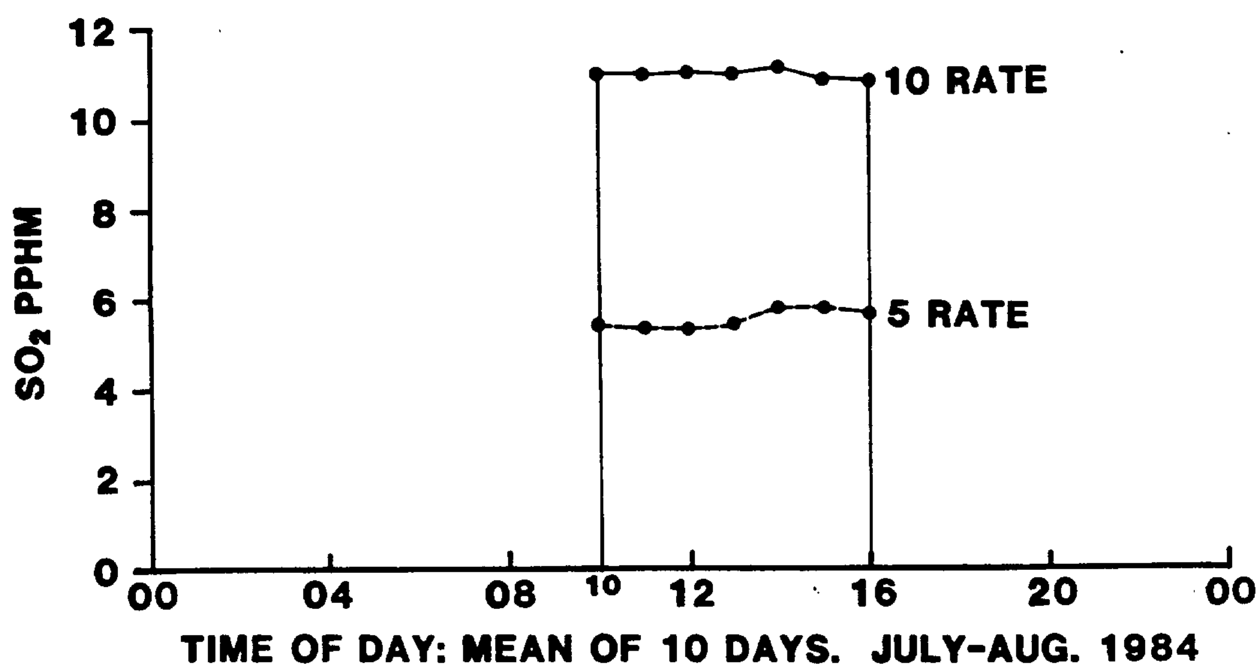
Day	May	June	July	August	September	October
1	7.4	8.4	4.6	11.6	5.5	7.7
2	7.5	9.6	6.6	11.9	6.5	8.5
3	8.9	10.3	7.2	13.6	7.8	9.3
4	9.8	9.5	10.7	7.8	9.8	9.8
5	8.7	9.0	10.7	14.2	11.7	7.7
6	7.8	8.1	6.5	10.1	11.3	7.5
7	6.7	7.1	6.1	9.4	8.9	7.6
8	5.8	7.2	5.9	11.6	7.0	5.1
9	6.4	8.2	5.0	6.7	7.2	7.8
10	7.4	9.4	9.6	7.1	10.6	8.0
11	7.4	9.2	11.5	10.8	10.7	
12	9.0	10.4	13.1	10.1	15.4	
13	10.4	10.6	11.7	10.3	13.2	
14	8.1	9.5	16.5	6.8	13.8	
15	7.5	9.4	9.4	9.6	13.4	
16	7.2	8.1	10.1	10.6	11.7	
17	6.7	7.5	6.2	8.4	12.7	
18	5.8	5.7	7.1	7.2	11.9	
19	6.1	6.7	5.7	6.2	8.8	
20	7.2	7.1	7.4	6.1	8.9	
21	8.0	9.0	14.5	6.1	6.0	
22	8.3	8.9	10.5	6.8	4.5	
23	9.5	11.0	10.8	8.8	4.3	
24	8.9	10.4	9.1	8.0	6.0	
25	7.7	9.4	6.8	9.3	5.6	
26	8.0	9.0	7.0	11.7	5.7	
27	6.3	7.3	8.0	11.9	4.9	
28	5.3	6.5	9.5	9.5	5.5	
29	6.4	7.3	12.7	11.9	3.6	
30	7.4	7.7	13.7	6.9	3.0	
31	9.0		14.3	5.5		

Appendix C

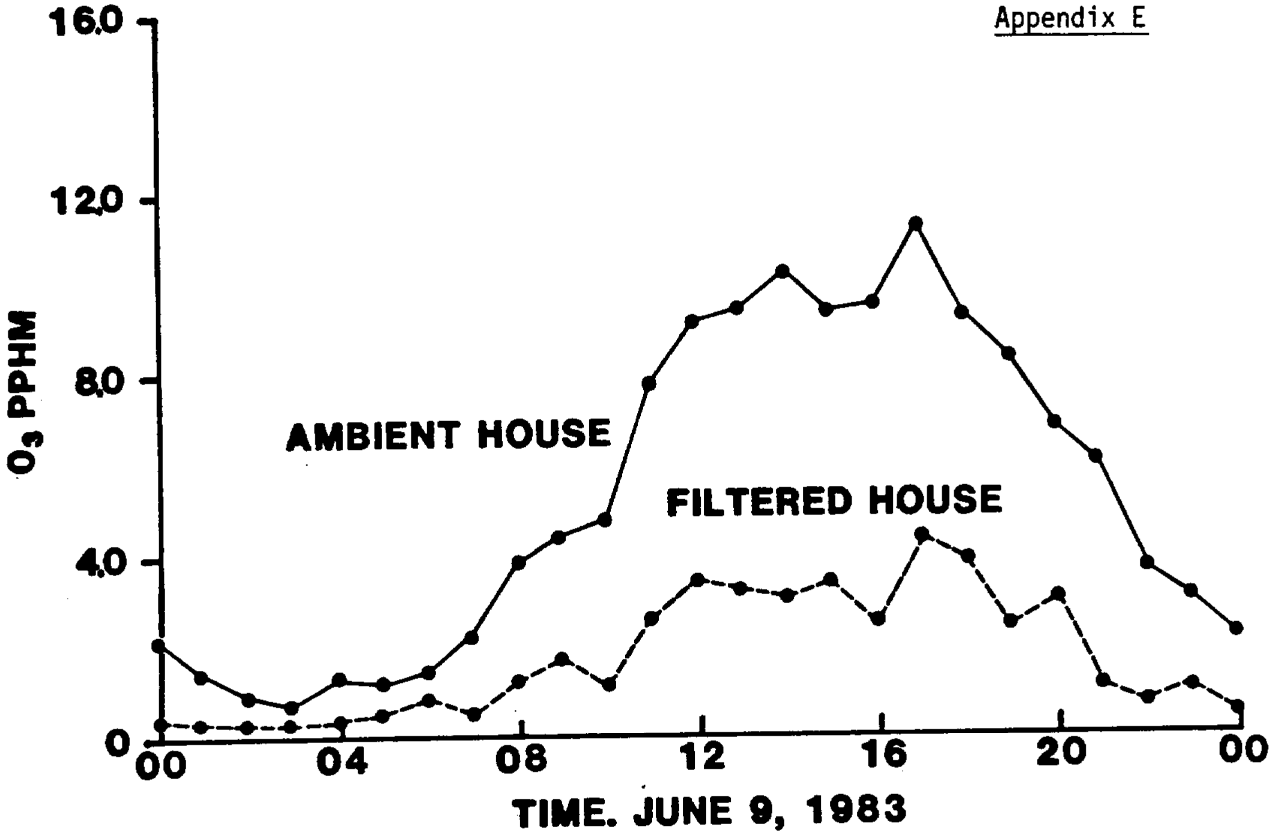
Peak hourly ambient ozone concentrations, Parlier, CA, 1984.
Concentrations are expressed as parts per hundred million (pphm)

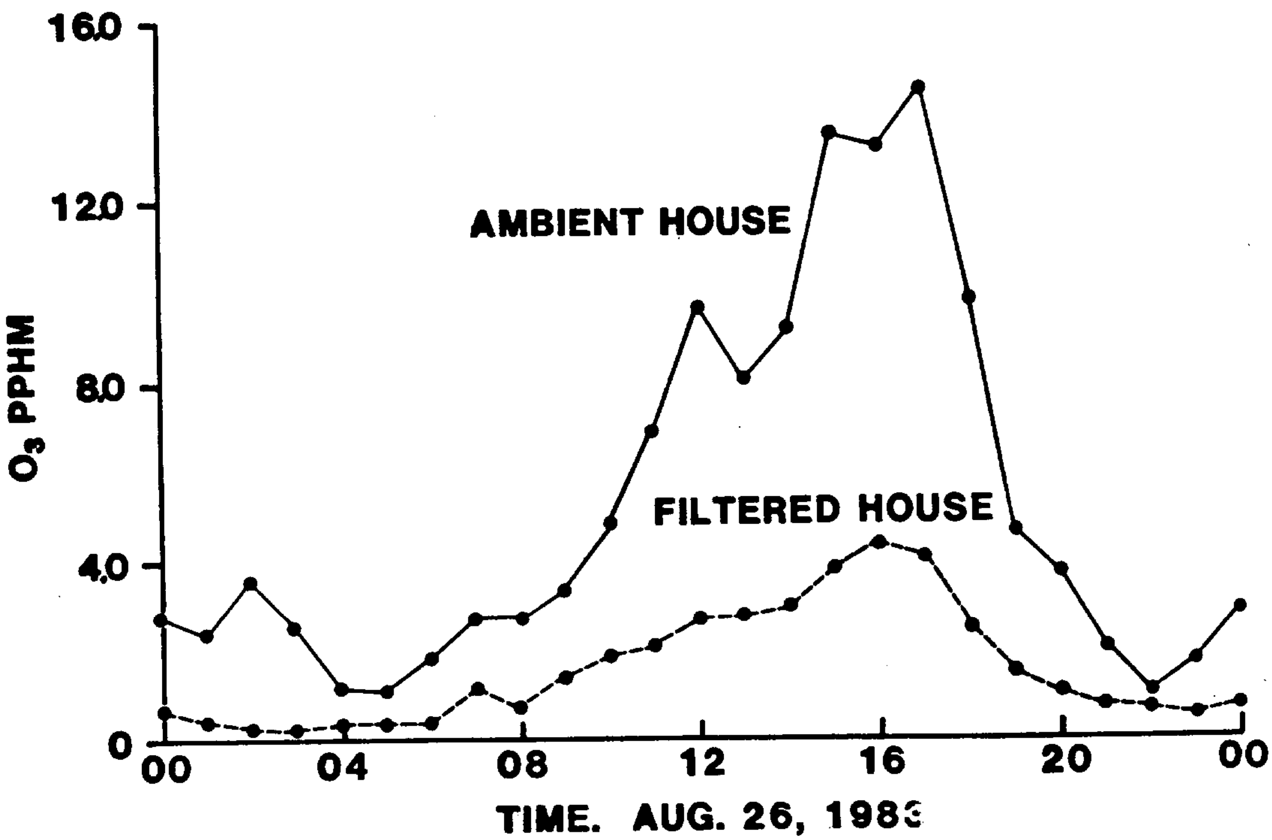
Day	May	June	July	August	September
1	4.3	10.9	14.0	11.2	8.4
2	6.0	12.2	13.1	6.0	11.1
3	4.4	12.6	9.9	7.4	9.5
4	5.0	5.7	12.6	11.9	8.5
5	5.0	7.5	11.6	10.4	10.8
6	8.1	9.3	13.8	8.0	6.8
7	8.1	8.0	13.6	12.0	9.8
8	10.3	6.9	9.6	14.4	8.0
9	10.5	7.8	10.5	13.0	10.7
10	5.2	6.1	10.8	14.4	7.7
11	7.7	9.0	12.1	11.0	5.3
12	5.1	8.4	12.7	12.4	10.0
13	4.9	9.5	17.4	13.0	10.8
14	9.4	11.2	11.9	12.4	10.2
15	5.7	11.9	12.9	6.1	13.2
16	8.7	12.3	8.8	12.7	9.9
17	11.8	12.9	13.2	13.6	10.9
18	9.1	10.3	10.5	13.1	9.5
19	7.4	9.9	9.9	9.9	11.2
20	12.3	5.7	10.2	9.8	6.2
21	9.7	7.0	8.4	12.2	8.7
22	7.1	10.2	5.9	11.1	9.4
23	9.5	13.3	8.7	10.6	9.3
24	11.6	9.9	9.9	10.1	6.7
25	10.1	12.5	10.2	9.4	9.8
26	7.0	9.1	11.1	11.9	9.6
27	6.4	12.3	11.8	10.1	8.5
28	12.6	10.9	9.3	10.3	9.7
29	12.2	6.2	7.0	12.9	11.3
30	11.6	9.5	8.3	8.6	5.3
31	8.8		11.3	9.1	



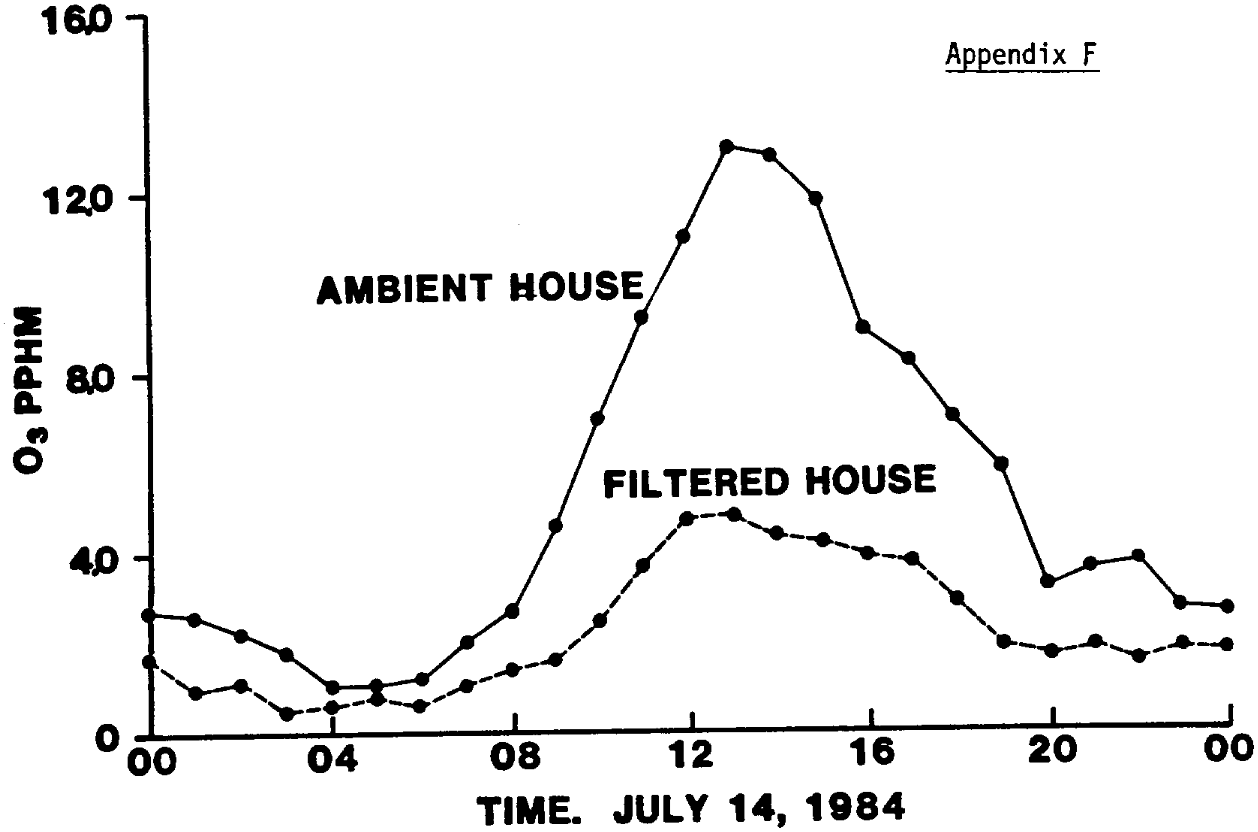


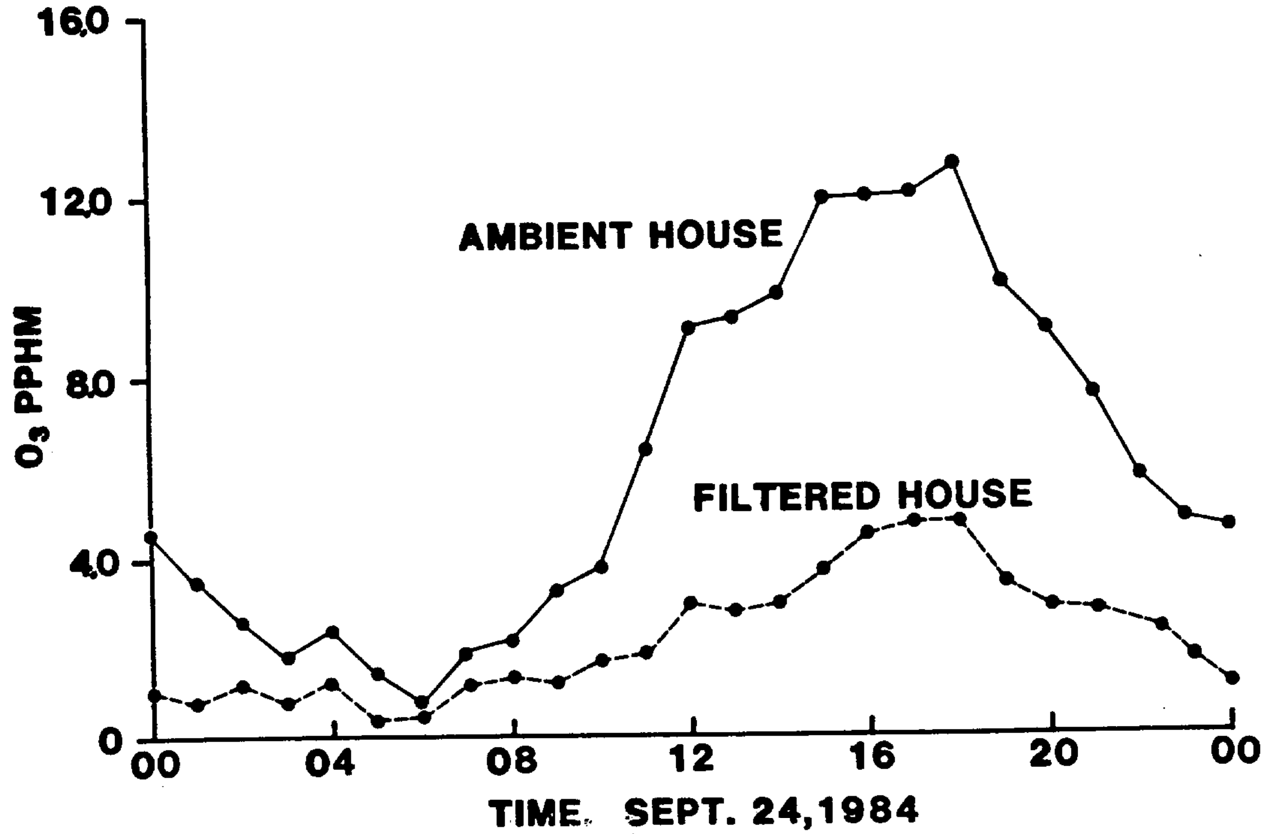
DAILY REPRESENTATIVE SO_2 CONCENTRATION





REPRESENTATIVE DAILY O_3 CONCENTRATIONS, 1983





REPRESENTATIVE DAILY O_3 CONCENTRATIONS, 1984

Appendix G

Data for the basic comparison (filtered plots vs. ambient plots) is shown below; yield of raw cotton (grams per plot) variety SJ-2 for years '78, '83, and '84; 3 reps. the first year and 2 reps for the others.

	1978	1983	1984	3 years
Filtered plot: 5	3026	2590	2054	
8	3146	2153	2326	
14	2477	-	-	
Mean	2873	2372	2190	2478
Ambient plot: 2	2569	2188	2161	
6	2513	2150	1844	
10	2333	-	-	
Mean	2472	2169	2002	2214
Yearly Mean	2672	2270	2096	
Filtered/Ambient Increase	16.5%	9.4%	9.4%	11.9%

Analysis of Variance:

Source	DF	S Sqs.	M Sqs.	F
Total	13	1,691,708		
Filtered vs. Ambient	1	281,161	281,161	5.31*
Years	2	880,675	440,337	8.31**
(F vs. A) x Y	2	36,604	18,302	
Within (reps)	8	493,268		
Error	10	529,872	52,987	

* P = .05
** P = .01