FIELD ASSESSMENT OF THE EFFECTS OF AMBIENT OZONE ON COTTON (GOSSYPIUM HIRSUTUM) IN THE SAN JOAQUIN VALLEY

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ABSTRACT

The primary objective of this study was to determine whether projected cotton yield losses due to ozone exposure, based on controlled experiments, actually occur in the field. This objective was addressed through three tasks. Task 1 was a determination of the percentage reduction in SJ2 cotton yield based on open-top field chamber research. The task was addressed with exposures to different ambient ozone concentrations at four sites in the San Joaquin Valley, using two filtered and two nonfiltered (ambient ozone) chambers per site. The chambers were placed over fields of cotton from approximately June through September, 1988.

Task 2 incorporated research with an antioxidant compound to determine if a chemical tool could be developed to determine ozone effects on crops without using chambers. The antioxidant sodium erythorbate (Ozoban®) was used to represent a filtered air (reduced ozone) condition for plants for comparison to ambient ozone. Ethylene diurea (EDU) was also used on a limited basis. Two cotton cultivars, SJ2 and GC 510, were used with the antioxidants.

For Task 3 the relative yields of 13 cotton cultivars were determined at each of eight sites in the San Joaquin Valley with different ambient ozone concentrations. This aided in the evaluation of whether yield loss estimates based on research with SJ2 cotton are also valid for other cultivars.

Ozone monitoring indicated an ozone concentration gradient across the San Joaquin Valley. Ambient (plant height) ozone concentrations were highest at Dinuba (0.060 ppm), moderate at Shafter (0.056 ppm) and Hanford (0.049 ppm), and lowest at Five Points (0.044 ppm). These ozone concentrations were based on seven-hour averages (0900-1600) for July through September, 1988.

Lint yields were significantly reduced by ambient ozone at Hanford and Dinuba. Yields were 16 and 34% lower in nonfiltered vs. charcoal-filtered chambers at Hanford and Dinuba, respectively. The Hanford reduction was reasonable as it occurred in a highly productive field. However, the cotton growing at Dinuba suffered from water deficiency and insect stress in different areas of the field, which may have exacerbated the ozone effect. The yield losses which occurred in nonfiltered vs.

charcoal-filtered chambers at the different sites were very close to those predicted based on the ozone exposure/yield loss models used in the Crop Loss Assessment Project. Thus, the losses reported for cotton from the crop loss project appeared to be reliable.

A large chamber effect on yield was also noted at Dinuba. Yields were also lower in nonfiltered vs. charcoal-filtered chambers at Shafter (20% lower) and Five Points (13%), but the differences were not statistically significant. There was significantly greater leaf injury due to ambient ozone at Shafter and Hanford.

The antioxidant sodium erythorbate had no affect on cotton lint yields or leaf injury for either cultivar at any site. The concentration of the antioxidant was sufficient and applications frequent enough to affect the crop if the antioxidant was active.

The cultivar GC 510 had a significantly higher lint yield than SJ2 at Shafter where ozone concentrations were higher. The cultivar SJ2 had a higher yield at Five Points where ozone concentrations were lower. Thus, the relative yields of the two cultivars at these sites would indicate that SJ2 is more susceptible to ozone than GC 510.

Lint yields for SJ2 tended to be lower than for most other cultivars at all sites in the southern San Joaquin Valley. The lower yields occurred both at estimated high ozone sites such as at Porterville and at low ozone sites such as Five Points and Firebaugh, indicating that relative cultivar yields did not correlate well with response to ozone in different areas. Cultivar SJ2 performed best at the more northerly sites in Madera and Merced Counties. Estimated ambient ozone exposures (as surrogate for oxidants) did not significantly correlate with yield for any cultivar, based on analysis of yield and ozone concentrations at six of the cultivar trial sites. However, there was a trend toward decreased yields with higher ozone concentrations for cultivar CPCSD C-4226.

Overall, this project documented the effects of ambient ozone on cotton yields in the San Joaquin Valley, and indicated differences in cultivar response to ozone. Additional research is needed to more carefully determine the effects of ozone on plant development at the different sites, and especially to determine more precisely the concentration of ozone and its effects at Dinuba. Dinuba is of special interest because it is located in the high ozone area southeast of Fresno.

DISCLAIMER

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 commercial products, their source, or their use is not to be construed as either an actual or implied endorsement of such products.

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SUMMARY AND CONCLUSIONS

Introduction

Cotton is one of the key contributors to California's agricultural wealth. The crop consistently ranks first or second in importance in California, with a value of nearly $1 billion annually. The San Joaquin Valley with its hot, dry summers and reliable irrigation system provides an ideal growing area for cotton. However, the San Joaquin Valley is also undergoing large-scale urbanization and is also subject to influences of neighboring large metropolitan areas, especially the San Francisco Bay area. Automobiles and industries in both the Bay area and valley itself emit pollutants, which, combined with local meteorology and topography, result in a significant air pollution problem in the valley.

Air pollution has been suspected of affecting cotton in the San Joaquin Valley for over 20 years. Photochemical oxidant smog is of primary interest, with ozone likely being the most toxic component of smog as far as plants are concerned. In the early 1970's scientists from the University of California Kearney Agricultural Center at Parlier evaluated the effects of ambient smog on SJ1 cotton. The study was conducted at Parlier, Hanford, Cotton Center, and Five Points in the San Joaquin Valley. Plants were grown in either clean air (charcoal-filtered) or smoggy air (nonfiltered) in closed plastic greenhouses at each site. Plants growing in smoggy air yielded 20-30% less raw cotton than plants in clean air at Parlier, Hanford, and Cotton Center. However, at Five Points, plants in smoggy air produced only 6% less cotton than plants in clean air. Scientists also demonstrated a large yield loss for SJ2 cotton growing in smoggy air vs. clean air at Parlier.

Based on subsequent carefully controlled cotton studies at Shafter, equations have been established which predicted cotton yield losses based on ozone concentrations (as a surrogate for total oxidants) at different locations in the San Joaquin Valley. The estimated losses ranged from <10% near Five Points to >20% near Fresno and Bakersfield, compared to the potential yields in clean air. The size of the estimated losses indicated that smog may be causing a substantial problem for cotton in the San Joaquin Valley.

However, uncertainty persists whether such large estimated losses actually are occurring in fields across the San Joaquin Valley because of the many variable conditions which can affect the response of crops to ozone. Ozone concentrations vary across the valley, as do soil types, environmental conditions, management practices, and many other factors. In addition, the open-top field chambers used for the exposures and very careful control of soil moisture in individual chambers may have influenced plant responses. Furthermore, while SJ2 remains the predominant cultivar, GC 510 is increasing in importance and other cultivars may also be grown in the future.

Objectives

To verify the yield loss estimates based on results of previous studies and to see how the estimated losses are affected by conditions across the valley, a new cotton study was initiated in 1988. The objectives of the study were:

1) To determine the percentage of yield reduction at sites with different ozone concentrations.

2) To determine if ozone effects could be documented by using a chemical to protect the plants as well as by using chambers.

3) To determine the yields of cotton cultivars across the valley to see if relative yields were related to ozone concentrations.

This wide-ranging study involved the valuable cooperation of many individuals including private growers, the BASF Chemical Company, U. S. Department of Agriculture (USDA) and University of California, Riverside, researchers, and University of California Cooperative Extension personnel.

Methodology

Field Chamber Experiment. Open-top field chambers were used at four sites; the USDA Cotton Research Station at Shafter in Kern County, the Dean Grabow farm near Hanford in Kings County, the BASF Research Station near Dinuba in Tulare County, and the University of California West Side Field Station near Five Points in Fresno County. At each site a field of SJ2 cotton was planted and grown using normal management practices for that area. Four open-top field chambers were placed over cotton in the field at each site; two with charcoal-filters to remove ozone and represent clean air, and two without charcoal-filters to represent "nonfiltered" air in the area. In addition, two open plots without chambers were used to detect any effects of the chambers themselves on the plants.

Antioxidant Study. An antioxidant chemical was used to determine if the effects of ozone on cotton could be verified without the use of the field chambers. If successful, this would provide a tool for assessing the effects of ozone on cotton in many different locations. The only available antioxidant was sodium erythorbate (Ozoban®), which has been believed to diminish the effects of ozone on leaves, thus representing a "clean air" situation. The cultivar GC 510 as well as SJ2 was used for this study, with research sites at Shafter (medium-high ozone) and Five Points (low ozone). Plants were sprayed with an antioxidant concentration of 2,000 ppm at a rate of 1.7 kg/ha. The antioxidant was applied with a surfactant once per week for seven or eight weeks from mid-June to mid-August. There were six plots per treatment per cultivar at each site.

Cultivar Responses to Ozone. The cultivar comparison study evaluated injury and yield for 13 cultivars of cotton growing at eight cultivar test sites. The tests were carried out by Dr. Dick Bassett at the USDA Cotton Research Station at Shafter, and were sponsored by the Acala Cotton Board. The sites were near Merced, Madera, Firebaugh and Five Points in Fresno County, Hanford in Kings County, Porterville in Tulare County, and Maricopa and Wasco in Kern County. Leaves were rated for percentage of leaf area exhibiting yellowing (chlorosis) or tissue death (necrosis). The rating occurred over the first three weeks of September, 1988. Lint yields were based on harvest data collected by Dr. Bassett in October 1988.

Findings

Field Chamber Experiment. Ambient ozone concentrations (as a surrogate for total oxidants) varied among the four sites. Over the mid-June to mid-September period, seven-hour (0900-1600 PST) ambient (plant height) ozone concentrations were highest (0.060 ppm) at Dinuba, southeast of Fresno, and lowest (0.044 ppm) at Five Points, on the west side of the valley. Ozone concentrations at Shafter and Hanford were in between at 0.056 ppm and 0.049 ppm, respectively.

Yield (lint weight) was of primary concern, but growth and leaf injury were also measured. Lint weights were lower in the nonfiltered or "smog affected" chambers than in the charcoal-filtered chambers or "clean air" at all four sites. The largest percentage of yield loss was 34% at Dinuba, which had the highest average ozone concentrations. There was a 20% loss at Shafter and a 16% loss at Hanford, but only a 13% loss at Five Points which had the lowest oxidant concentrations. Only the losses at Dinuba and Hanford were "statistically" significant (i.e., there was greater than a 95% probability that the oxidant effect was real).

There were significantly more senescent leaves on plants in non-filtered than in charcoal-filtered chambers at Shafter and Hanford. At Five Points, there were fewer harvestable bolls in nonfiltered than in charcoal-filtered chambers.

Yields at Hanford and Five Points were reasonably high, and equivalent to approximately 2.9 and 3.3 bales of cotton per acre, respectively, for the ambient plots. In contrast, the ambient plot yield for Shafter was only 2.1 bales. This may have been due to a possible nitrogen deficiency in the field because of the difficulty in applying uniform nitrogen to the plots after the chambers were placed in the field.

The ambient plot of 1.3 bales per acre yield at Dinuba was very low because of a combination of problems, including the necessity to replant the field in late spring, unseasonable rain, cold weather, pests, and insufficient water in some areas of the field. The existence of these multiple stresses at Dinuba indicated that ozone may exacerbate the adverse effects of other factors on cotton yield.

Antioxidant Study. The antioxidant had no affect on cotton lint yields for either cultivar at either site. Both the open-top field chamber experiments and presence of ozone injury symptoms on cotton at Shafter indicated that ozone was affecting cotton, especially SJ2.

Cultivar Responses to Ozone. Cultivar SJ2 placed near the top of the susceptibility ranking at all sites except Wasco, however cotton growth was poor at that site. Injury symptoms were greater at southern sites (Fresno, Kings, Tulare, and Kern Counties) than at northern sites (Madera and Merced Counties). However, it could not be determined whether this difference in injury was due to higher ozone concentrations in the south, or due to other factors, such as earlier maturing in the southern areas of the valley. Injury was not measured at Firebaugh and Five Points.

Lint yields for SJ2 were lower than for other cultivars at all southern sites. The lower yields occurred both at estimated high ozone exposure sites such as at Porterville and at low ozone sites such as Five Points and Firebaugh, indicating that relative cultivar yields did not correlate well with possible ozone injury symptoms in different areas. The cultivar SJ2 performed best at the more northerly sites.

Ozone exposure (as a surrogate for oxidants) did not correlate significantly with yield for any cultivar, based on analysis of yield and estimated ozone exposures at six of the cultivar trial sites. However, there was a trend toward decreased yields with high ozone exposures, especially for cultivar CPCSD C-4226. The lack of ozone exposure and yield correlations may have been due to the limited number of sites available for analysis, use of 1986 ozone data as a surrogate for 1988 ozone exposure, and because the effects of air temperature and Verticillium wilt were more important than ozone in affecting cotton yields at the different sites.

Conclusions

- Actual yield loss due to oxidants at different sites in the valley were similar to those predicted by existing ozone exposure/yield loss models. Thus, the crop loss assessment procedures currently used by California researchers appear to be valid, and the estimates of yield losses found with them are reliable. Yield reductions appeared to be exacerbated by stress other than oxidants at Dinuba and Shafter, and possibly by the open-top chambers at Dinuba due to enhanced water deficits in the chambers compared with the outside plots.
- The antioxidant chemical used in this study apparently had no effect on injury or yield losses from ambient oxidants for cotton and could not be used for crop loss assessment purposes. Therefore, chambers such as those used in research sponsored by the Air Resources Board still appear to be the most reliable methodology for assessing oxidant effects to crops.

- The most widely grown cotton cultivar, SJ2, tended to have more injury and lower yields than other cultivars at most sites surveyed. Thus, the crop loss assessments based on data from this cultivar are reliable. The injury also tended to be greatest at the southern San Joaquin Valley sites. This pattern of injury coincided with the suspected greater ozone sensitivity of SJ2 and higher ozone concentrations at more southerly sites.

RECOMMENDATIONS

This project needs to be repeated in 1989 in order to definitively determine the effects of oxidants on cotton as data from only one growing season is not considered to be adequate to detect treatment effects in agronomic field studies. Environmental conditions are always different for each growing season in the field. A "normal" year is actually the average of conditions over several years. Therefore, detection of "typical" cotton response to oxidants in the field requires an average over several years.

The results indicated that crop loss models based on experiments in open-top field chambers at one site can be used to estimate ozone effects on crops at different locations. Thus, researchers should continue to use the current models to estimate crop losses from oxidants.

However, results obtained from air pollution studies where additional stresses (e.g., water stress) are present may not be useful for crop loss assessments. Oxidant-related yield losses obtained from plants under additional stress may overestimate actual losses occurring in the field.

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I. INTRODUCTION

A. Cotton Losses from Ozone

The Statewide Air Pollution Research Center (SAPRC) and the University of California at Riverside (UCR) have a continuing mission to investigate the effects of air pollution on agriculture. Of primary interest have been the effects of photochemical oxidants (i.e. "smog") of which the gas ozone is the major phytotoxic component. Over the past 35 years many field research studies have indicated decreased yield, increased foliar injury, and other responses of plants exposed to ambient ozone. This research has resulted in ozone concentration/yield loss equations for 20 crops, including cotton (*Gossypium hirsutum*). These equations have been used in the Air Resources Board (ARB) sponsored California Crop Loss Assessment Project (Olszyk et al., 1988a,b; Thompson and Olszyk, 1986), which estimates potential yield losses from ozone in all counties of California.

However, a number of key areas still need to be investigated to evaluate crop losses from ozone. As part of the Crop Loss Assessment Project a workshop was held in 1987 in Riverside to assess these future research needs. One of the areas emphasized at the workshop was the need for a field assessment to determine if losses actually are occurring in California crops as predicted by the crop loss models. In lieu of assessing field effects to all crops potentially affected, a recommendation from the workshop was that field studies focus on one crop which is economically important and which has demonstrated definite ozone effects based on controlled research.

Cotton is the most important annual crop in California. It is grown on 1,320,000 acres and was valued at approximately one billion dollars in 1985 (CDFA, 1986). Cotton was shown to be relatively sensitive to ozone, with losses found in field studies both in the San Joaquin Valley at Shafter (Temple et al., 1985), Parlier (Brewer, 1985), and other sites (Brewer and Ferry, 1974), as well as in the South Coast Air Basin (McCool et al., 1986). Based on the research at Shafter, an ozone concentration/lint yield loss equation was produced for SJ2, the most widely grown cotton cultivar (Temple et al., 1985).

The ozone concentration/crop yield loss equation was used in the Crop Loss Assessment Project to predict a potential yield loss from ozone based on ambient ozone data for 1984 from sites in the San Joaquin Valley and in Riverside and Imperial Counties in the southeast desert. The equation used statewide cotton production data (Figure 1) and statewide ozone data (San Joaquin Valley sites, Figure 2). Based on the equation, potential lint yield losses from 14.3 to 23.2% were estimated in the counties where the crop was grown in 1984 (Table 1). Based on weight of individual county losses by percent of total statewide production, the statewide potential loss was 19.6% (Thompson and Olszyk, 1986). Use of two other ozone concentration/yield loss equations gave similar results (Table 1). The Heagle et al. (1986) equation was based on cotton research in North Carolina using cultivars grown in that state. The Brewer (1985) equation was based on research at Parlier also using cultivar SJ2.

B. Approaches to Field Studies

Use of open-top field chambers to control the ozone concentration around the plant canopy has been the most widely used procedure for evaluating air pollution effects on all vegetation (Heck et al., 1982), including cotton (Brewer et al., 1985; Temple et al., 1985; Heagle et al., 1986). An alternative means of evaluating crop losses from ozone in the field is determination of relative yields for a crop grown along a pollutant gradient. This procedure was at first used for evaluations of sulfur dioxide effects at different distances from point sources such as coal-fired power plants (Skelly et al., 1979). However, the inherent differences in soil and microclimate between different sites made pollutant effects very difficult to detect unless the pollutant impact was great. An improvement on this "gradient" method of effects analysis was the system of controlled soil condition plots set out along the ozone gradient across the South Coast Air Basin of southern California (Oshima et al., 1976). This method produced crop yield, ozone concentration as a surrogate for total oxidants, and environmental condition data which could be analyzed through multiple regression analysis to produce ozone exposure/crop yield loss equations. However, the particular high peak ozone pattern in this area has resulted in caution for application of this data to other growing areas.

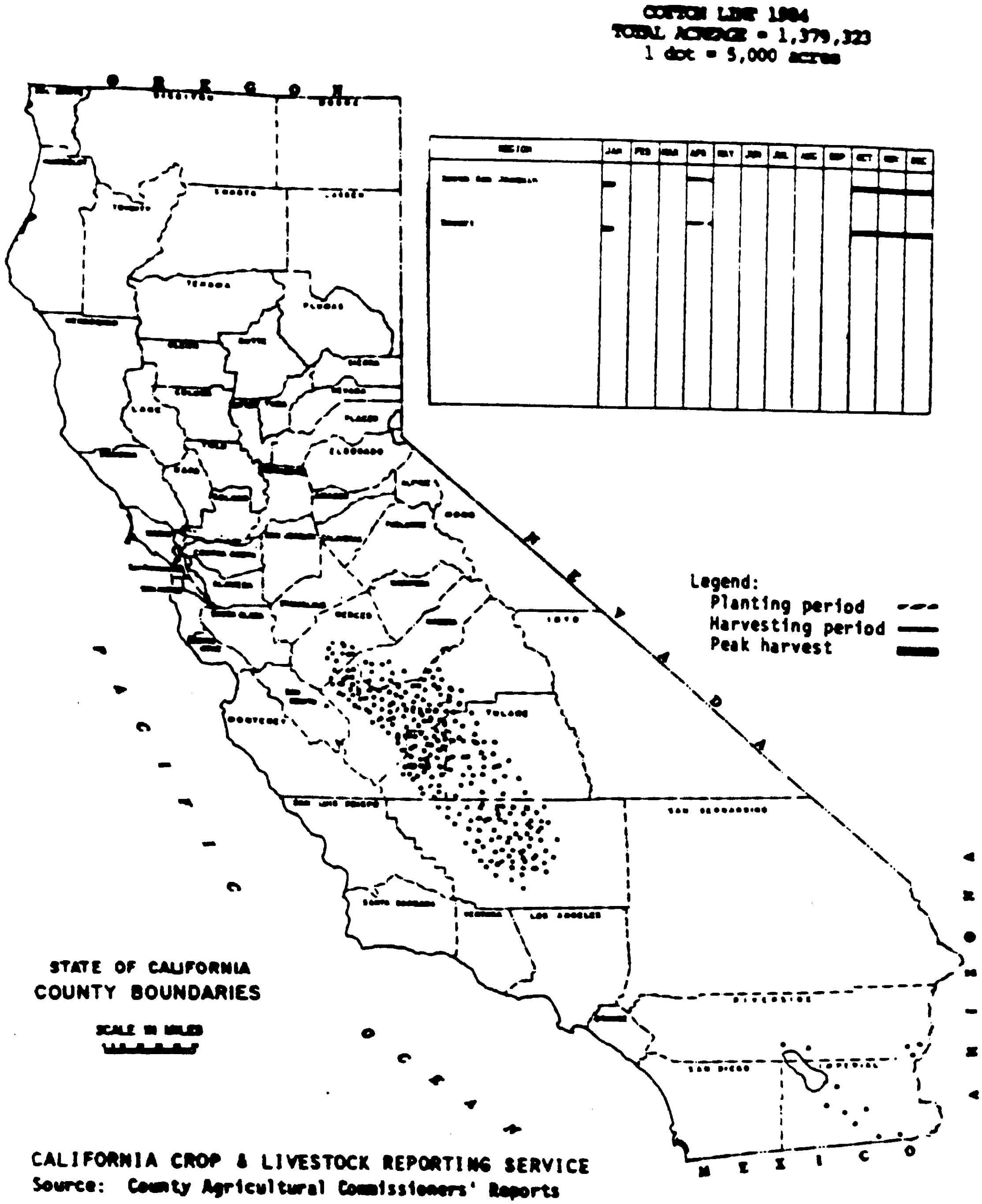

Figure 1. Cotton lint production acreage in 1984 (CDFA, 1985).

SAN JOAQUIN VALLEY AIR BASIN
MONITORING STATIONS OPERATING DURING 1984

LEGEND

- ● Gaseous pollutant or multipollutant monitoring site
- ○ High volume particulate sampling only
- ✧ ARB operated site
- ■ Discontinued during year
- † Site relocated

Figure 2. Air monitoring sites in the San Joaquin Valley (ARB, 1985). Gaseous pollutant sites generally include ozone monitoring. An * indicates a field chamber site for the 1988 study.

Table 1. Estimated Crop Losses for Cotton in 1984 Using Three Different Ozone Exposure/Yield Loss Equations[a]

County	Production (tons)	7-Hr O_3 Avg. (ppm)	Estimated % Yield Loss[b] Heagle	Brewer	Temple
Fresno	230,076	0.078	30.2	21.0	23.2
Imperial	20,440	0.060	15.9	15.6	15.6
Kern	173,040	0.069	22.7	18.2	19.5
Kings	132,310	0.057	13.8	14.0	14.3
Madera	23,866	0.072	25.1	19.1	20.7
Merced	35,000	0.067	21.3	17.6	18.7
Riverside	16,818	0.060	15.9	15.1	15.6
Tulare	95,288	0.069	22.7	18.2	19.4
Statewide	726,838		23.6	18.2	19.6

[a]Based on 7-hr (0900-1600), May-September, growing season. Equations described in Thompson and Olszyk (1986).
[b]Yield loss vs. a clean air background average of 0.025 ppm.

An improvement on both the single site, open-top chamber studies and past ozone gradient studies would be a study whereby chambers would be set up along an ozone gradient. In this case, environmental variability would still occur between sites. However, only large differences in yield which can be detected in the chambers are likely to be of concern. The natural ozone gradient could be used to produce estimated losses with different ozone concentrations for use in calculating an ozone exposure/crop loss model.

One early study which followed this protocol was the San Joaquin Valley cotton study conducted by Brewer in 1972 and 1973 (Brewer and Ferry, 1974). In that study, pairs of filtered and ambient (nonfiltered) greenhouses were established over SJ1 cotton plots at four locations. The locations were chosen because of potentially different ambient ozone concentrations. The estimated losses for ambient compared to filtered chambers for Parlier, Hanford, and Cotton Center are within the range predicted for ambient ozone in 1984 [i.e., 19-29% indicating that, given all the changes in over 10 years in terms of cotton production and/or ozone concentrations, the results from the 1986 crop loss modeling project were reasonable (Thompson and Olszyk, 1986)]. The lower yield loss (5-7%) at the "more ozone free" Five Points site compared with the other sites indicated that predicted losses do coincide with relative ozone concentrations in different areas. However, the exposures were conducted in chambers of a closed design which resulted in considerable environmental modification. This modification resulted in increased pest problems which resulted in ambient chamber yields lower than outside plot yields, particularly in 1973. Thus, the question remained whether the predicted yield losses were actually occurring in the field.

Two other potential alternative means of identifying crop losses in the field are (1) evaluation of relative yields of ozone susceptible and tolerant cultivars of a crop at sites with different ambient ozone concentrations, and (2) evaluation of yield increase with application of an antioxidant compound to a crop to block ozone effects at a biochemical level. A study by Foster et al. (1983) illustrated the possible use of both loss assessment procedures for potato. In that study, an ozone susceptible cultivar (Centennial Russet) and tolerant cultivar (White Rose) were grown at a high ozone site (Riverside) and a low ozone site in Kern County. Both cultivars were treated with the antioxidant ethylenediurea (EDU) at both sites. In regard to cultivar response, Centennial Russet yield was only 20% of White Rose yield at Riverside, but 54% of White Rose yield in Kern County. While other environmental factors undoubtedly played a role in the relative yields at the two sites, the increase in relative yield for Centennial Russet in Kern County could be, at least in part, ascribed to the lower ozone concentration.

EDU, the antioxidant used in the Foster et al. study, has been widely used and has recognized antisenescent properties (Smith et al., 1987; Clarke et al., 1983; Lee et al., 1981; and Carnahan et al., 1978). In the potato study, the EDU treatment resulted in an increase in yield of over 70% in Riverside County, and only a 16% increase in yield in Kern County for Centennial Russet. The White Rose yield was not affected by EDU treatment at either site. Thus, the large increase in yield with EDU in Riverside, but not in Kern County, along with the effect on only the ozone susceptible cultivar and accompanying ozone data from both sites, strongly suggested that crop losses could be determined in the field without use of chambers if several other experimental methods were used simultaneously.

II. METHODS

A. San Joaquin Valley Cotton Meetings

To initiate the study an organizational meeting was held in the San Joaquin Valley on February 23, 1988. The objectives of the meeting were to present the proposed research to key individuals in the area, to review final plans for the study, and to obtain final input on details of the experimental tasks. Overviews were given on various air pollution projects, including the ARB-sponsored Crop Loss Assessment Project, the Cotton Field Assessment Project, and the San Joaquin Valley Air Quality Study, followed by an extended discussion to answer questions and obtain any additional information available.

Invited participants included county farm advisors, statewide cotton experts, University of California (U.C.) research staff, and ARB staff. Other experts invited included agricultural commissioners and cotton industry representatives from Merced, Madera, Fresno, Kings, Tulare, and Kern Counties in the San Joaquin Valley. The meeting was held at the Tulare County Farm Advisor's headquarters in Visalia, and was hosted by Ms. Stephanie Johnson. An attendance list and agenda are shown in Appendix A.

On July 7, 1988, a second project meeting was held in the San Joaquin Valley to discuss the progress of the meeting and plans for the future. The meeting was held in Hanford and was hosted by Mr. Bruce Roberts of the Kings County Farm Advisor's office. The meeting was a follow-up to the initial project meeting held in February at Visalia. The attendance list and agenda for this meeting also are shown in Appendix A.

Tours were provided of the Hanford and Five Points sites before and after the meeting, respectively. In general, discussion covered the following points: (1) All cultural decisions will be based on recommendations of cooperators for the different sites. (2) A defoliant (PIX®) will be used at all sites prior to harvesting. (3) The time of application will be determined by the cooperators. (4) The cotton is now coming along well at all sites, but problems in the spring were reviewed. (5) Remote sensing may provide a useful tool for evaluating ozone effects, if a proper control can be located in the field. Stephanie Johnson may be able to obtain infrared remote sensing data for the Five

Points site. (6) A second year of study was recommended. Cotton was the crop suggested by all participants.

The primary environmental problems in the spring was the occurrence of warm weather during April followed by very cool weather in May. Thus, the cotton germinated quickly and began to grow rapidly during April at all four sites. However, growth then essentially stopped until early June because cotton requires warm temperatures for growth. The slow growth in May did not allow the cotton to ward off infestations of thrips (an insect normally present in cotton fields) early in the season at all sites. Thus the combination of cool weather and thrips set back cotton growth until June when temperatures returned to normal. This set back the placing of chambers over the plants at Hanford, Five Points and Dinuba.

The Dinuba site also had problems with a pythium infestation (a root fungus) associated with the cool weather. Thus, the field had to be replanted which set back the date for placing the chambers over the plants to early July.

B. Open-Top Field Chamber Study

1. Site Selection

Four sites were chosen for this study based on suggestions from an earlier planning meeting on July 23, 1987 and the initial project meeting on February 23, 1988, both at Visalia. Appendix A includes the attendance lists and agendas for the meetings. The sites chosen included a research field near Dinuba in Tulare County (expected high ozone exposure research field), a research field at the UC West Side Field Station at Five Points (low ozone), a research field site at the USDA Cotton Field Station at Shafter (moderate ozone), and a commercial field near Hanford in Kings County (moderate ozone). The sites are indicated in Figure 3. Individuals who were cooperators or contacts included Ms. Stephanie Johnson, UC County Cotton Farm Advisor, Tulare County; Mr. Richard Schetter, Director, UC West Side Field Station; Dr. Eliot, Director, USDA Cotton Field Station; Dr. Thomas Kerby, UC Statewide Cotton Farm Advisor; and Mr. Bruce Roberts, UC County Cotton Farm Advisor, Kings County. The Kings County site was in a commercial field, but the farm advisor supervised the site. The Tulare site was set up in cooperation

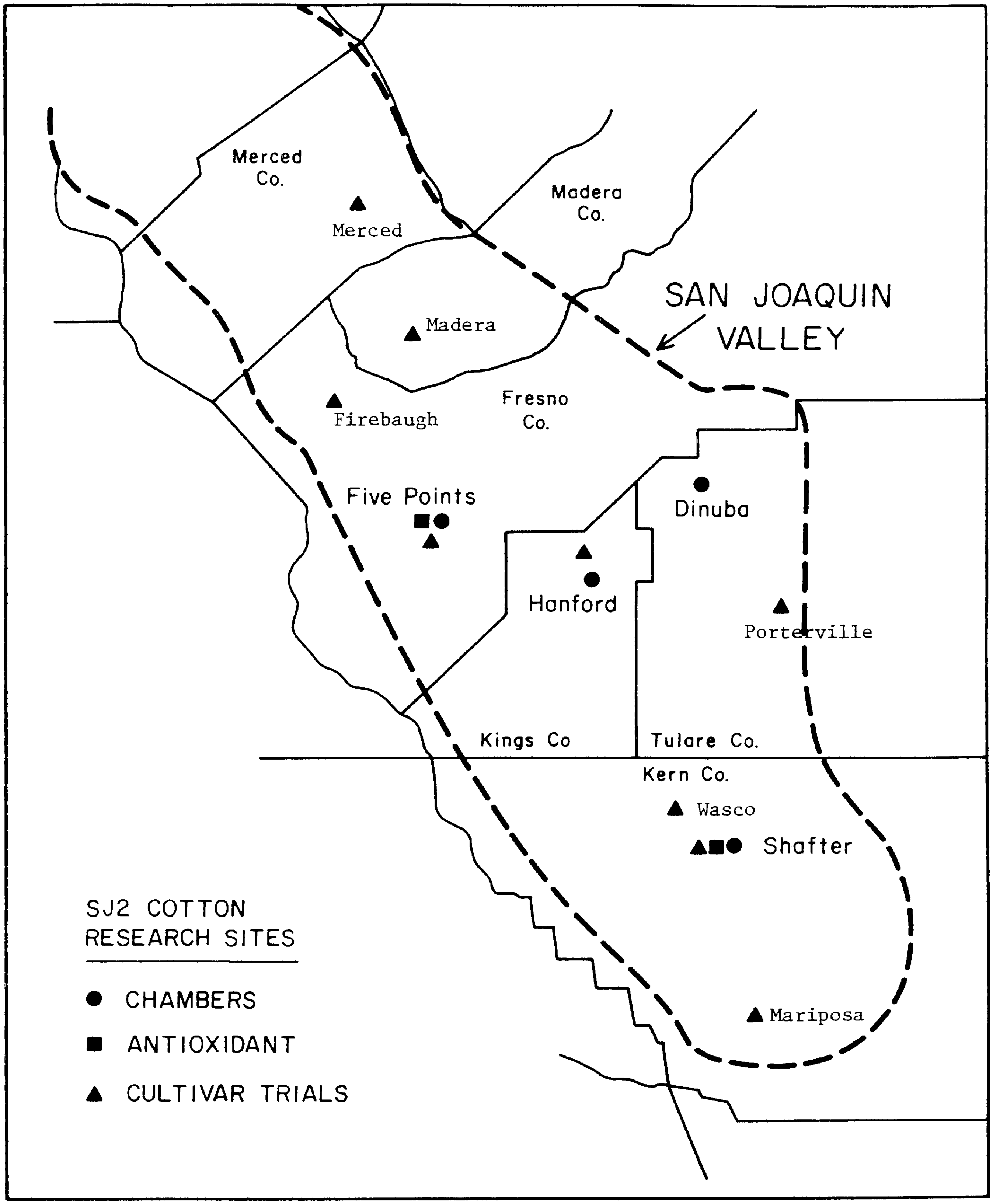

Figure 3. Sites for chamber, antioxidant, and cultivar trial studies in 1988.

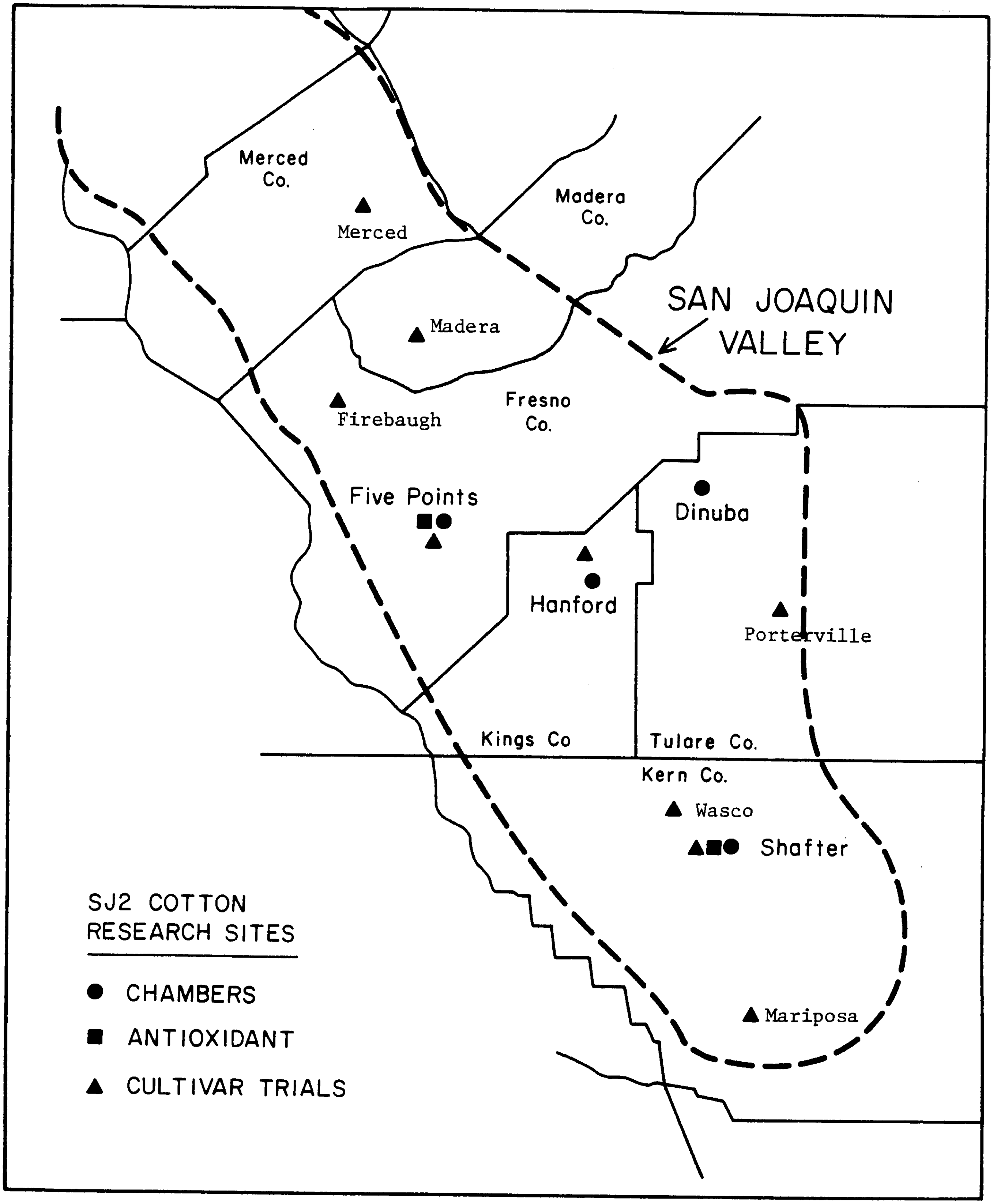

Figure 3. Sites for chamber, antioxidant, and cultivar trial studies in 1988.

with Dr. David Millhouse of the BASF Corporation, and the Kings County site set up on the Dean Grabow farm.

Each site met the following criteria: (1) space for an ozone air monitoring station; (2) space for placement of open-top chambers over four, approximately 4 m x 4 m, plots of cotton, along with permission to use two other outside plots; (3) power source adequate for four chamber blowers; (4) power source and protection for an ozone analyzer, a computer data acquisition system and a strip chart recorder; (5) security for the chambers in the form of a fence, isolation, or other means; (6) easy access by road; and (7) procedures could be set up for normal irrigation and pest control of the cotton.

Table 2 lists the contributions by the cooperators and UCR staff toward the work tasks of the study. The local cooperators were actively involved in advising UCR staff regarding site selection, placement of chambers on the site, and cultural details regarding growing cotton on the site. The Dinuba and Five Points cooperators paid electrical costs at those sites. The cooperator at Hanford took care of, on a reimbursement basis, electrical costs for the site. Electrical costs at Shafter were billed directly to UCR.

2. Chamber Construction and Operation

The open-top chambers were of the basic dimensions (3.0 m diameter x 2.4 m high) and design as the National Crop Loss Assessment Network (NCLAN) chambers (Heck et al., 1982). Each chamber had a cone shaped baffle at the top to reduce ambient air incursion. Six new frame parts were purchased in order to have enough parts to put together a total of 16 chambers. Sixteen blowers were chosen from the stock currently on hand. Eight of the blowers were outfitted with filters containing fresh charcoal to remove approximately 70-80% of the ambient photochemical oxidants. All 16 blowers were outfitted with particle filters which were replaced periodically during the study.

The chamber parts were transferred to the field sites where final assembly took place in April and May 1988. The chambers were placed over rows of cotton when plants were 0.15-0.3 m high and secured to the ground to prevent damage from any high winds during the growing season. The blowers were on for approximately 16 hours daily, until spraying of the plants with defoliant in mid-September. The chambers were on from

Table 2. Assignment of Work Tasks at Different Cotton Sites

Task	Dinuba	Five Points	Hanford	Shafter
Ground preparation and cotton planting	Cooperator	Cooperator	Cooperator	Cooperator
Electrical hookup	UCR	UCR	UCR	Cooperator[a]
Electrical trenching	Cooperator	Cooperator	---	---
Electrical costs	Cooperator	Cooperator	UCR	UCR
Equipment set-up and maintenance	UCR and Cooperator	UCR and Cooperator	UCR and Cooperator	UCR
Routine irrigation	Cooperator	Cooperator	Cooperator	Cooperator
Pest and weed control in chambers	UCR	UCR	UCR	UCR
Pest and weed control in general field	Cooperator	Cooperator	Cooperator	Cooperator
Daily checks	UCR and Cooperator	UCR and Cooperator	UCR and Cooperator	UCR
Antioxidant spray	---	UCR	---	UCR
Growth regulator	UCR and Cooperator	UCR and Cooperator	UCR and Cooperator	UCR and Cooperator
Physiological measurements	UCR	UCR	UCR	UCR
Harvest	UCR and Cooperator	UCR and Cooperator	UCR and Cooperator	UCR and Cooperator

[a]Already existing power drop at Shafter; much more extensive power hookups required at Dinuba, Five Points, and Hanford.

approximately 0600-2000 at Shafter, 0500-2030 at Hanford, 0500-2000 at Five Points, and 0600-2100 at Dinuba. These slight differences in operating times would have little effect on air pollution exposures as daily ozone concentrations occur largely between 0600 and 2000. There were two chambers per treatment at each of the four sites.

Because another proposal to study cotton in the San Joaquin Valley was submitted to the ARB in September 1988 and approved in early January 1989, efforts were made during the winter and early spring months of 1988-1989 to maintain the sites. This included visits to insure that equipment was still in place, visits to cooperators and especially repair and refurbishment of the equipment.

3. Ozone Exposures and Data Analysis

The treatments consisted of different levels of the full compliment of ambient photochemical oxidant pollutants. This oxidant mixture likely contained nitrogen oxides, especially nitric oxide and nitrogen dioxide, peroxyacetyl nitrate (PAN), and other trace pollutants. However, the pollutant normally at the highest concentration in the mixture and which is toxic to vegetation is ozone (U.S. EPA, 1986). Only ozone was measured at the sites because it has been considered to be of greatest importance as far as plants are concerned, because ozone has long been considered to be a surrogate for detecting effects of the oxidant mixture as a whole, and especially because the State and Federal air quality standards are based on ozone and not oxidant concentrations.

Thus, even though the air quality treatments used in this study were actually oxidant treatments, they are described from here on in terms of ozone concentrations. The three treatments were charcoal-filtered chambers (low oxidants representing a "clean" air environment), nonfiltered chambers (high oxidants representing the normal or outside air), and ambient plots in outside air. Oxidant concentrations were expected to be slightly lower (5-10%) in nonfiltered chambers than in outside air due to impaction and subsequent loss of pollutants to the blower assembly and chamber walls.

Each chamber site was equipped with a Dasibi® Model 1003 AH ozone analyzer, a microcomputer for data gathering, and a solenoid switching system. Ozone concentrations were measured for all chambers and outside plots at each site four times per hour. Air was sampled from each plot for 2½ minutes per time, with data saved from the last one minute. Strip chart recorders were used as a back-up to the microcomputers. Ozone was monitored ≃10 cm above the plant canopy in the chambers and in ambient plots. Ambient ozone also was measured at a fixed height of four meters above the ground.

Ozone calibrations indicated that there were no major problems with the instruments. The ARB staff (Aerometrics Division, Mr. Bob Evanosky) conducted an independent calibration of the instruments at the start of the study and near the end of the study. The initial calibrations were done during the week of June 6, 1988 for all sites except Dinuba and during the week of June 20, 1988 for Dinuba. The final calibrations were done during the week of September 26, 1988 for all sites. In addition to the ARB calibrations, SAPRC staff performed calibrations of all instruments just prior to taking the ozone analyzers to the field in June, and performed final calibrations after the instruments were returned to Riverside in early November. Calibrations were made using a transfer standard instrument maintained by the ARB.

The ozone analyzers and data acquisition systems were shut off just prior to spraying with defoliant at each site. However, the instruments were turned back on again as soon as possible within one to three days. The instruments remained on to monitor ambient ozone through the end of October. This extra ozone data provided additional information regarding ozone exposures in different parts of the San Joaquin Valley, which may be of importance for longer season crops such as oranges or fall crops such as onions and lettuce.

4. Plant Culture

Table 3 indicates the known dates for important cultural practices during the season. The chambers were placed over rows of cotton planted according to commercial practices recommended by cooperators. Only plants from 2.0 m sections of center rows were included in the analysis; the outside rows near the chamber walls were considered to be guard rows and were not used. There also were rows of cotton just outside the chamber walls to provide natural root competition for chamber plants.

Irrigation and pest control were done in accordance with the decisions of site operators. Irrigation was by furrow under the walls and

Table 3. Cotton Culture at Different Sites

Task	Dinuba	Five Points	Hanford	Shafter
Cotton planted	5/9/88[a]	3/29/88	3/31/88	4/5/88
Fertilization	Preplanting 6/13/88 (tape in)[b]	Preplanting	Preplanting 5/27/88 6/2/88 6/29/88 (field Zn) 7/1/88 (NH_3)	Preplanting 6/15/88
Cultivation	6/13/88	5/26/88 (weeding)	5/27/88 6/2/88 6/29/88 (field)	Preplanting
Irrigation	6/17, 7/8 7/19, 8/16	6/24, 7/19	7/1,7/16 7/21,7/26, 8/2,8/13, 8/20,8/23, 8/26/88	6/15, 6/29 6/26, 7/8 7/19, 7/26 8/2, 8/15 8/26
Verticillium wilt soil sample	5/12/88	5/18/88	5/11/88	5/11/88
ARB calibration	6/22/88	6/7/88	6/8/88	6/6/88
Pesticide sprays	7/1/88 (Azodrin-aphids) 7/25/88 (loopers) 8/29/88 (Liquinox-aphids)	6/30/88 (Diazonon-aphids) 7/5/88 (as 6/30 Ch. 3) 7/26/88 (Malathione, aphids) 7/27/88 (Difor-mites)	6/8/88 (Kelthane-mites) 6/29-7/1/88 (Kelthane-mites) 8/16,26/88 (aphids)	6/28/88 (Dicofor-mites) 8/2/88 (Malathione grasshoppers) 8/9/88 (Darsban-mites)

(continued)

Table 3 (continued) - 2

Task	Dinuba	Five Points	Hanford	Shafter
		8/16/88 (Javelin® army worms) 8/16/88 (Dexakhlor-aphids, mites) 9/6/88 (Dicofor-mites)		
Treatment began	6/23/88	5/24/88	6/8/88	5/20/88
PIX sprayed	Midsummer	7/8/88	7/12/88 (6/29, field)	7/18/88
Plastic removed	9/23/88	9/21/88	9/13/88	9/18/88
Defoliant sprayed	10/3/89	9/21/89	9/25/88 (Prep. 9/16/88)	9/20/88 9/30/88
Harvest	10/19/88	10/11-12/88	10/4/88	10/10-11/88

[a] Originally planted in early April, but had to be replanted due to disease and insect damage related to cool, wet spring weather.
[b] Cotton at Dinuba received occasional fertilization via the drip tape.

through the chambers. Pest control was by backpack sprayer within chambers and for outside plots. PIX® was applied at a rate of 7.4-11.1 g/ha/l water (8-12 oz/acre/20 gal of water) depending on the site. Nitrogen was applied at Dinuba via a drip tape.

Verticillium wilt disease potential was determined for each of the four chamber sites by Dr. Jim DeVay, Department of Plant Pathology, U.C. Davis. Samples were taken at each site in early May (Table 3). Each sample consisted of eight soil cores taken at between 0 and approximately 0.34 m deep in the soil using a 2.5 cm diameter auger. The samples were taken from the sides of the cotton rows in the general area where the chambers were to be located. The samples were placed in plastic bags and returned to Riverside where they were pooled per site before mailing to Davis. Upon arrival at Davis, the samples were air dried for one to four weeks. The dried soil was ground to a fine powder using a hand mortar and pestle. Two 10-g samples were taken from each site and placed into small snap cap vials. The vials were capped and incubated at 33°C for one week in the dark. After removing the vials from the incubator, the caps were removed, and the soil once again was dried at room temperature for one to two weeks. The dry soil was ground again to a fine powder using a hand mortar and pestle. Five 0.1 g portions of the sample were then placed onto six sodium polypectate plates using a modified Andersen sampler. The plates were then moistened in the dark at room temperature for two to six weeks before counting the Verticillium colonies. The results were expressed as average propagules per gram of soil by multiplying the propagules per six plates (0.5 g soil) by two. The two samples were averaged for the final data presentation.

In general, the plants grew well at all sites. However, there were site-specific problems which are characteristic of any cotton growth in commercial fields. A summary of the significant cultural practices and dates is shown in Table 3. The major problem at Shafter appeared to be a persistent nitrogen deficiency in the chamber plots based on foliar chlorosis. This was due to an inability to disk nitrogen into the soil after the chambers had been put in place in the field.

There were several problems at the Dinuba site which were linked to differences in soil across the field. There was a water stress gradient from west (least stress) to east (most stress) across the chamber plots. Before each irrigation the plants to the west would be turgid with open stomata, whereas the plants to the east would be wilting with closed stomata. This may have been related, in part, to the herbicide infiltration into the field as seen in the area surrounding the chamber. This area of the field, however, had to be used, as the surrounding cotton was sparse due to the herbicide contamination. Insect problems persisted at the Five Points site, especially mites in one charcoal-filtered chamber and caterpillars in the antioxidant plots late in the season. The caterpillars came from the neighboring corn field after it was harvested. There were no major cultural problems at the Hanford site; however, the field was somewhat variable, especially in the area of the ambient plots.

5. Plant Response Measurement

Plant responses to ozone were measured in terms of visible leaf injury, leaf senescence, boll development, yield, growth, and leaf physiology (stomatal conductance and transpiration).

Visible leaf injury was rated on a 0-100% scale with increments of 0, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% injury. Injury was noted as percentage of the upper leaf surface showing necrotic and chlorotic markings. No attempt was made on a quantitative basis to distinguish whether injury was representative of ozone or other factors. Upper and lower portions of plants were noted separately. Two observations were made in each of the 2.0 m central portions of the two rows, per plot, resulting in four observations per plot. Leaf injury was measured in early September.

Leaf senescence was measured by removing five plants per chamber and counting total nodes per plant and nodes without leaves. The percentage of leaf senescence was measured as number of empty nodes/total nodes. The sampled plants came from just outside the 2.0 m sections in the center rows to be used for yield determination.

Plant development was determined by "plant mapping," a procedure by which the fate of flowers set at each node of a plant is noted. Five plants per plot were used for the mapping, with plants removed from just outside the 2.0 sections in the center (the same plants as for leaf senescence determination). At each node of the main stems, the presence or absence of a lateral branch, flower, or boll was noted. The presence of flowers or bolls also was recorded for the main laterals. The data were put on special notation sheets and then entered into a computer data file. The data were put through a special computer program at the USDA Shafter Research Station in order to determine boll abscission at different nodes. The plant mapping was carried out in late August at the Shafter, Five Points, and Hanford sites, and mid-September at the Dinuba site.

Stomatal conductance was monitored at least four times during the growing season to determine whether the cotton at the four different chamber sites has the same potential to take up pollutants. The LI-COR 1600 steady state porometer was used. Data were obtained from three plants in each chamber or ambient plot for a total of six observations per treatment per site on each measurement date. Measurements were made on plants in the center two rows of the chamber using healthy appearing leaves near the top of the plant. The LI-COR photosynthesis meter (LI-6000) was not used because staff were not available for the intensive measurements needed.

Harvest dates were in October as shown in Table 3. Only the center 2.0 m of the middle two rows of each plot were harvested. Plants in the outside rows and at the end 0.185 m of each center row were considered to be guard plants and were not harvested. The data for each of the two center rows per plot were harvested separately to provide for subsamples within plots. The subsamples were taken to provide additional information in case there appeared to be a positional effect between the two rows. However, this was not the case. The average response in a chamber across the two subsamples was the actual experimental unit for detecting treatment effects in the statistical analysis. Maximum plant height was measured in the center of each row and the number of plants per row was counted. The open cotton bolls were picked leaving the bracts on the stem. Green bolls were also picked and subdivided between mature bolls (would likely have opened eventually) and young bolls (would not have grown or opened). Counts were made for open, green, mature and young bolls. All plant material was taken to Shafter for weighing. The bulk cotton was then ginned, and lint and seed weights were measured separately.

Lint quality was determined for the pooled cotton lint from both rows in each chamber or outside plot. The pooled lint was divided into two samples for analysis. The samples were sent to Textiles Research Center of Texas Tech University, Lubbock, Texas. Quality was measured by the motion control system providing double line data. Parameters reported included two micronaire readings, four lengths (upper half mean), four uniformity ratios (UR), four strengths (grams/tex), four elongations (%), +B, and one color index per sample. Micronaire indicated the fineness of the lint. Length was for the upper half of the longest fibers as determined by weight. The uniformity ratio was for the mean length vs the upper half mean length, with a higher value indicating greater uniformity. The strength was that force necessary to break a constant weight of fibers when held in clamps approximately 10 cm apart. Elongation was a measure of the ability of the fibers to stretch, measured as percent elongation at breaking. The RD was a measure of brightness of the fibers. The +B was a measure of yellowness of the fibers. Finally, a general color index was measured. All of the lint quality variables are indicators which determine the market value of cotton from a particular field.

C. Antioxidant Study

The antioxidant study was a pilot project to determine whether yield losses from ozone could be detected by inhibiting the action of ozone on a biochemical level. Ethylenediurea (EDU) had been the preferred antioxidant compound because of its widespread use in field tests (Clarke et al., 1983; Foster et al., 1983; Smith et al., 1987), and because of at least some research on its physiological mechanism of action (Lee et al., 1981). However, only enough EDU could be obtained to spray one plot each of SJ2 and GC510 cotton at Shafter and Five Points (Figure 3). Therefore a compound which mimics natural ascorbic acid (Mehlhorn et al., 1986; Ormrod and Adedipe, 1974), was used on six plots of SJ2 and GC510 at Shafter and Five Points.

The central two-meter long sections of row in the middle of each plot were harvested at the end of the study. The same yield variables were measured as for the open-top field chamber study, except that quality parameters were not evaluated.

The antioxidant treatments went smoothly and indicated that foliar applications could be successfully completed for a large number of plots over a relatively short time period. Approximately one and one-half hours were needed to spray a total of 26 plots per site. The commercial compound sodium erythorbate (Ozoban®) was applied at a concentration of 2,000 ppm [i.e., a rate of 748 l/ha (80 gallons per acre)]. The application rate is typical for many agricultural chemicals. This rate resulted in treatment of the plants with 1.7 kg/ha of the antioxidant. Sodium erythorbate was supplied as a 60% wettable powder containing approximately 1% of the wetting agent pluronic acid. The compound was donated by Mr. Charles Cookston of Pfizer Chemical Company.

The experimental research compound, EDU, was applied at a concentration of 500 ppm. The compound was a 50% wettable powder. It was originally made by the Dupont Chemical Company and was donated by Dr.

William Manning of the University of Massachusetts. Control plots were sprayed only with 1% solution of pluronic acid (6.3 mg $plot^{-1}$). All plots were sprayed at a rate of 748 l/ha resulting in treatment with 0.4 kg/ha of the antioxidant.

Antioxidant applications began on July 2, 1988 at Shafter and June 30, 1988 at Five Points. Applications continued once a week for approximately eight weeks on 7/2, 7/11, 7/15, 7/22, 7/29, 8/5, 8/12 and 8/19/88 at Shafter, and for seven weeks on 6/30, 7/11, 7/15, 7/21, 8/4, 8/17 and 8/22 at Five Points. Extra data were also collected from four check plots not sprayed with pluronic acid to determine the effects of this surfactant on the plants.

D. Cultivar Comparison Study

The cultivar screening trials were carried out by Dr. Richard Bassett of the USDA Cotton Research Station at Shafter, and sponsored by the Acala Cotton Board of California. Data were used from variety tests (Figure 3). The variety tests were used because they contained a manageable number of cultivars (13) for rating, and were located over a wide area at eight sites from Merced to Kings Counties. The trials were conducted either alongside commercial fields or at research stations. Mr. Gerrit Kats accompanied Dr. Richard Bassett on a tour of all of these sites (except for Maricopa) in mid-August.

The variety tests included 13 cultivars, with each cultivar replicated in each of four blocks per site. Variety tests were held near Maricopa and Wasco in Kern County, Porterville in Tulare County, Hanford in Kings County, Five Points and Firebaugh in Fresno County, Madera in Madera County, and Merced in Merced County. The tests were rated for injury in early September using the same scale as for the open-top chamber plots with four observations per cultivar from one block. Separate observations were made for both lower and upper leaves of the plants. The locations and dates for the rating were as follows: Wasco, Porterville, and Hanford, September 7; Five Points, September 8; Merced, September 13; and Madera and Firebaugh, September 14. The cotton at Maricopa could not be rated as the plants were already drying from defoliant. Leaf injury was also evaluated at other trials at Stratford in Kings County and Shafter. However, these data could not be compared to the variety test data as the same cultivars were not present.

Harvesting of the cotton occurred in October. The harvest data were obtained from Dr. Bassett and compared to relative ozone exposures for the different sites, and degree days for May through September 15, 1988, and indices of vascular injury and foliar injury from verticillium wilt. Additional growth parameters that were measured for the chamber study were not measured for the variety trials as originally proposed. This was because the growth maturity and other factors varied considerably between cultivars at the same site, and between sites. Instead we carried out more intensive measurements at the chamber sites.

Ozone exposures at the variety test sites were determined by reviewing ozone data for the valley for 1986 (the year with the most recent data). These data gave relative ozone exposures among the eight sites, which should have been representative of actual conditions in 1988. The ozone exposures were based on seven-hour (0900-1600) averages for May-September from the ozone air monitoring site closest to the variety screening site. Seven-hour ozone averages were used as this is the characteristic of ozone exposure commonly used to assess yield losses in cotton (Temple et al., 1985).

There are numerous pitfalls with the approach of using 1986 data for 1988 ozone concentrations due to the lack of adequate ozone monitoring across the valley. For example, the nearest ozone site to Madera and Merced counties is at the Herndon site, to the northwest of downtown Fresno. In 1986 data were incomplete even for this site, so another Fresno site to the north of downtown had to be substituted for those months when the Herndon site was not operable. The data for Five Points and Firebaugh is estimated based on relative ozone concentrations at Parlier and Five Points in the past, as determined for the current ARB sponsored Crop Loss Assessment Project. Similarly, no data were available for near Porterville, Wasco, and Maricopa so the nearest site had to be selected.

Degree days were calculated for May 1 - September 15, 1988, using the University of California IMPACT system developed for integrated pest management. Degree days were calculated on the basis of single sine days above 15.5°C (60°F). The temperature of 15.5°C was appropriate for stimulation of cotton growth.

Degree days were chosen as the indicator of variation in climate in the San Joaquin Valley which may have affected cotton yields. Degree day data were based on air temperatures for May 1 - September 15, 1989. Degree days were calculated using daily temperatures greater than 15.5°C as this temperature was recommended as required for cotton growth. Values were calculated assuming a bell-shaped distribution of temperatures (single sine correction). Other climatic variables also were considered, such as evapotranspiration, solar radiation, air temperature (maximum, minimum, and average daily), and relative humidity. However, those variables were not used because cotton experts indicated that degree days were the most important variables affecting cotton yields. Data for all variables were obtained through the University of California IMPACT (Integrated Pest Management) program data base. Both CIMIS and Touchtone stations were used. Monthly averages for these variables are shown in Appendix B. The data were collected at sites near the cultivar trial sites.

Data for ozone exposures were based on ozone concentrations for 1986, the most recent year for which data available from the Air Resources Board. Actual ozone concentrations for 1988 will likely not be available until early 1990. Thus the 1986 data were used with the assumption that the gradient in ozone concentrations in the San Joaquin Valley would not differ between years, and that the 1986 data would give meaningful relative ozone exposures for the cultivar sites.

The ozone exposures were calculated as seven-hour (0900-1600) averages from all hourly values for May-September 1986 using the general procedures described by Olszyk et al. (1988a,b). Data were used from the nearest air monitoring site. These sites were Hanford for the Hanford cultivar site, Edison Oildale for the Maricopa and Wasco sites, and sites northwest of Fresno for Madera and Merced sites. Data from Parlier were used for the Firebaugh and Five Points sites. However, the data from Parlier on the east side of the San Joaquin Valley have to be adjusted downward (x 0.673) to obtain realistic ozone exposures for the Firebaugh and Five Points sites in the cleaner west side of the valley.

The potential for verticillium wilt to affect plants at the sites was based on the severity of foliar and vascular injury to SJ2 from wilt at each site. This was based on the recommendation of Dr. Richard Bassett as SJ2 is the most verticillium wilt susceptible cotton cultivar.

E. Models for Calculating Cotton Yield Losses Due to Ozone Exposure

The relationship between the actual cotton yield losses found in the field in this study and estimated losses based on modeling, was determined using the ozone exposure/yield loss equation developed for SJ2 cotton by Temple et al. (1985). The equation took the form of % yield loss = {{[2059-(8200 x 7-hr average)]/[2059-(8200 x base)]} + 1} x 100. In this equation the 7-hr average was for 0900-1600 over the cotton growing season. The base was equal to 0.014-0.019 ppm, i.e., the 7-hr average charcoal-filtered chambers over the growing season.

Estimated cotton yield losses were calculated three ways depending on the air monitoring data used, and reflect the differences in ozone concentrations at the different monitoring locations as described in Section III.A. Losses were calculated based on air monitoring data for nonfiltered air in chambers just above the plant canopy, ambient air just above the canopy and ambient air from four meters above the plant canopy.

F. Statistical Analysis

Each of the three experimental portions of the project was analyzed separately. All plant response and ozone data as available were entered into computer data bases. Data were analyzed using general procedures described by Steel and Torrie (1960).

1. Open-Top Chamber Study

The data from each of the four open-top field chamber sites were analyzed separately. At each site the experimental design was a randomized block. Each of the three treatments (filtered chambers, nonfiltered chambers, and ambient plots) was repeated in each of two blocks. The blocks were used in order to account for possible variability in soil conditions across fields, and to increase the likelihood of detecting ozone effects. Each chamber or outside plot was the experimental unit for the analysis of variance. There usually were several observations within each plot in order to provide an indication of variability between samples. Each type of response parameter had a slightly different way of assigning degrees of freedom (df) depending on how the observations were made.

Harvest data were evaluated using the analysis of variance shown in Table 4. Two observations were made per plot, one from each of the two

Table 4. Analysis of Variance for Open-Top Chamber Harvest Data

Source	df
Block	1
Air	2
Filtered vs. Nonfiltered	(1)
Nonfiltered vs. Ambient	(1)
Error-Plot (for air)	2
Row	1
Row X Air	2
Error B	3
Total	11

center rows. The row locations were fixed as split-plots in order to account for possible variation in plant response due to position in the chambers. Thus, there was a split-plot effect as well as block and air treatment effects in the analysis. The Error-Plot was used to test the significance of the effects. The Error B was considered the split-plots.

Leaf injury (measured as percentage necrosis), data were evaluated using the analysis shown in Table 5. The analysis was the same as for yields except that there were four split-plots in each plot, i.e. northwest, northeast, southeast and southwest locations. The necrosis data were arc sine transformed prior to analysis.

Injury (measured as senescence) data were evaluated using the analysis of variance shown in Table 6. The five observations in each plot were taken randomly, resulting in omission of the split-plot effect. Lint quality data were evaluated using a similar analysis of variance (Table 7), except that there were only two observations per plot. Stomatal conductance and transpiration data were evaluated using the analysis of variance shown in Table 8. The analysis was similar to that for senescence data except that there were three observations per plot.

Table 5. Analysis of Variance for Open-Top Chamber Leaf Necrosis Data

Source	df
Block	1
Air	2
Filtered vs. Nonfiltered	(1)
Nonfiltered vs. Ambient	(1)
Error-Plot (for air)	2
Row	3
Row x Air	6
Error B	9
Total	23

Table 6. Analysis of Variance for Open-Top Chamber Leaf Senescence Data

Source	df
Block	1
Air	2
Filtered vs. Nonfiltered	(1)
Nonfiltered vs. Ambient	(1)
Error-Plot (for air)	2
Error B	24
Total	29

Table 7. Analysis of Variance for Open-Top Chamber Lint Quality Data

Source	df
Block	1
Air	2
Filtered vs. Nonfiltered	(1)
Nonfiltered vs. Ambient	(1)
Error-Plot (for air)	2
Error B	6
Total	11

Table 8. Analysis of Variance for Open-Top Chamber Stomatal Conductance and Transpiration Data

Source	df
Block	1
Air	2
Filtered vs. Nonfiltered	(1)
Nonfiltered vs. Ambient	(1)
Error-Plot (for air)	2
Error B	12
Total	17

Plant mapping data from the chambers were evaluated using the analysis of variance shown in Table 9. The analysis was similar to that for the injury data except that Error B was omitted as there was only one measurement per plot.

Table 9. Analysis of Variance for Open-Top Chamber Plant Mapping Data

Source	df
Block	1
Air	2
Filtered vs. Nonfiltered	(1)
Nonfiltered vs. Ambient	(1)
Error-Plot (for air)	2
Total	5

A linear regression analysis was carried out using the ozone concentrations and lint yields from the filtered and ambient chambers at the four sites. The regression analysis table is shown in Table 10. The seven-hour ozone concentrations from the charcoal-filtered and nonfiltered chambers at each of the four sites were used as the independent variables. The cotton lint weights, as a percentage of the charcoal-filtered weight at each site, were used as the dependent variables. This adjustment was necessary because of the highly variable yields between sites. The equation was compared to the linear equations obtained in previous cotton yield loss studies (Brewer, 1985; Heagle et al., 1986; Temple et al., 1985). Because significant treatment effects were actually found with only the two replicate plots, additional analysis was not necessary to determine how many replicates would have been required to detect treatment effects.

2. Antioxidant Study

The data from the two antioxidant sites were analyzed separately. The experimental design at each site was a randomized block. Each field was divided into two blocks, one for cultivar SJ2 and one for GC510. Six antioxidant and six control plots were randomly located within each block. Each plot was the experimental unit for the analysis of variance. The control plots received sprays of the same surfactant (carrier and dispersant) used for the antioxidant plots, but no antioxidant chemical.

Table 10. Regression Analysis for Open-top Chamber Ozone and Yield Data

Source	df
Regression	7
Error	6
Total	7

Harvest data from the antioxidant study were evaluated using the analysis of variance shown in Table 11. Data were taken from two rows in the center of each plot. However, row was not a factor in this analysis as it was for the chamber data because in the antioxidant study there were no structures which could have affected plant growth differently in the two rows. Therefore, the 12 total (2 rows x 6 plots) observations per antioxidant treatment per cultivar were considered to be random observations for the analysis.

Injury data from the antioxidant study were evaluated using the analysis of variance shown in Table 12. The analysis was similar to that for the harvest data except that the Error B and Total df were much larger due to the four observations per plot for injury vs. two per plot for harvest data.

At the end of the study we decided to take extra samples for determination of the possible effect of the surfactant carrier itself on plant growth. Samples were taken from two rows in each of four extra plots from each cultivar at each site. Only data from four of the six antioxidant or surfactant control plots were used in the analysis. The data were analyzed according to an analysis of variance table similar to that shown in Table 11 except there were two df for antioxidant (antioxidant, surfactant control, and no spray treatments), two df for cultivar x antioxidant, 18 df for Error-Plot, and 24 df for Error B.

Table 11. Analysis of Variance for Antioxidant-Harvest Data

Source	df
Cultivar	1
Antioxidant	1
Cultivar x Antioxidant	1
Error Plot (Antioxidant, Cult.)	20
Error B	24
Total	47

Table 12. Analysis of Variance for Antioxidant Injury Data

Source	df
Cultivar	1
Antioxidant	1
Antioxidant x Cultivar	1
Error Plot (Antioxidant, Cult.)	20
Error B	72
Total	95

3. Cultivar Study

The data from each cultivar comparison site were analyzed separately. The experimental design at each site was a randomized block. Separate plots of each of the 13 cultivars were grown in each of four blocks. The cultivars were randomly located in each block. Yield data from the cultivar study were evaluated using the analysis of variance shown in Table 13. Each plot was considered to be the experimental unit for the analysis. There were both cultivar and block effects. Cultivar means at each site were separated using Student-Newman-Keul's test at $p < 0.05$.

Table 13. Analysis of Variance for Cultivar Trial Yield Data at Each Site

Source	df
Cultivar	12
Block	3
Error	36
Total	51

The injury data from the cultivar study were evaluated using the analysis of variance shown in Table 14. Only plots from one block at each site were observed, with ratings made for four plants per plot. Thus, the four individual observations per cultivar were the experimental units for the analysis and there was no block effect.

A matrix of correlation coefficients was calculated for each cultivar in the screening trials. There were four independent variables (ozone exposures, degree days, vascular injury from verticillium wilt, and foliar injury from verticillium wilt), and one dependent variable (average yield per site). The cultivar data from six sites were considered as the observations for the analysis (n=6). Only the data from Porterville, Hanford, Five Points, Firebaugh, Merced, and Madera were used as yields from these sites were within the normal range expected for cotton at those locations. Data were not used from Wasco or Maricopa as the yields were lower than normal at those two sites due to weather conditions early in the year which were unrelated to the independent variables. Linear regression analyses were to be run only for cultivars and independent variables which had significant correlations between yields and ozone concentrations ($p<0.05$ level). However, there were no significant correlations between these two variables.

Table 14. Analysis of Variance for Cultivar Trial Yield Data at Each Site

Source	df
Cultivar	12
Error	39
Total	51

III. RESULTS

A. Open-Top Field Chamber Study

1. Ozone Exposures

The ozone monitoring provided the exposure data for evaluation of differences in air quality among the charcoal-filtered chambers, nonfiltered chambers, and ambient plots. This evaluation was critical for addressing the primary objective of determining whether projected cotton losses based on modeling are actually occurring at multiple sites in the field.

The ozone monitoring began at different times at different sites depending on when the cotton was ready for the chambers, and the availability of instrumentation and personnel. Sites became operational over a period of six weeks from late May to early July, 1988 (Table 15). The Shafter site (where project staff were headquartered), became operational first. The Dinuba site where the cotton had to be replanted in May became operational last. Monitoring continued until mid-to-late September when the instruments were turned off after the plastic was removed from the chambers in preparation for spraying the fields with defoliant. After a lag of one or two days, the instruments were turned back on to continue monitoring in ambient air until approximately November 1st. There were problems with instruments at various sites throughout the season. Condensation in the sample lines and mechanical problems resulted in the low percentage of hours with valid data at Dinuba (60%). In contrast, there was a very high percentage of hours with valid data at Shafter and Hanford over the growing season (>96%).

The ozone concentrations for the different treatments during the growing season were expressed in various ways. Table 16 indicates the values for the most important expressions of ozone exposure.

* Maximum one-hour average. This value related to the California ambient air quality standard for ozone (0.09 ppm for one hour, not to be exceeded).

Table 15. Summary of Ambient Ozone Data Collected as Part of the San Joaquin Valley Cotton Study

Parameter	Site			
	Five Points	Dinuba	Shafter	Hanford
		Entire Growing Season		
Monitoring Dates[a]	5/27-9/21/88	7/5-9/23/88	5/20-9/19/88	6/11-9/13/88
Number of Days	117	80	122	94
Number of Hours	2796	1908	2914	2241
Hours with Data[b]	2167	1147	2721	2157
% Valid Data	78	60	93	96
		Extended Monitoring Period for 4-Meter High Channel		
Monitoring Dates[a]	5/27-11/2/88	7/5-11/3/88	5/20-10/31/88	6/11-10/25/88
Number of Days	159	121	164	136
Number of Hours	3816	2904	3936	3264
Hours with Data[b]	3026	2015	3665	2759
% Valid Data	79	69	93	85

[a]Assumed data for 24 hours on each of monitoring days, except that growing season hours go through 1200 on 9/23/88 for Dinuba, 0800 on 9/13/88 for Hanford, 0900 on 9/19/88 for Shafter, and 1200 on 9/21/88 for Five Points.
[b]May differ by a few hours between the six channels.

* Seven-hour average. The average of all hours during the daylight period over the growing season when plants should be at maximum sensitivity to air pollution (0900-1600 PST). This average has been used in the crop loss assessment equation to estimate cotton yield losses reported in Table 1.

* Twelve-hour average. The average of all hours during daylight over the growing season. This average has been used for loss assessments for many crops besides cotton.

Table 16. Growing Season Ozone Concentrations in ppm

Site	Treatment			
	Charcoal-Filtered	Nonfiltered	Ambient	4-Meter
		High 1-Hour Average[a]		
Shafter	0.077	0.095	0.094	0.121
Dinuba	0.058	0.106	0.120	0.116
Hanford	0.091[b]	0.117	0.116	0.141
Five Points	0.057	0.069	0.083	0.098
		0900-1600 7-Hour Average		
Shafter	0.016	0.050	0.056	0.060
Dinuba	0.019	0.049	0.060	0.053
Hanford	0.014	0.049	0.049	0.058
Five Points	0.019	0.038	0.044	0.053
		0800-2000 12-Hour Average		
Shafter	0.015	0.047	0.051	0.056
Dinuba	0.017	0.046	0.055	0.049
Hanford	0.013	0.045	0.045	0.053
Five Points	0.019	0.037	0.043	0.039
		24-Hour Average		
Shafter	0.016	0.033	0.036	0.040
Dinuba	0.017	0.033	0.039	0.035
Hanford	0.013	0.031	0.031	0.037
Five Points	0.019	0.030	0.033	0.039
		Hours x pphm > 10 pphm Cumulative Dose		
Shafter	0	0	0	7
Dinuba	0	2	15	8
Hanford	0	4	5	9
Five Points	0	0	0	0

[a]The highest 1-hour average for the whole monitoring period.
[b]Late in the day, after blowers off.

* Twenty-four hour average. The average of all hours during the day over the growing season. This average indicated the total plant exposure to ozone.

* Hours x pphm > 10 pphm. This is a cumulative dose and not an average. It is calculated as the summation of all values of (hourly average minus 10 pphm) for values greater than 10 pphm (ppm x 10). This dose has been used to estimate losses from ozone by the California Department of Food and Agriculture.

The data indicated that there was a gradient of ozone concentrations across the San Joaquin Valley. Dinuba had the highest ozone concentrations for ambient air, i.e. just above the plant canopy in the outside control plots (Table 16). Dinuba had the highest values for all characteristics of ozone exposure ranging form the highest one-hour maximum value (0.120) ppm), to the highest seven hour average (0.060 ppm). In contrast, Five Points had the lowest values ranging from the lowest one-hour maximum value (0.083 ppm) to the lowest seven hour average (0.044). The seven-hour averages especially indicated that ozone concentrations were over 25% higher at Dinuba, southeast of the Fresno urban area, than at Five Points in the sparsely populated west side of the valley.

There was some concern that the data from these two sites were not compatible because of the difference in percentage of days with valid data on a growing season basis. However, a similar difference between Dinuba and Five Points occurred when data were evaluated only for those hours when all sites were in operation.

Ambient air data for Shafter and Hanford indicate that average ozone concentrations were between those for Dinuba and Five Points (Table 16). The peak ozone concentration and cumulative dose at Hanford were more similar to those for Dinuba, whereas the longer seven, 12, 24 hour averages for Shafter were more similar to those for Dinuba.

Nonfiltered chamber data tended to follow the same pattern of ozone exposures between sites as for the ambient air data (Table 15). However, there were important differences in that the seven and 12 hour averages were approximately the same for the Dinuba, Shafter, and Hanford sites; though all were higher than the corresponding averages for Five Points. Hanford actually had the highest one-hour value for a nonfiltered chamber. In general, nonfiltered chamber values were lower than ambient air values, as was expected due to removal of some ozone by the air handling system and chamber itself. The reduction in ozone concentrations for nonfiltered vs. ambient air was 11% for Shafter, 18% for Dinuba, 0% for Hanford, and 14% for Five Points on a seven-hour average basis. The reason for a lack of reduction at Hanford is unknown, whereas the percentage reductions for the other three sites were about as expected.

Charcoal-filtration resulted in reduction in ozone concentrations compared to ambient sites (Table 16). There was little difference between sites. The .005 ppm difference between the sites is about at the noise level for the ozone analyzers. Five Points actually tended to have the highest values, possibly because charcoal-filters were not working as well as at the other sites. The reduction in ozone concentrations for charcoal-filtered vs. nonfiltered air was 68% for Shafter, 61% for Dinuba, 71% for Hanford, and 50% for Five Points on a seven-hour average basis. There were some relatively high one-hour averages even in the charcoal-filtered chambers, ranging up to 0.077 ppm at Shafter. These high values occurred late in the day, after the blowers were turned off between 1900 and 2000. As shown in Figure 4, there was an increase in ozone concentrations in charcoal-filtered chambers at all sites late in the day after the blowers were turned off and the ozone concentration rose to equal that in nonfiltered chambers. The ozone concentration in charcoal-filtered chambers dropped again in early morning between 0500 and 0600 as the blowers came on again.

The high ozone values in charcoal-filtered chambers are an indication of the relatively high ambient ozone concentrations that persist at night in a relatively rural area such as the San Joaquin Valley (Figure 4). Evidently, there are not enough automobiles or point sources producing nitrogen oxides which tend to reduce ozone at night. For example, ozone concentrations drop to near zero at night in heavily urbanized areas such as Riverside (Olszyk, 1989). However, the significance of this nighttime ozone is uncertain. Plants can be injured by ozone at night if the stomata are open (Olszyk and Tingey, 1984), but few plants actually keep the stomata fully open at night.

The air monitoring at a height of four meters resulted in some interesting findings. Ozone concentrations were considerably higher at four meters than just above the cotton canopy for most exposure parameters and sites (ambient data) (Table 16). For example, seven-hour ozone concentrations were 7, 18, and 21% higher at four meters than in ambient air at Shafter, Hanford, and Five Points, respectively. At Dinuba ozone

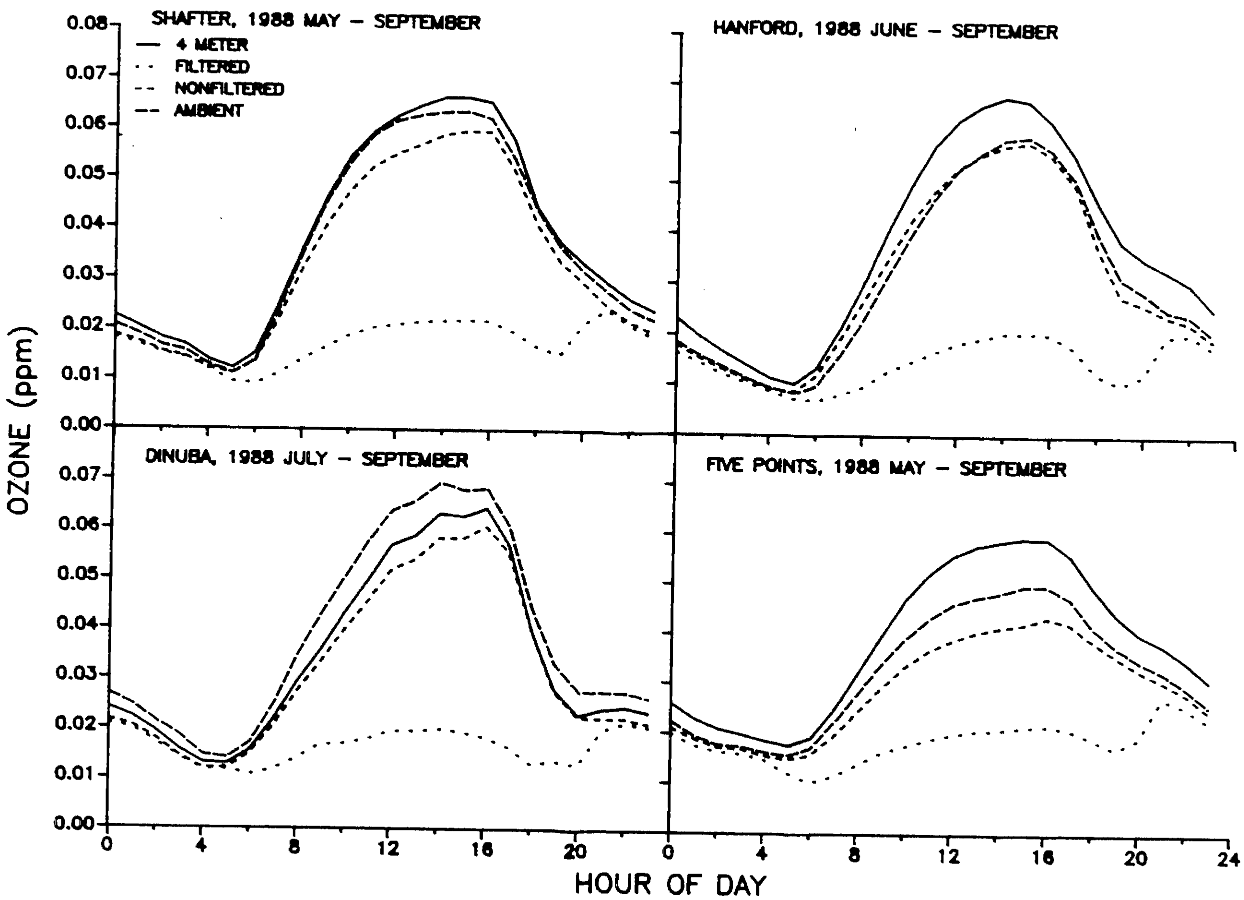

Figure 4. Diurnal ozone patterns for four sites across growing season.

concentrations at four meters were actually lower than at the canopy height. The seven-hour concentrations were 12% lower and maximum one-hour concentration 3% lower at four meters than at canopy height.

The relationship between ozone measurements at four meters and just above the plant canopy has not been discussed previously in any State or Federal Ozone Air Quality Criteria Documents in relation to plant effects (to our knowledge). Yet, the relationship between the two locations is critical for accurately using ambient ozone data and experimental plant response models in crop loss assessments. Most routinely monitored ambient ozone data from air monitoring stations is sampled at four meters, including the data in the ARB statewide database. In contrast, the ozone exposure data reported from field experiments is based on air samples from just above the plant canopy. This is necessary as the air must be sampled within the open-top chambers used for these studies and as close to the leaves as possible in order to document the ozone exposure.

The consistency of the gradient in ozone concentrations at four meters and just above the plant canopy is critical for determining the reliability of ozone exposure-yield loss models. For example, ozone concentrations may be usually 20% higher at four meters than above the canopy due to absorption of ozone by leaves. If this is true, then the ozone concentrations from plant height used in the models would be a reasonable surrogate for ozone at four meters and the yield loss assessments made using the models would be reliable.

However, if the relationship between ozone at four meters and plant height was variable from site to site (or from day to day, season to season, etc.) then the data in the ARB database may not be giving reliable estimates of yield losses from ozone. Therefore, a critical issue for future research is the evaluation of the relationship between four meter and canopy data.

Copies of files containing the raw ozone data were mailed to Mr. Andrew Ranzieri of the ARB staff in early January, 1989.

2. Plant Responses

The plant response data were used to address the sub-objective of this study which was to determine whether actual cotton yield losses from ozone at multiple sites in the San Joaquin Valley were similar to the projected losses based on modeling.

a. General Growth

The plant mapping data indicated that both ambient ozone and the chambers themselves could affect plant development. As shown in Table 17 (treatment means in Appendix C, Table C-1), there was a significantly higher percentage of harvestable bolls in the filtered compared to nonfiltered chamber at the Five Points site. Even though the difference in percent harvestable bolls was not statistically significant between filtered and nonfiltered chambers at the other sites, there was a clear trend which might have been significant if there had been more than two replicates per treatment at each site.

There was a significant effect of the chamber itself on percentage of harvestable bolls at Five Points, and on both percent harvestable bolls and percent aborted bolls at Dinuba (Table 17). However, the response was different at each site with nonfiltered chambers having a greater percentage of harvestable bolls at Five Points, but ambient plots having a greater percent harvestable bolls at Dinuba. We have no explanation for this.

Verticillium wilt was not a problem at any of our sites. There were very few verticillium wilt propagules in the four soil samples from the chamber sites. Average propagules per gram of soil were as follows: Five Points, 3; Dinuba, 3; Hanford, 0; and Shafter, 5. Dr. DeVay indicated that these results were similar to those obtained for other soil samples submitted to him by cotton farm advisors from the San Joaquin Valley, and were surprisingly low for all sites.

b. Injury

The leaf senescence data indicated significant effects of ozone on leaf loss at Shafter and Hanford (Table 18, treatment means in Appendix C, Table C-2). There was a significant ozone effect on leaf senescent and abscision at Shafter and Hanford.

There were a few chamber effects on leaf senescence at two sites. At Shafter there were fewer empty nodes but more senescent nodes in non-filtered chambers than in ambient air (Table 18). At Hanford there were more senescent nodes in nonfiltered chambers than in ambient air.

There were no significant differences in amount of upper leaf injury due to ozone using a visible symptom rating scheme (Table 18). However, there tended to be more injury for nonfiltered than charcoal-filtered

Table 17. Results from Statistical Analysis of Plant Mapping Data[a]

Parameter	Five Points		Dinuba		Shafter		Hanford	
	Ozone[b]	Chamber[b]	Ozone	Chamber	Ozone	Chamber	Ozone	Chamber
Harvestable Bolls (#)	ns	ns	ns	ns	ns	ns	ns	ns
Harvestable Bolls (%)	*[c]	*[d]	ns	*[e]	ns	ns	ns	ns
Aborted Bolls (%)	ns	ns	ns	*[d]	ns	ns	ns	ns

[a]Based on one-way analysis of variance with contrasts. A "ns" indicates no significant difference at $p<0.05$; a * indicates a significant difference at $p<0.05$.
[b]Ozone indicates the difference between filtered and nonfiltered air, chamber indicates the difference between nonfiltered and ambient air.
[c]Filtered>nonfiltered.
[d]Nonfiltered>ambient.
[e]Ambient>nonfiltered.

chambers for all three sites with higher ozone concentrations; Shafter, Dinuba, and Hanford. There was more injury in nonfiltered air for lower leaves at Hanford and Shafter, and upper leaves at Dinuba. Leaf injury levels were most similar in nonfiltered and charcoal-filtered chambers at Five Points, where ozone concentrations were lowest. This indicated that the injury to plants was likely associated with ozone in the air, as the injury was reduced by charcoal filtration only at sites where ambient ozone concentrations were high. However, the general lack of a significant difference in injury for upper or leaves at all sites may have been related to the high amount of variability in injury between plants.

Two of the sites had greater leaf injury in ambient air than in nonfiltered air for upper leaves of plants (Table 18). At Shafter this difference may have been related to greater nitrogen deficiency in the area of ambient plots. At Hanford the greater ambient injury may have been related to greater water stress for the ambient than for the chamber plots. The ambient plots were along the edge of the field and elevated

Table 18. Results from Statistical Analysis for Leaf Injury, Senescence and Loss Data From Open-Top Chamber Study[a]

Parameter	Five Points		Dinuba		Shafter		Hanford	
	Ozone[b]	Chamber[b]	Ozone	Chamber	Ozone	Chamber	Ozone	Chamber
Empty Nodes (#)	ns	ns	ns	ns	ns	*[c]	ns	ns
Senescent Nodes (#)	ns	ns	ns	ns	**[d]	**[e]	**[d]	*[e]
Green Leaves (#)	ns	ns	ns	ns	ns	ns	ns	ns
Total Nodes (#)	ns	ns	ns	ns	ns	ns	ns	ns
Empty Nodes (%)	ns	ns	ns	ns	ns	ns	ns	ns
Empty + Sen. (%)	ns	ns	ns	ns	*[d]	ns	ns	ns
Injury- Upper (%)[f]	ns	ns	ns[g]	ns	ns	ns	ns	ns
Injury- Lower (%)[f]	ns	ns	ns	ns	ns	ns	ns	ns

[a]Based on one-way analysis of variance with contrasts. A "ns" indicates no significant difference at p<0.05; a *, **, or *** indicates a significant effect at p<0.05, 0.01, and 0.005, respectively.
[b]Ozone indicates the difference between filtered and nonfiltered air, chamber indicates the difference between nonfiltered and ambient air.
[c]Nonfiltered<ambient air.
[d]Nonfiltered>charcoal-filtered.
[e]Nonfiltered>ambient air.
[f]Based on arc sine transformation of 0-100% visible necrosis rating. Data were analyzed separately for upper and lower leaves.
[g]Nonfiltered>charcoal-filtered at p<0.08.

slightly compared to the chamber plots - which may have reduced water input to the soil.

c. Yield and Quality

Ambient ozone was associated with a statistically significant reductions in cotton lint yield at Dinuba and Hanford (Table 19). As illustrated by Figure 5, cotton lint weights were 34 and 16% lower in nonfiltered air than charcoal-filtered air. Lint weights were 20 and 13% lower in nonfiltered than in charcoal-filtered air at Shafter and Five Points, respectively, but the differences were not significant.

The significant ozone effect at Hanford was found using the block and split-plot analysis of variance. However, if the blocks were not used, the ozone effect at Hanford would be barely nonsignificant as discussed in Appendix D.

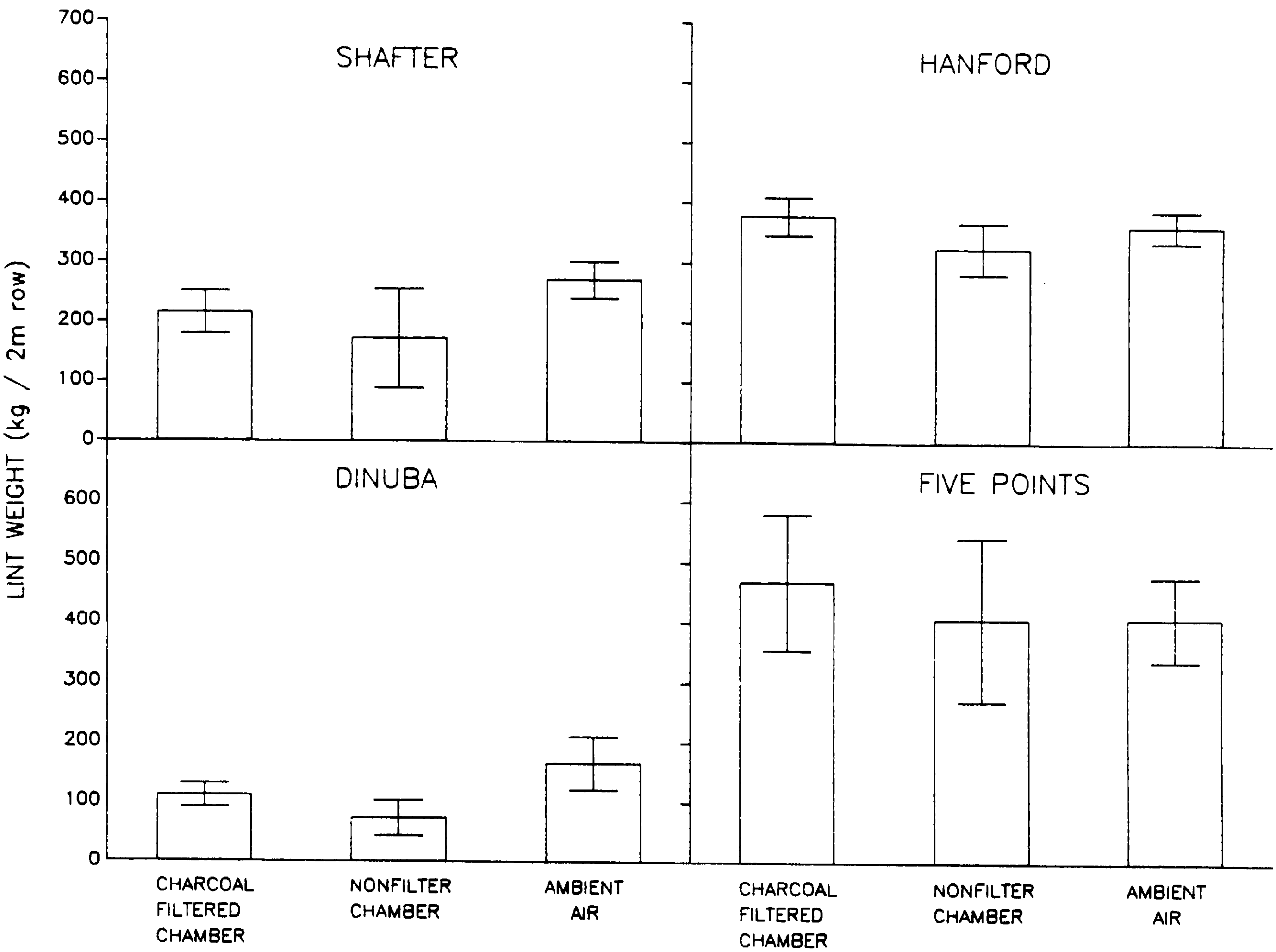

Figure 5. Lint weights at the four chamber sites. Each bar is the mean ± SD of four observations, two from each of two chamber or ambient air plots.

Ambient ozone had few significant effects on any other harvest parameter at any site. The total weight of open bolls and seed weights were lower for nonfiltered than for charcoal-filtered chambers at both the Dinuba and Hanford sites (Table 19). This reflected the ozone effect on lint weight at these sites. The only other parameter affected by ozone was the higher number of young bolls in nonfiltered than charcoal-filtered air at Hanford. This may reflect delayed maturity of bolls due to ozone at that site.

As shown in Figure 5, the general yields for ambient plots at Hanford and Five Points were high at 362 and 408 g/2 m row, respectively (equivalent to approximately 2.9 and 3.3 bales of cotton per acre). Commercial yields in 1987, the best year on record averaged 2.6 bales/acre across California. However, yields on research plots can easily reach 3 bales/acre or more. Values of g/2 m row were multiplied x 0.00807 to obtain estimated commercial bales/acre of cotton lint, assuming that standard research harvesting was 9% more efficient than commercial harvesting. In contrast, the ambient plot yield for Shafter was 270 g/2m of row (2.1 bales), possibly likely due to a nitrogen deficiency in the field. This nitrogen deficiency may have been accentuated in the chambers, resulting in the low yield especially for the nonfiltered air plants. The deficiency may also have contributed to variability in yields between plots which made it difficult to determine if the yield loss due to ozone was statistically significant.

The ambient plot yield for Dinuba was very low at 165 g/2m row an equivalent to 1.3 bales per acre (Figure 5), and significantly less than the yield in nonfiltered chambers (Table 19). This low yield at Dinuba likely was due to a combination of problems accentuated by the necessity to replant the field in late Spring due to the rains and cold weather, pests, and water stress. All of these problems seemed to be accentuated by the chambers and possibly by ozone resulting in the very low yields in the nonfiltered chambers at this site. However, the existence of these multiple stresses at Dinuba also indicated that the adverse effects of other factors may only exacerbate the effects of ozone on cotton yield at some sites.

The chamber effects at Dinuba resulted in a significantly lower number of bolls and total lint and seed weights in nonfiltered chambers

Table 19. Results from Statistical Analysis for Harvest Data From Open-Top Chamber Study[a]

Parameter	Five Points		Dinuba		Shafter		Hanford	
	Ozone	Chamber	Ozone	Chamber	Ozone	Chamber	Ozone	Chamber
Plant Ht. (m)	ns	ns	ns	ns	ns	ns	ns	ns
No. Plants	ns	ns	ns	ns	ns	ns	ns	ns
No. Open Bolls	ns	ns	ns	*[b]	ns	ns	ns	ns
Wt. Open Bolls (g)	ns	ns	*[c]	**[b]	ns	ns	*[c]	ns
Lint Weight (g)	ns	ns	*[c]	**[b]	ns	ns	*[c]	ns
Seed Weight (g)	ns	ns	*[c]	**[b]	ns	ns	*[c]	ns
No. Green Bolls	ns	ns	ns	ns	ns	ns	ns	ns
Wt. Green Bolls (g)	ns	ns	ns	ns	ns	ns	ns	ns
No. Mature Bolls	ns	ns	ns	ns	ns	ns	ns	ns
Wt. Mature Bolls	ns	ns	ns	ns	ns	ns	ns	ns
No. Young Bolls	ns	ns	ns	ns	ns	ns	*[d]	*[e]
Wt. Young Bolls (g)	ns	ns	ns	ns	ns	ns	ns	ns
No. Open Bolls/Plant	ns	ns	ns	ns	ns	ns	ns	ns

[a]Based on one-way analysis of variance with contrasts. A "ns" indicates no significant difference at $p<0.05$; a *, **, or *** indicates a significant effect at $p<0.05$, 0.01, and 0.005, respectively.
[b]Outside>nonfiltered.
[c]Charcoal-filtered>nonfiltered.
[d]Nonfiltered>charcoal-filtered.
[e]Nonfiltered>outside.

compared to ambient air (Table 19). The only other significant chamber effect was an increased number of young bolls in chambers at Hanford.

Ambient ozone had no consistent effects on cotton quality. The only statistically significant response was decreased fiber length in nonfiltered vs. charcoal-filtered air at Dinuba (Table 20, Treatment means in Appendix C, Tables C 6-9).

There were a few significant chamber effects on cotton quality (Table 20). Fiber elongation was decreased in chambers vs. ambient air at Five Points. Fiber length was decreased in chambers whereas +B was increased in chambers vs. ambient air at Dinuba. There were also a number of other parameters which were almost statistically significantly different for chambers vs. outside plots. Some of these parameters were greater in chambers, others were greater in outside plots.

d. Stomatal Conductance and Transpiration

Neither ozone nor the chambers themselves had much effect on water vapor exchange in this study. Transpiration was significantly higher for cotton leaves in charcoal-filtered air than in nonfiltered air only for Shafter on one date (Table 21, Treatment means in Appendix C, Tables C 10 and C 11). The lack of other significant ozone effects may have been due to lack of measurement on days with high ozone concentrations, insufficient replication to detect an ozone effect, or ozone concentrations too low to have much effect on water vapor exchange.

Temple (1986) reported a significant reduction in conductance and transpiration for cotton exposed to a seven-hour growing season average of 0.092 ppm ozone compared to 0.012 ppm ozone in charcoal-filtered air. However, there was only a nonsignificant trend toward reduced water vapor exchange with 0.044 ppm ozone in nonfiltered chambers in Temple's study. Conductance rates in Temple's study were approximately the same as in our study at 21.0 cm s^{-1}. Transpiration rates were slightly lower in Temple's study at $\simeq$10-15 μg m^{-2} s^{-1} vs. 7-28 μg m^{-2} s^{-1} in our study.

There was a significant decrease in stomatal conductance due to the chambers at Hanford on two of the four measurement dates (Table 21). This was possibly due to more water stress near the edge of the field where the ambient plots were located.

B. Antioxidant Study

The antioxidant study addressed the secondary objective of determining whether yield changes are found for cotton plants treated with an antioxidant compound which may inhibit the effects of ozone at a metabolic level.

1. Injury

Casual observations of leaf injury in the antioxidant plots during July and August did not indicate any obvious effects of the compounds on leaf chlorosis or necrosis. This was expected since these antioxidants are believed to reduce premature senescence of leaves, in which case responses would not be expected to become evident until

Table 20. Results from Statistical Analysis of Quality Data[a]

Fiber Parameter[b]	Five Points		Dinuba		Shafter		Hanford	
	Ozone	Chamber	Ozone	Chamber	Ozone	Chamber	Ozone	Chamber
Micronaire	ns	ns	ns	ns	ns	ns	ns	ns
Length	ns	ns	*	*[d]	ns	ns	ns	ns
UR	ns	ns[e]	ns	ns	ns	ns	ns	ns[e]
Strength	ns	ns	ns	ns	ns	ns	ns	ns
Elongation	ns	*[d]	ns	ns[e]	ns	ns	ns	ns
+B	ns	ns	ns	*[f]	ns	ns	ns	ns
Color Index	ns	ns	ns	ns	ns	ns	ns	ns

[a]Based on one-way analysis of variance with contrasts. A "ns" indicates no significant difference at p<0.05; a * or ** indicates a significant difference at p<0.05.
[b]Meaning of fiber parameters described in Methods Section.
[c]Filtered>nonfiltered.
[d]Nonfiltered<ambient
[e]Barely nonsignificant at p<0.10, i.e. for Hanford- UR- nonfiltered>ambient at p<0.072; Dinuba- elongation- nonfiltered>ambient at p<0.072; Five Points - UR- nonfiltered>ambient at p <0.072.
[f]Nonfiltered>ambient.

September when normal cotton leaf senescence begins. Leaf injury was rated using the same scale as that used for the open-top field chamber study. Measurements were made on September 7, 1988 at Shafter and on September 8, 1988 at Five Points. Results from data from the rating are shown in Table 21 (treatment means in Appendix E, Tables E-1 and E-2). There was essentially no difference in the injury rating between any Ozoban® and control plots at either the Shafter or Five Points sites for either cultivar SJ2 or GC510, or for upper or lower leaves. The only exception was a possibly greater amount of injury to the Ozoban® compared to control plants for lower leaves of GC510 at the Five Points site. This exception may be due to slight Ozoban® toxicity at this site, but the potential for inaccuracy associated with the injury evaluation procedure makes this effect highly questionable.

Table 21. Results from Statistical Analysis for Water Vapor Exchange Measurements[a]

Date	Five Points		Dinuba		Shafter		Hanford	
	Ozone	Chamber	Ozone	Chamber	Ozone	Chamber	Ozone	Chamber
				Transpiration				
7/5-7/88	ns	ns	ns	ns	ns	ns	ns	ns
7/5/7/88	ns	ns	ns	ns	ns	ns	ns	ns
7/27-28/88	ns	ns	ns	ns	--	--	--	--
8/24-26/88	ns	ns	ns	ns	*[b]	ns	ns	ns
8/31-9/9/88	ns	ns	ns	ns	ns	ns	ns	ns
				Stomatal Conductance				
7/5-7/88	ns	ns	ns	ns	ns	ns	ns	ns
7/5/7/88	ns	ns	ns	ns	ns	ns	ns	ns
7/27-28/88	ns	ns	ns	ns	--	--	--	--
8/24-26/88	ns	ns	ns	ns	ns	ns	ns	*[c]
8/31-9/9/88	ns	ns	ns	ns	ns	ns	ns	*[c]

[a]Based on one-way analysis of variance with contrasts. A "ns" indicates no significant difference at $p<0.05$; a * indicates a significant effect at $p<0.05$.
[b]Charcoal-filtered>nonfiltered.
[c]Nonfiltered>outside air.

There was no obvious differences between injury with EDU vs. control plants. No statistical analysis could be made on the EDU data, as the measurements were made for only one plot vs. six plots for controls.

2. Yield

The antioxidant had no effect on any measure of cotton growth or yield. In contrast, there were many differences in responses between the two cultivars at both sites. At Five Points SJ2 plants were taller, had a higher bulk weights, number of open bolls of all types, and greater boll weights of all types than for GC510 plants (Table 22, Treatment Means in Appendix E, Tables E-1 and E-2). In contrast, at Shafter SJ2 plants had lower bulk weights, and lower number of open bolls per plant than GC510 plants.

As shown in Figure 6, cotton plants sprayed with the antioxidant had similar lint yields as control plants for both SJ2 and GC510 at both Shafter and Five Points. Statistical analysis for these data are shown in Table 22, with treatments means found in Appendix D. The lack of an antioxidant effect means that either a) the chemical was working but ozone was not affecting the cotton at either site or for either cultivar, b) the chemical was working but either the concentration or frequency of application was not appropriate to prevent ozone effects to the cotton, c) the chemical did not affect the sensitivity of cotton plants to ozone under the conditions used in this study, or d) the effect of ozone on yields at both Shafter and Five Points was not great enough to affect yields. Thus, neither the chambers nor antioxidant would detect any ozone effects.

Explanation c) is the most likely in this case as both the open-top field chamber experiments and presence of ozone injury symptoms on cotton at Shafter indicated that ozone was affecting the cotton leaves, even if yield was not affected. The antioxidant concentration was high enough and frequency of application often enough to affect the sensitivity of grapes to ozone in a previous study, thus it should have been adequate to affect cotton if indeed it was active in this species.

The cultivar GC510 had a significantly higher lint yield, and greater growth than SJ2 at Shafter when data are averaged across the control and antioxidant treatments (Table 22). In contrast, SJ2 had a higher lint yield (though not statistically significant), and greater growth than GC510 at Five Points. This relatively lower growth of SJ2, which is believed to be more susceptible to ozone than GC 510, at Shafter compared to Five Points could be associated with the higher ozone concentrations at Shafter. However, differences in soils and climate between the two sites, as well as well as the nitrogen deficiency at Shafter but not Five Points may also have been largely responsible for the relative yields between SJ2 and GC 510 in the two areas of the valley.

There were few significant interactions between Ozoban® and cultivar. At Five Points the control SJ2 plants had the highest number of open bolls, and at Shafter the control SJ2 plants had the highest weight

Table 22. Results from Statistical Analysis for Antioxidant Study[a]

Parameter	Five Points			Shafter		
	Ozoban	Cultivar[b]	O x C	Ozoban	Cultivar[d]	O x C
Plant Height (m)	ns	***	ns	ns	ns	ns
No. Plants	ns	ns	ns	ns	ns	ns
No. Open Bolls	ns	ns	*[c]	ns	ns	ns
Wt. Open Bolls (g)	ns	*	ns	ns	*	ns
Wt. Lint (g)	ns	ns	ns	ns	**	ns
Wt. Seed (g)	ns	ns	ns	ns	ns	ns
No. Green Bolls	ns	***	ns	ns	ns	ns
Wt. Green Bolls (g)	ns	***	ns	ns	ns	ns
No. Mature Bolls	ns	***	ns	ns	ns	ns
Wt. Mature Bolls (g)	ns	***	ns	ns	ns	*[c]
No. Young Bolls	ns	*	ns	ns	ns	ns
Wt. Young Bolls (g)	ns	**	ns	ns	ns	ns
No. Open Bolls/Plant	ns	ns	ns	ns	*	ns
Injury- Upper (%)[e]	ns	**[f]	ns	ns	ns	ns
Injury- Lower (%)[e]	ns	ns	ns	ns	**[g]	ns

[a]Based on two-way analysis of variance. A "ns" indicates no significant difference at $p<0.05$; a *, **, or *** indicates a significant effect at $p<0.05$, 0.01, or 0.005, respectively.
[b]All cultivar effects are SJ2>GC 510.
[c]Highest value for control SJ2 plants.
[d]All cultivar effects are GC 510>SJ2.
[e]Based on arc sine transformation of leaf injury rating.
[f]More injury for GC 510 than SJ2.
[g]More injury for SJ2 than GC 510.

of mature bolls (Table 22). Neither of these interactions was reflected in terms of cotton yield.

A separate statistical comparison was made between surfactant controls and nonspray controls in order to determine if any effects from the surfactant itself were present. The results of that analysis and treatment means are shown in Appendix E, Tables E3-E7. The surfactant had no effects on yields, but did increase the number of young and green bolls at Shafter.

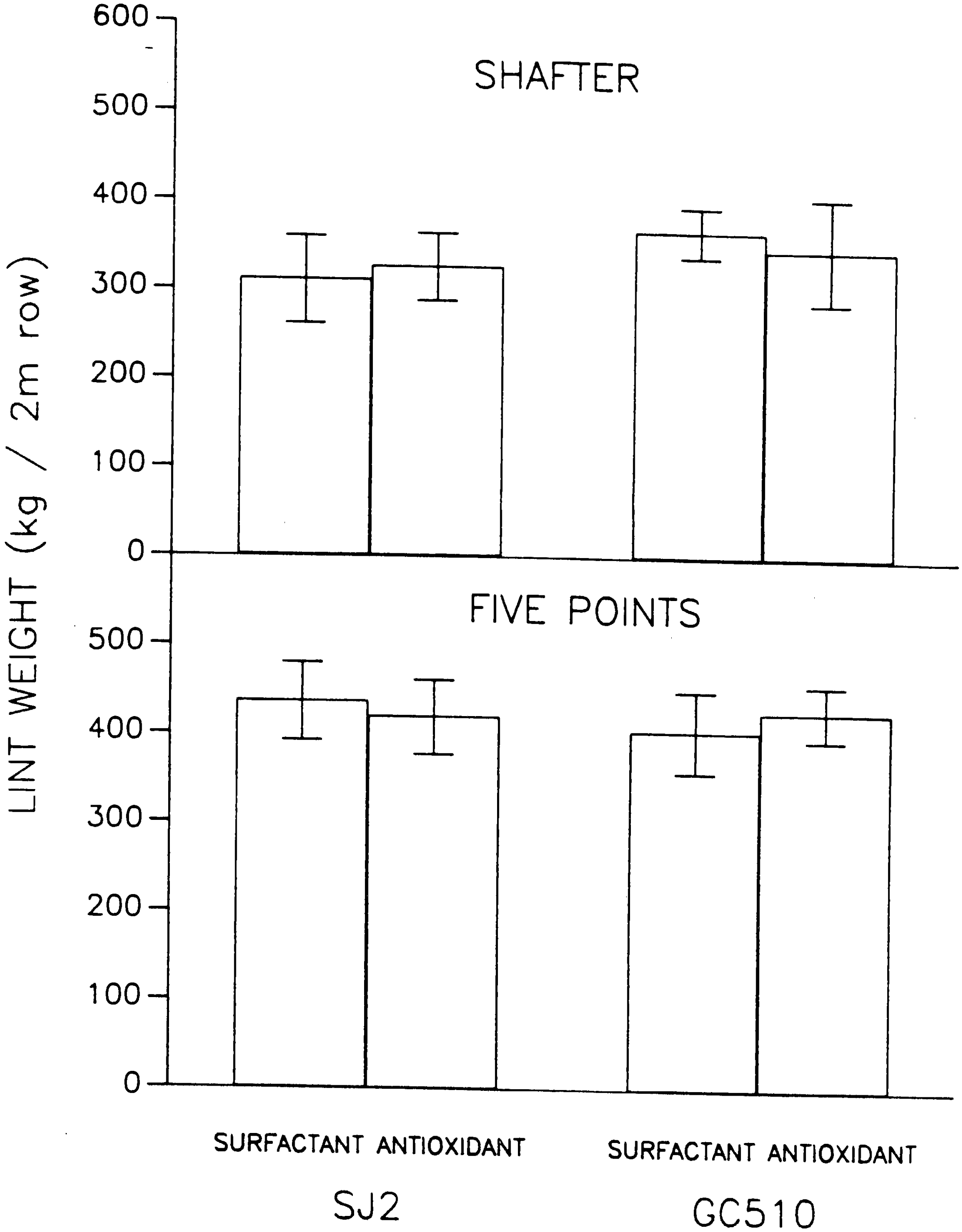

Figure 6. Lint weights with the antioxidant (Ozoban) and control treatments at Shafter and Five Points. Each bar is the mean ± SD for six plots.

C. Cultivar Trial Study

The cultivar trial study addressed the secondary objective of determining relative yields and injury to different cotton cultivars at sites expected to have different ambient ozone concentrations.

1. Injury

The injury ratings indicated that SJ2 had severe injury at nearly all sites, ranking in the top four cultivars in terms of injury for six of the eight sites: Shafter, Porterville, Hanford, Five Points, Madera, and Merced. The results from statistical analysis for upper leaf injury data are shown in Table 23, and for lower leaves in Table 24. Appendix F includes the treatment means at the different sites.

Cultivar SJ2 ranked near the bottom in terms of injury at Wasco. Interestingly, this was also one of the few sites where the lint yield for SJ2 was higher than for the other cultivars. However, because of the abnormally low yields for all cultivars at Wasco the importance of this relationship was questionable.

In general, injury was greater at southern sites than at northern sites. However, it could not be determined whether this difference in injury was due to higher ozone concentrations in the south, or due to other factors such as earlier maturing in the southern areas of the valley. Injury was not rated for Firebaugh and Maricopa.

2. Yield

The results from the statistical analysis of lint yields for all cultivars in the screening trials are shown in Table 25 (treatment means are shown in Appendix F). Lint yields for SJ2 tended to be lower than for other cultivars at all sites in the southern San Joaquin Valley. The lower yields occurred both at high estimated ozone sites such as at Porterville and at low ozone sites such as Five Points and Firebaugh indicating that relative cultivar yields do not correlate well with response to ozone in different areas. Yields for SJ2 also were similar to yields for GC510 at most sites. The cultivar SJ2 performed best at the more northerly sites in Madera and Merced County.

The independent parameters used for the correlation analysis are shown in Table 26. The results of correlation analysis for all cultivars at six sites are shown in Table 27. The data from Maricopa and Wasco could not, unfortunately, be included in the analysis as yields were

Table 23. Results from Statistical Analysis for Upper Leaf Injury Data from Cotton Cultivar Trials[a]

Shafter[b]		Wasco		Porterville		Hanford		Five Points		Madera		Merced	
Acala SJ2	vw	CPCSD C-4164	w	CPCSD C-32	v	Acala SJ2	x	CB 2	x	CB 2	x	Acala SJ2	w
CB 2	wx	CPCSD C-4226	wx	Acala GC-714	vw	Acala GC-350	xy	Acala SJ2	xy	Acala SJ2	y	CB 2	wx
Acala GC-260	wx	CPCSD C-32	wx	Acala SJ2	vw	Westlake 10	xy	CPCSD C-4164	xy	Acala GC-260	y	Acala GC-260	wx
Acala 714	xy	Acala GC-510	wx	CPCSD C-37	vwx	DPL 6	xy	CPCSD C-32	yz	CPCSD C-4226	yz	CPCSD C-4226	xy
Acala GC-510	xy	Acala GC-260	wx	CB 2	vwx	CPCSDC-4226	xy	CPCSD C-4272	yz	Acala GC-356	yz	CPCSD C-4272	xy
CPCSD C-4272	xy	CB 2	wxy	Acala GC-510	vwx	Acala GC-260	xy	Acala GC-714	yz	Acala GC-714	z	CPCSD C-32	xy
CPCSD C-37	xy	CPCSD C-4272	wxy	Acala GC-356	wx	Acala GC-714	yz	CPCSD C-37	yz	Acala GC-510	z	Acala GC-510	xy
CPCSD C-32	xy	CPCSD C-37	xy	Acala GC-260	wx	CPCSD C-32	yz	Westlake 10	yz	CPCSD C-37	z	Westlake 10	xy
DPL 6	xy	DPL 6	xy	CPCSD C-4226	wx	CPCSD C-37	yz	DPL 6	yz	CPCSD C-4164	z	Acala GC-356	y
CPCSD C-4226	xy	Acala GC-356	xy	CPCSD C-4164	wxy	CPCSD C-4164	yz	Acala GC-510	z	Westlake 10	z	DPL 6	y
Westlake 10	yz	Westlake 10	y	DPL 6	xyz	Acala GC-510	z	CPCSD C-4226	z	CPCSD C-32	z	Acala GC-714	z
Acala GC-356	yz	Acala GC-714	z	Westlake 10	yz	CB 2	z	Acala GC-260	z	CPCSD C-4272	z	CPCSD C-37	z
CPCSD C-4164	z	Acala SJ 2	z	CPCSD C-4272	z	Acala GC-356	z	Acala GC-356	z	DPL 6	z	CPCSD C-4164	z

[a]Based on one-way analysis of variance based on arc sine transformation of data shown in Appendix D. Cultivars in a column at each site that are followed by different letters are significantly different at $p<0.05$ based on Student-Newman-Keuls Test. Greatest injury is for cultivar at top of column.
[b]Also Paymaster 145 uv, Coker 139 vw, Acala 1517-75 vw, and DPL 50.

Table 24. Results from Statistical Analysis for Lower Leaf Injury Data from Cotton Cultivar Trials[a]

Shafter[b]		Wasco		Porterville		Hanford		West Side		Madera		Merced		Firebaugh[c]	
Acala SJ2	w	CPCSD C-4226	w	CPCSD C-37	u	Acala GC-260	t	CB 2	x	CB 2	v	Acala SJ2	v	CB 2	v
CB 2	x	CPCSD C-32	w	Acala SJ2	u	DPL 6	u	Acala SJ2	y	Acala GC-260	vw	Acala GC-260	w	Acala GC-714	vw
Acala GC-260	x	Acala GC-260	w	CPCSD C-32	uv	CPCSD C-4226	uv	CPCSD C-4164	z	Acala SJ2	vw	CPCSD C-32	w	Acala GC-356	vw
Acala GC-714	xy	CPCSD C-4164	w	Acala GC-714	uvw	Acala SJ2	uvw	Acala GC-714	z	Acala GC-714	wx	CB 2	w	CPCSD C-37	vwx
DPL 6	yz	CB 2	wx	CB 2	uvwx	CPCSD C-32	vwx	CPCSD C-32	z	CPCSD C-4226	wx	CPCSD C-4226	wx	Westlake 10	wx
Acala GC-510	yz	CPCSD C-37	wx	Acala GC-510	vwxy	Acala GC-350	wx	CPCSD C-37	z	Acala GC-356	wx	Acala GC-510	wxy	CPCSD C-32	wxyz
CPCSD C-37	yz	DPL 6	xy	CPCSD C-4226	vwxy	Westlake 10	xy	CPSD C-4272	z	Acala GC-510	xy	Acala GC-356	wxy	CPCSD C-4272	wxyz
CPCSD C-4272	yz	Acala GC-510	xy	Acala GC-356	wxyz	CPCSD C-37	xy	CPSD C-4226	z	CPCSD C-4164	yz	DPL 6	wxy	DPL 6	wxyz
CPCSD C-32	yz	CPCSD C-4272	yz	Acala GC-260	xyz	CB 2	yz	Westlake 10	z	CPCSD C-37	yz	CPCSD C-4272	wxy	Acala GC-510	yz
CPCSD C-4226	z	Acala GC-356	yz	CPCSD C-4164	yz	Acala GC-510	yz	Acala GC-356	z	CPCSD C-32	yz	Westlake 10	wxy	Acala GC-260	z
CPCSD C-4164	z	Acala SJ2	yz	DPL 6	z	Acala GC-714	z	Acala GC-260	z	Westlake 10	z	CPCSD C-37	xyz	CPCSD C-4164	z
Acala GC-356	z	Westlake	yz	CPCSD C-4272	z	CPCSD C-4164	z	Acala GC-510	z	CPCSD C-4272	z	Acala GC-714	yz	CPCSD C-4226	z
Westlake	z	Acala GC-714	z	Westlake 10	z	CPCSD C-4272	z	CPL 6	z	DPL 6	z	CPCSD C-4164	z		

[a]Based on one-way analysis of variance based on arc sine transformation of data shown in Appendix D. Cultivars in a column at each site that are followed by different letters are significantly different at $p<0.05$ based on Student-Newman-Keuls Test. Greatest injury is for cultivar at top of column.
[b]Also Paymaster 145 vw, DPL 50 vw, Coker 139 x, and Acala 1517-75 x.
[c]No SJ2 at Firebaugh.

Table 25. Results from Statistical Analysis for Yield Data from Cotton Cutlivar Trials[a]

Maricopa		Wasco		Porterville		Hanford		Five Points		Madera		Merced		Firebaugh	
CPCSD C-4164	w	CPCSD C-4226	y	DPL 6	x	CPCSD C-4226	x	CPCSD C-4226	s	CPCSD C-4226	v	Aala SJ2	x	DPL 6	v
CPCSD C-4226	w	CPCSD C-4164	yz	CPCSD C-4272	x	CPCSD C-4164	xy	CPCSD C-4164	t	Acala SJ2	vw	CPCSD C-4226	xy	CPCSD C-4226	v
DPL 6	x	Acala SJ2	yz	Acala GC-714	xy	CPCSD C-37	yz	CPCSD C-4272	u	CB2	wx	Acala GC-356	xyz	CPCSD C-4272	vw
CPCSD C-4272	xy	Acala GC-356	yz	CPCSD C-4226	xy	CPCSD C-32	yz	DPL 6	uv	CPCSD C-4164	wxy	CPCSD C-4164	xyz	Acala GC-714	vw
CB 2	xyz	Acala GC-510	yz	CPCSD C-4164	xy	CPCSD C-4272	yz	CPCSD C-37	vw	DPL 6	wxy	CB 2	xyz	Acala GC-260	vwx
Acala GC-510	xyz	CPCSD C-4272	yz	Acala GC-260	xy	Acala GC-510	yz	Acala GC-260	wx	Acala GC-260	wxy	Acala GC-260	yz	CPCSD C-4164	vwx
Acala SJ2	xyz	Acala GC-714	yz	CPCSD C-37	xyz	Acala GC-260	yz	Acala GC-510	wx	Acala Gc-510	wxy	DPL 6	yz	CPCSDC-37	wxy
Acala GC-260	wxyz	Acala GC-260	yz	Acala C-356	xyz	Acala GC-714	yz	Acala GC-356	wx	CPCSD D-4272	wxy	Acala GC-714	yz	Acala GC-510	wxy
Westlake 10	xyz	CPCSD C-32	yz	CB 2	xyz	DPL 6	z	Acala GC-714	wx	Acala GC-714	wxy	CPCSD C-32	yz	Westlake 10	xy
CPCSD C-37	xyz	CPCSD C-37	yz	Westlake 10	xyz	Acala GC-356	z	Westlake 10	xy	CPCSD C-37	xyz	CPCSD C-37	yz	CB 2	y
Acala GC-356	xyz	CB 2	z	CPCSD C-32	xyz	CB 2	z	Acala SJ2	xyz	Acala GC-32	yz	CPCSD C-4272	yz	Acala GC-356	y
Acala GC-714	yz	DPL 6	z	Acala GC-510	yz	Acala SJ2	z	CPCSD C-32	yz	Acala GC-356	yz	Acala GC-510	yz	CPCSD C-32	y
CPCSD C-32	z	Westlake 10	z	Acala SJ2	z	Westlake 10	z	CB 2	z	Westlake 10	z	Westlake 10	z	Acala SJ2	z

[a]Based on one-way analysis of variance using data shown in Appendix D. Cultivars in a column at each site that are followed by different letters are signficantly different $p<0.05$ based on Student-Newman-Kuels Test. Greatest yield is for cultivar at the top of the column.

Table 26. Degree Days, Relative Ozone Exposures, Foliar Wilt Index, and Vascular Wilt Index for Cotton Cultivar Sites[a]

Cultivar Trial Site	Ozone Exposures[b]		Degree Days[c]		Vascular[d] Wilt (%)	Foliar[d] Wilt (%)
	Site	Conc. (ppm)	Site	Days		
Maricopa	Edison Oildale	0.060	Maricopa	2465	4	11
Wasco	Edison Oildale	0.060	Shafter	2191	2	11
Porterville	Visalia	0.080	Visalia	2239	89	61
Hanford	Hanford	0.060	Hanford	2324	29	46
Five Points	Fresno, Parlier	0.049[e]	Five Points	2150	90	44
Firebaugh	Fresno, Parlier	0.049[e]	Firebaugh	1925	80	52
Madera	Fresno-northwest	0.067	Madera	2284	1	10
Merced	Fresno-northwest	0.067	Los Banos	2091	0	10

[a]Data from Maricopa and Wasco sites not used for correlation coefficient determinations as cotton growth was not normal.
[b]Ozone exposures based on air quality data for 1986 assuming relative concentrations are similar between sites. Ozone data are seven-hour (0900-1600) averages for May-September, 1986.
[c]Degree day data based on May-September 15, 1988 period using the University of California IMPACT system for integrated pest management.
[d]Index of relative wilt potential between sites is based on the percentage damage for vascular and foliar wilt. It is based on rating for SJ2 cultivar at each site. Other cultivars were not rated at each site.
[e]Five Points and Firebaugh ozone concentrations based on a percentage of the average between sites northwest and southeast of Fresno. Five Points concentration based on multiplying the Fresno concentration by 0.673.

abnormally low at those two sites. No statistically significant correlations were found between yield and ozone concentration for any cultivar. This may have been at least in part due to the small number of sample sites. The highest correlations were found for CPCSD 4164, CPCSD C-4226, and CPCSD C-4272, which may indicate that these two cultivars are potentially more susceptible to ozone than the others. One reason for the high correlation coefficient (r value) for CPCSD C-4272 is likely the very low correlation with foliar or vascular wilt for this cultivar. This possible resistance to verticillium wilt would make it much easier to detect an affect of ozone on yield.

Table 27. Correlation Coefficients for Yield vs. Relative Ozone Exposures Degree Days, Vascular Wilt Index, and Foliar Wilt Index[a]

Cultivar	Correlation Coefficient (r) for Yield vs. Parameter			
	Ozone Exp.	Degree Days	Vascular Wilt	Foliar Wilt
Acala GC-260	-0.555	-0.700	-0.351	-0.321
Acala GC-356	-0.426	-0.574	-0.536	-0.527
Acala GC-510	-0.604	-0.586	-0.420	-0.369
Acala GC-714	-0.467	-0.757	-0.247	-0.177
Acala SJ-2	-0.169	-0.234	-0.816*	-0.850*
Acala CB-2	-0.218	-0.402	-0.700	-0.631
CPCSD C-32	-0.401	-0.426	-0.598	-0.439
CPCSD C-37	-0.648	-0.606	-0.367	-0.298
CPCSD C-4164	-0.742	-0.577	-0.317	-0.270
CPCSD C-4226	-0.770	-0.573	-0.316	-0.347
CPCSD C-4272	-0.667	-0.837*	-0.035	-0.026
DPL 6	-0.578	-0.868*	-0.057	-0.071
Westlake 10	-0.587	-0.746	-0.292	-0.287

[a]For n=6 sites, df of 4 for one independent variable. The r values followed by * are statistically significant at $p<0.05$, i.e., $p>0.811$, was necessary for statistical significance. With four independent variables an r of 0.930 at $p<0.05$ would have been necessary, in which case no correlation coefficient would be statistically significant.

The very low correlation coefficient for SJ2 vs. ozone exposure was likely indirectly due to the significant effect of verticillium wilt on this cultivar (Table 27). This was not surprising because one of the main purposes of the cultivar screening trials was to determine the relative yields of other cultivars to SJ2 in areas where SJ2 would be expected to be highly affected by the wilt. Therefore, sites with low wilt potential would have to be chosen to get a true picture of the relationship of SJ2 yield and ozone concentration.

IV. DISCUSSION

A. Relationship Between Actual and Estimated Cotton Yield Losses

In general, the actual cotton yield losses documented in this study were within a few percentage points of the estimated losses based on ozone monitoring data and the ozone exposure-yield model, for all sites except Dinuba (Table 28). The close association between actual and estimated losses at Five Points, Hanford, and Shafter, despite the normal variability in growing conditions between sites, indicated that crop loss estimates based on modeling are reasonable. At Dinuba the actual losses were much higher than estimated losses, probably because of the other stresses present at this site.

The estimated losses based on nonfiltered air data (from inside the chambers themselves), should have provided the best correlation with the actual losses. This is because the ozone concentrations in the equation used to estimate the losses were also taken from just above the plants and inside open-top chambers (Temple et al., 1985). However, the actual losses tended to be higher than as estimated from the loss equation for all sites (Table 28).

The estimated losses based on the four meter ozone data are the losses which would have been calculated using the procedures developed for the California Crop Loss Assessment Project (Olszyk et al., 1988a,b). For that project the ozone data are taken from ambient air monitoring sites from around the state where data are normally collected at a height of about four meters above the ground. Thus, for three of the four sites the actual losses demonstrated with the chambers were about the same as estimated from using the crop loss assessment procedure (Table 28). This finding verifies that the estimated losses calculated in the statewide assessment are reasonable.

The estimated losses based on the plant height air monitoring data (11-15%) are generally midway between the estimated losses using the nonfiltered air (8-15%) and four meter ozone data (15-19%) (Table 28). These values may mean little for crop loss assessment calculations as they neither reflect what plants are exposed to in open-top field chambers, nor the ozone data available to conduct loss assessment. However, the ambient ozone data may actually best reflect the actual ozone exposure for plants in the field.

Table 28. Estimated Cotton Lint Yield Reductions from an Ozone Exposure-Yield Loss Equation vs. Actual Losses Found in Nonfiltered vs. Charcoal-Filtered Air

Site	Estimated Losses[a]			Actual Loss
	Nonfiltered Air	Canopy Height[b]	Four Meter Air[c]	
Five Points	8	11	15	13
Dinuba[d]	13	18	15	34
Shafter	15	17	19	20
Hanford	15	15	19	16

[a]Loss vs. ozone concentration in charcoal filtered air at each site, i.e., 7-hour 0900-1600 average over growing season of 0.014-0.019 ppm.
[b]Ambient air at 10 cm above plants.
[c]Ambient air at 4 m above the ground, i.e., ~3 m above the plants.
[d]Much ozone data from Dinuba was missing and the pattern concentration at four-meters vs. ambient air was different from the other three sites.

The actual losses in our chambers were similar to losses found for SJ1 cotton in the early 1970's at several sites using a totally different type of field chamber (Brewer and Ferry, 1974). At that time a 24% loss was reported at Parlier, which is only approximately 16 km from Dinuba. A 19% loss was reported for the Hanford area which is very similar to the loss found in the current study for Hanford. A loss of only 6% was found earlier at Five Points, which may have reflected the even lower ozone concentrations which may have occurred on the west side of the San Joaquin Valley prior to construction of Interstate 5 and increase in population in the east side of the valley.

The linear regression analysis using the charcoal-filtered and nonfiltered chamber data from each site resulted in a significant linear equation at $p<0.05$. The equation was: yield = 1.11 - 6.79 x (7 hr ozone average between 0900-1600 over growing season in ppm), where $n=8$, df for regression = 6, and r (correlation coefficient) = 0.91. Using this equation a sample growing season ambient ozone concentration of 0.05 ppm would result in an estimated yield loss of 17% compared to a assumed clean air ozone concentration of 0.027 ppm. This is greater than the 10% estimated loss using an equation based on cotton research by Temple et al. (1985), the 10% loss based on research by Brewer et al. (1985), and the 9% loss based on research by Heagle et al. (1986) using formuli described in Thompson and Olszyk (1986). The estimated greater loss based on the loss equation generated from the 1988 cotton study is probably due to the very high loss in nonfiltered vs. charcoal-filtered chambers at Dinuba.

B. Antioxidants and Cotton Response to Ozone

"Ozoban" was applied in accordance with the recommendations received from the manufacturer, and the reasons why it did not work were not known. However, the lack of an apparent protectant effect against ozone injury to cotton by sodium erythorbate was not surprising. The only information available for Ozoban when the study began was the reported protective effect of sodium erythorbate against ozone injury in grapes (Brewer et al., 1987). After the initiation of this study, unpublished results from field trials with this antioxidant on cotton were obtained (R. Brewer, personal communication). Those results indicated that sodium erythorbate had no affect on cotton yields, as found in our study.

We could not really say whether EDU affected the plants as there was too small of a sample to conduct any statistical analysis. However, it was possible that the EDU was not affecting the plants in this study for much the same reasons sodium erythorbate did not affect them. The antioxidant EDU has been shown to reduce leaf injury and yield losses for many crops such as peanuts (Ensign et al., 1985, 1986), potatoes (Bisessar, 1982; Foster et al., 1983; Clarke et al., 1987), beans (Carnahan et al., 1978; Hofstra et al., 1978), clover (Lee et al., 1981), onions (Wikasch and Hofstra, 1977), and other species. In some species such as potatoes (Foster et al., 1983) and peanuts (Ensign et al., 1985, 1986), ozone susceptible cultivars were protected from ozone effects by EDU whereas tolerant cultivars were not.

The effects of EDU on ozone injury to cotton plants were not as clear cut as for other species. R. Brewer of the Kearney Agricultural Center reported that SJ2 cotton sprayed with EDU showed less visual injury symptoms typical for ozone than unsprayed cotton plants. However, this protective effect of EDU was noticed primarily in mid-August and disappeared by mid-September, one month after the final spraying. However, these data have not been published and their reliability has not been established. Heggestad (1988) recently reported that EDU treatment increased cotton yields slightly in nonfiltered air (high ozone) but dramatically reduced yields in charcoal-filtered air (low ozone). Thus, EDU was somewhat phytotoxic, which was masked by its antioxidant effects at high ozone concentrations.

C. Relative Productivity of Cotton Cultivars In Relation to Ambient Ozone Concentrations

Examination of cultivar yield data from across the San Joaquin Valley indicated that this procedure may still prove to be useful for assessing air pollutant effects to crops. However, data from many more years than just one would have to be examined.

Cultivar data rarely have been used to estimate yield losses due to ambient ozone. The only paper reporting such a study was by Ensing et al. (1986) who found that relative yields were highly correlated for ozone sensitive and resistant cultivars of peanuts grown at the same site over a 10-year period. However, yield was not correlated with seasonal ozone exposure for any of six cultivars grown at the same location, and a correlation analysis was not made considering ozone exposure, cultivar, and plant response.

D. Public Information Resulting from the 1988 San Joaquin Valley Cotton Study

The major contributions of this study were the research data relative to the response of cotton to ozone in the San Joaquin Valley. However, benefits of the study were the opportunities to present information on air pollution and crops to local growers, farm advisors, governmental officials and the press.

The project received considerable attention in the local press including stories in newspapers from Fresno, Hanford, Visalia, and Bakersfield. In addition, television stations from Fresno and Bakersfield visited the sites and reported on the project. An interview was also given to staff from a trade magazine dealing with cotton in California and Arizona. Project staff participated in two grower field days, one at Shafter on September 1, 1988; and one at Five Points on September 8,

1988. The chamber sites at those two locations were part of a public tour and growers were shown what ozone injury to cotton looks like, told how the chambers operate, and given information as to how ozone affects crops in general.

Preliminary data from the study were presented at the Annual Meeting of the American Society of Agronomy, held in Anaheim, California in late November and early December, 1988. The investigators for this project thought that it was especially important to present data at this meeting as more representatives from California's agricultural community would be present that when the meeting is held in other areas of the country. A copy of the abstract for the poster presentation is shown in Appendix F.

Finally, preliminary data from this project was made available to growers in the spring of 1989 when the annual California cotton report was published and distributed (Appendix G). Mr. Bruce Roberts was coordinator of this year's report, which was a brief summary of the project written in a layperson's style.

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APPENDIX A

ATTENDANCE LISTS AND AGENDAS

FOR SAN JOAQUIN VALLEY PLANNING MEETINGS

AGENDA

SAN JOAQUIN VALLEY COTTON PROJECT: PLANNING MEETING

February 23, 1988

Chair: Dr. David M. Olszyk, UC Riverside

08:30	Introductions
08:45	General Overview of ARB Perspective on Field Crop and Air Pollution Research
09:00	General Overview of Past Air Pollution and Crop Loss Research-Especially for Cotton
09:30	General Overview of the 1988 San Joaquin Valley Cotton Study
10:00	Break
10:15	Detailed Description of the Field Chamber Portion of the Cotton Study
10:45	Discussion
11:30	Adjourn

Attendees at Cotton Planning Meeting
February 23, 1988
Visalia, CA

Name	Organization
Dr Dick Bassett	UC Davis (at USDA Cotton Research Station)
Dr. Homero Cabrera	ARB Research Division
Mr. Cal Dooley	Dooley Farms and State Senator Rosanne Vuich's Office
Mr. Robert Edwards	Kern County Agricultural Commissioner
Ms. Stephanie Johnson	Tulare County Cotton Farm Advisor
Ms. Laurena Johnson	Tulare County Farm Bureau
Mr. Gerrit Kats	UC Riverside
Ms. Shirley Kirkpatrick	ARB Agricultural Advisory Committee
Dr. David Millhouse	BASF Dinuba
Dr. David Olszyk	UC Riverside
Mr. Bruce Roberts	Kings County Cotton Farm Advisor
Dr. Clif Taylor	UC Riverside
Ms. Sydney Thornton	ARB Research Division
Dr. Tony Van Curen	ARB Research Division

AGENDA

SAN JOAQUIN VALLEY COTTON PROJECT: PLANNING MEETING

July 7, 1988

Chair: Dr. David Olszyk, UC Riverside

09:00	Tour of Hanford Site, Including Local Press
10:00	Meeting at Hanford, Introductions
10:10	Current Status of Cotton Project
11:00	Schedule for Rest of Summer
11:30	Ideas for 1989
12:00	Lunch
13:30	Tour of Five Points Site

Attendees at Cotton Planning Meeting
July 7, 1988
Hanford, CA

Name	Organization
Dr. Dick Bassett	UC Davis (at USDA Cotton Research Station
Dr. Homero Cabrera	ARB Research Division
Ms. Garnett Cook	UC Riverside (at Hanford)
Ms. Stephanie Johnson	Tulare Co. Cotton Farm Advisor
Ms. Tammy Kerby	UC Riverside (at Shafter)
Dr. David Millhouse	BASF Dinuba
Dr. David Olszyk	UC Riverside
Mr. Chris Reagan	UC Riverside (at Shafter)
Dr. Bill Retzlaff	UC Davis (at Kearney)
Mr. Bruce Roberts	Kings County Cotton Farm Advisor
Ms. Sydney Thornton	ARB Research Division
Ms. Ann Turner	UC Riverside (at Visalia)
Dr. Tony Van Curen	ARB Research Division
Dr. Dane Westerdahl	ARB Research Division
Dr. Larry Williams	UC Davis (at Kearney)

APPENDIX B

SUMMARY OF ENVIRONMENTAL CONDITIONS DURING 1988 GROWING SEASON NEAR COTTON CULTIVAR TRIAL SITES

Table B-1. Average Environmental Conditions Near Cotton Cultivar Trial Sites

Month	Days	ETo (in.)	Solar Radiation (Ly/day)	Air Temperature Max	Min (oF)	Ave	Humidity Ave (%)
			Fresno/Fresno State University				
May	31	6.84	662	84	52	68	49
June	30	7.41	680	90	59	74	48
July	31	8.73	702	101	66	84	42
August	31	6.98	602	96	63	79	49
September	25	5.54	499	92	58	75	52
Average[a]		33.45	634	93	60	76	48
			Five Points/West Side Field Station				
May	31	7.34	639	82	50	67	44
June	30	7.74	672	89	58	74	48
July	31	8.36	676	100	69	85	48
August	31	7.35	589	92	62	77	50
September	30	6.54	511	90	57	73	44
Averages[a]		37.33	618	91	59	75	47
			Shafter/USDA Cotton Research Station				
May	31	7.71	653	82	50	66	45
June	30	7.83	668	89	57	73	45
July	31	8.68	681	98	65	82	45
August	31	7.63	610	94	61	77	48
September	30	6.60	522	91	55	72	45
Average[a]		38.45	629	91	58	74	46
Firebaugh/Telles							
May	31	7.25	609	79	49	64	47
June	30	7.47	623	86	56	71	46
July	31	8.40	678	97	62	79	48
August	31	6.72	617	91	58	74	60
September	30	5.31	516	88	54	69	57
Average[a]		35.16	609	88	55	71	52

(continued)

Table B-1 (continued) - 2

Month	Days	ETo (in.)	Solar Radiation (Ly/day)	Air Temperature Max	Min (oF)	Ave	Humidity Ave (%)
			Lamont				
May	31	6.55	610	82	51	67	39
June	30	6.91	625	89	58	74	44
July	31	8.83	646	102	66	84	42
August	31	7.62	570	96	63	79	48
September	30	5.68	486	92	57	74	47
Averages[a]		35.59	588	92	59	76	44
			Visalia/ICI Americas				
May	31	6.97	616	82	49	65	56
June	30	7.74	655	88	56	72	48
July	31	8.04	666	98	65	82	50
August	31	6.42	563	94	62	77	57
September	30	4.42	436	92	55	72	57
Average[a]		33.59	588	91	57	74	54
			Mendota/Murietta USDA				
May	31	7.46	604	79	47	63	53
June	30	7.98	641	88	54	71	51
July	31	8..27	675	98	62	79	49
August	31	7.10	601	93	59	75	52
September	30	6.17	501	90	54	71	43
Average[a]		37.08	605	89	55	72	50
			Los Banos				
July	31	9.98	672	96	61	78	50
August	31	6.82	596	91	58	74	60
September	30	4.43	491	88	53	69	56
Average[a]		21.23	587	92	57	74	55

[a]Total for ETo.

APPENDIX C

TREATMENT MEANS FOR ALL RESPONSE PARAMETERS FROM OPEN-TOP FIELD CHAMBER SITES

Table C-1	Treatment means for plant mapping data.
Tables C-2 through C-5	Treatment means for leaf injury rating and harvest data.
Tables C-6 through C-9	Treatment means for lint quality data.
Tables C-10 through C-11	Treatment means for stomatal conductance and transpiration data.

Table C-1. Plant Mapping Measurements at Different Sites[a]

Parameter	Site	Treatment		
		Filtered	Nonfiltered	Ambient
Harvestable Bolls (#)	Shafter	59.0 ± 9.4	57.0 ± 5.5	75.8 ± 7.1
	Dinuba	73.3 ± 9.7	42.5 ± 3.0	84.3 ± 21.2
	Hanford	123.9 ± 27.9	98.3 ± 20.9	110.9 ± 3.7
	Five Points	93.1 ± 7.2	93.2 ± 27.4	86.7 ± 7.9
Harvestable Bolls (%)	Shafter	42.3 ± 0.5	36.1 ± 2.3	38.9 ± 3.2
	Dinuba	31.4 ± 0.1	27.1 ± 3.3	47.5 ± 0.7
	Hanford	50.3 ± 6.6	43.7 ± 2.4	45.1 ± 3.4
	Five Points	46.0 ± 0.1	42.8 ± 1.2	38.6 ± 0.3
Aborted Bolls (%)	Shafter	43.5 ± 2.2	44.6 ± 5.4	50.0 ± 1.8
	Dinuba	55.9 ± 1.1	61.8 ± 3.8	40.3 ± 0.8
	Hanford	33.8 ± 1.0	43.6 ± 2.8	42.6 ± 5.2
	Five Points	43.2 ± 1.0	44.7 ± 0.7	47.6 ± 0.3

[a]Means ± standard deviation for two observations, one from each replicate plot, with five plants measured per observation.

Table C-2. Treatment Means for Cotton at Hanford Site[a]

Parameter	Nonfiltered	Charcoal Filtered	Ambient Air
Plant Height (m)	1.04 ± 0.10	1.12 ± 0.10	0.94 ± 0.03
Plants (#)	22 ± 2	23 ± 4	23 ± 2
Open Bolls (#)	144 ± 10	175 ± 8	152 ± 9
Open Bolls (g)	897 ± 109	1065 ± 81	971 ± 61
Green Bolls (#)	9 ± 4	1 ± 2	0
Green Bolls (g)	140 ± 82	29 ± 44	0
Mature Bolls (#)	7 ± 3	1 ± 2	0
Mature Bolls (g)	116 ± 71	23 ± 47	0
Young Bolls (#)	3 ± 1	0	0
Young Bolls (g)	25 ± 13	6 ± 12	0
Lint Weight (g)	325 ± 43	387 ± 32	362 ± 26
Seed Weight (g)	566 ± 66	673 ± 50	601 ± 37
Open Bolls/Plant	6.5 ± 0.6	7.6 ± 0.9	6.6 ± 0.2
Empty Nodes (#)	8 ± 1	7 ± 1	10 ± 3
Senescent Lvs. (#)	5 ± 1	1 ± 1	3 ± 1
Green Leaves (#)	5 ± 2	10 ± 1	5 ± 1
Total Nodes	17 ± 1	18 ± 1	17 ± 2
% Empty Nodes	45 ± 7	41 ± 6	55 ± 11
% Emp. + Sen. Nds.	74 ± 11	46 ± 5	73 ± 9
Injury- Upper (%)	14 ± 5	16 ± 16	61 ± 18
Injury- Lower (%)	55 ± 14	33 ± 17	64 ± 15

[a]Values are means ± SD for a 2 m length of row for height, # plants, boll weights and numbers, seed and lint weights, and injury; with four observations, two from each of two plots. Values are means ± SD for leaf and node data; with 10 observations, five from each of two plots.

Table C-3. Treatment Means for Cotton at Shafter Site[a]

Parameter	Nonfiltered	Charcoal Filtered	Ambient Air
Plant Height (m)	0.84 ± 0.08	0.91 ± 0.08	0.89 ± 0.05
Plants (#)	19 ± 4	19 ± 2	18 ± 3
Open Bolls (#)	100 ± 18	119 ± 20	130 ± 7
Open Bolls (g)	466 ± 60	573 ± 95	717 ± 68
Green Bolls (#)	1 ± 2	3 ± 5	0.3 ± 0.5
Green Bolls (g)	22 ± 32	34 ± 67	5 ± 9
Mature Bolls (#)	7 ± 3	1 ± 2	0
Mature Bolls (g)	1 ± 2	2 ± 5	0.3 ± 0.5
Young Bolls (#)	0	0.3 ± 0.5	0
Young Bolls (g)	22 ± 32	2 ± 3	5 ± 9
Lint Weight (g)	172 ± 23	215 ± 36	270 ± 31
Seed Weight (g)	293 ± 38	357 ± 61	445 ± 37
Open Bolls/Plant	5.4 ± 0.8	6.4 ± 1.4	7.4 ± 1.2
Empty Nodes (#)	9 ± 2	8 ± 1	13 ± 2
Senescent Nodes (#)	6 ± 2	1 ± 1	2 ± 1
Green Leaves (#)	2 ± 2	7 ± 2	4 ± 2
Total Nodes	17 ± 3	16 ± 2	19 ± 2
% Empty Nodes	54 ± 13	50 ± 6	68 ± 8
% Emp. + Sen. Nds.	88 ± 10	56 ± 8	81 ± 8
Injury- Upper (%)	11 ± 9	2 ± 4	37 ± 36
Injury- Lower (%)	74 ± 22	21 ± 8	66 ± 35

[a]Values are means ± SD for a 2 m length of row for height, # plants, boll weights and numbers, seed and lint weights, and injury; with four observations, two from each of two plots. Values are means ± SD for leaf and node data; with 10 observations, five from each of two plots.

Table C-4. Treatment Means for Cotton at Five Points Site[a]

Parameter	Nonfiltered	Charcoal Filtered	Ambient Air
Plant Height (m)	1.17 ± 0.05	1.17 ± 0.05	1.22 ± 0.05
Plants (#)	12 ± 1	11 ± 3	12 ± 2
Open Bolls (#)	170 ± 28	202 ± 25	161 ± 30
Open Bolls (g)	963 ± 128	1182 ± 166	1085 ± 181
Green Bolls (#)	21 ± 8	20 ± 18	24 ± 14
Green Bolls (g)	440 ± 203	425 ± 412	554 ± 344
Mature Bolls (#)	18 ± 7	18 ± 17	22 ± 13
Mature Bolls (g)	413 ± 187	387 ± 409	517 ± 373
Young Bolls (#)	3 ± 1	3 ± 2	2 ± 1
Young Bolls (g)	27 ± 19	37 ± 7	37 ± 33
Lint Weight (g)	407 ± 136	468 ± 113	408 ± 70
Seed Weight (g)	686 ± 236	795 ± 189	673 ± 113
Open Bolls/Plant	14.8 ± 1.1	19.2 ± 4.4	13.5 ± 4.3
Empty Nodes (#)	7 ± 2	8 ± 2	9 ± 3
Senescent Nodes (#)	3 ± 1	1 ± 1	3 ± 1
Green Leaves (#)	10 ± 1	14 ± 2	11 ± 2
Total Nodes	20 ± 2	23 ± 3	23 ± 1
% Empty Nodes	35 ± 8	36 ± 7	37 ± 10
% Emp. + Sen. Nds.	51 ± 4	40 ± 6	52 ± 10
Injury- Upper (%)	18 ± 15	33 ± 20	29 ± 11
Injury- Lower (%)	30 ± 11	38 ± 31	45 ± 11

[a]Values are means ± SD for a 2 m length of row for height, # plants, boll weights and numbers, seed and lint weights, and injury; with four observations, two from each of two plots. Values are means ± SD for leaf and node data; with 10 observations, five from each of two plots.

Table C-5. Treatment Means for Cotton at Dinuba Site[a]

Parameter	Nonfiltered	Charcoal Filtered	Ambient Air
Plant Height (m)	1.65 ± 0.41	1.40 ± 0.25	1.17 ± 0.20
Plants (#)	19 ± 6	21 ± 6	17 ± 4
Open Bolls (#)	52 ± 23	81 ± 16	102 ± 25
Open Bolls (g)	222 ± 55	345 ± 71	480 ± 133
Green Bolls (#)	7 ± 7	3 ± 3	0.3 ± 0.5
Green Bolls (g)	111 ± 134	63 ± 64	6 ± 13
Mature Bolls (#)	6 ± 8	3 ± 3	0.3 ± 0.5
Mature Bolls (g)	27 ± 54	17 ± 33	0
Young Bolls (#)	1 ± 1	0.5 ± 1	0
Young Bolls (g)	85 ± 138	47 ± 65	6 ± 13
Lint Weight (g)	73 ± 20	111 ± 20	165 ± 45
Seed Weight (g)	147 ± 36	231 ± 48	311 ± 85
Open Bolls/Plant	2.9 ± 1.3	3.9 ± 0.8	6.2 ± 0.7
Empty Nodes (#)	14 ± 3	13 ± 2	14 ± 2
Senescent Nodes (#)	2 ± 2	1 ± 1	2 ± 2
Green Leaves (#)	7 ± 3	10 ± 2	9 ± 2
Total Nodes	23 ± 5	24 ± 3	25 ± 2
% Empty Nodes	60 ± 6	52 ± 9	56 ± 7
% Emp. + Sen. Nds.	70 ± 7	58 ± 7	63 ± 4
Injury- Upper (%)	29 ± 8	4 ± 5	24 ± 5
Injury- Lower (%)	94 ± 7	88 ± 14	93 ± 9

[a]Values are means ± SD for a 2 m length of row for height, # plants, boll weights and numbers, seed and lint weights, and injury; with four observations, two from each of two plots. Values are means ± SD for leaf and node data; with 10 observations, five from each of two plots.

Table C-6. Lint Quality for Cotton at Shafter Site[a]

Parameter	Nonfiltered	Charcoal Filtered	Ambient Air
Micronaire	4.7 ± 0.1	4.8 ± 0.0	4.6 ± 0.1
Length	1.17 ± 0.04	1.16 ± 0.04	1.17 ± 0.03
UR	84 ± 1	84 ± 2	85 ± 1
Strength	27 ± 1	28 ± 1	27 ± 2
Elongation	6.0 ± 0.4	6.5 ± 0.3	6.2 ± 0.3
Leaf Index	3 ± 1	3 ± 1	3 ± 2
+B	8.1 ± 0.3	8.4 ± 0.2	7.9 ± 0.7
Color Index	19 ± 5	21 ± 0	26 ± 13

[a]Values are means ± SD for four observations, two from each of two plots.

Table C-7. Lint Quality for Cotton at Hanford Site[a]

Parameter	Nonfiltered	Charcoal Filtered	Ambient Air
Micronaire	4.7 ± 0.2	4.4 ± 0.2	4.5 ± 0.2
Length	1.17 ± 0.02	1.18 ± 0.02	1.15 ± 0.02
UR	86 ± 1	86 ± 1	85 ± 1
Strength	32 ± 1	29 ± 1	28 ± 2
Elongation	6.7 ± 0.2	6.7 ± 0.4	6.5 ± 0.3
Leaf Index	2 ± 0	2 ± 0	3 ± 2
+B	8.5 ± 0.3	8.7 ± 0.5	8.1 ± 0.7
Color Index	16 ± 6	16 ± 6	26 ± 10

[a]Values are means ± SD for four observations, two from each of two plots.

Table C-8. Lint Quality for Cotton at Five Points Site[a]

Parameter	Nonfiltered	Charcoal Filtered	Ambient Air
Micronaire	4.7 ± 0.2	4.7 ± 0.2	4.5 ± 0.2
Length	1.12 ± 0.03	1.18 ± 0.04	1.16 ± 0.03
UR	86 ± 1	86 ± 1	85 ± 1
Strength	32 ± 2	30 ± 1	29 ± 3
Elongation	6.0 ± 0.3	6.1 ± 0.3	6.2 ± 0.3
+B	8.2 ± 0.4	8.5 ± 0.5	8.2 ± 0.9
Color Index	26 ± 10	24 ± 5	26 ± 10

[a]Values are means ± SD for four observations, two from each of two plots.

Table C-9. Lint Quality for Cotton at Dinuba Site[a]

Parameter	Nonfiltered	Charcoal Filtered	Ambient Air
Micronaire	3.6 ± 0.5	4.1 ± 0.4	3.5 ± 0.9
Length	1.16 ± 0.02	1.16 ± 0.02	1.15 ± 0.02
UR	83 ± 2	84 ± 3	82 ± 4
Strength	28 ± 1	28 ± 3	29 ± 1
Elongation	5.8 ± 0.4	6.1 ± 0.2	6.3 ± 0.5
+B	8.8 ± 0.4	8.9 ± 0.2	8.4 ± 0.2
Color Index	19 ± 5	19 ± 5	26 ± 6

[a]Values are means ± SD for four observations, two from each of two plots.

Table C-10. Stomatal Conductance Measurements at Different Sites

Date	Site	Conductance (cm^{-1})		
	Filtered	Nonfiltered	Ambient	
7/5-7/88	Shafter	1.06 ± 0.04	1.01 ± 0.13	1.12 ± 0.22
	Dinuba	0.42 ± 0.14	0.49 ± 0.46	0.48 ± 0.18
	Hanford	1.04 ± 0.36	0.83 ± 0.30	1.00 ± 0.15
	Five Points	0.92 ± 0.27	0.92 ± 0.20	0.90 ± 0.26
7/12-13/88	Shafter	1.77 ± 0.08	1.62 ± 0.16	1.89 ± 0.26
	Dinuba	1.85 ± 0.33	1.66 ± 0.27	1.78 ± 0.13
	Hanford	0.87 ± 0.37	0.71 ± 0.30	1.08 ± 0.51
	Five Points	1.10 ± 0.26	1.34 ± 0.35	1.15 ± 0.40
7/27-28/88	Five Points	2.35 ± 0.26	2.00 ± 0.08	2.08 ± 0.22
	Dinuba	1.85 ± 0.52	1.07 ± 0.81	0.97 ± 0.78
8/24-26/88	Shafter	1.19 ± 0.12	0.75 ± 0.09	0.96 ± 0.32
	Dinuba	1.33 ± 0.39	1.22 ± 0.35	0.79 ± 0.46
	Hanford	0.95 ± 0.11	0.98 ± 0.11	0.81 ± 0.06
	Five Points	1.63 ± 0.15	0.87 ± 0.36	1.54 ± 0.36
8/31-9/9/88	Shafter	1.19 ± 0.25	0.94 ± 0.13	0.76 ± 0.20
	Dinuba	0.20 ± 0.08	0.25 ± 0.09	0.15 ± 0.05
	Hanford	0.63 ± 0.11	0.60 ± 0.15	0.20 ± 0.07
	Five Points	1.67 ± 0.15	1.57 ± 0.12	1.33 ± 0.25

[a]Means ± standard deviation for six single plant replicates, three from each of two replicate plots.

Table C-11. Transpiration Measurements at Different Sites

Date	Site	Transpiration (μg cm⁻¹ s⁻¹) Filtered	Nonfiltered	Ambient
7/5-7/88	Shafter	14.1 ± 0.3	14.4 ± 0.9	14.3 ± 2.1
	Dinuba	12.4 ± 2.7	10.5 ± 7.9	12.6 ± 3.1
	Hanford	16.1 ± 3.1	13.3 ± 3.2	15.4 ± 2.0
	Five Points	15.4 ± 2.8	16.5 ± 3.4	15.8 ± 2.0
7/12-13/88	Shafter	17.2 ± 1.2	18.1 ± 1.8	17.8 ± 3.1
	Dinuba	20.8 ± 2.1	19.0 ± 2.8	19.8 ± 2.1
	Hanford	6.7 ± 2.7	6.1 ± 2.0	6.8 ± 4.5
	Five Points	17.8 ± 2.6	18.0 ± 3.9	17.8 ± 3.8
7/27-28/88	Five Points	28.8 ± 1.1	28.2 ± 1.2	26.0 ± 2.3
	Dinuba	13.4 ± 3.7	13.5 ± 7.5	12.9 ± 8.2
12/24-26/88	Shafter	18.5 ± 1.9	12.4 ± 3.8	16.1 ± 1.5
	Dinuba	12.3 ± 3.1	11.3 ± 2.2	7.9 ± 3.8
	Hanford	11.3 ± 1.1	11.4 ± 1.0	11.6 ± 1.1
	Five Points	19.6 ± 1.5	13.9 ± 3.1	17.2 ± 2.9
8/31-9/9/88	Shafter	12.4 ± 2.7	9.7 ± 2.3	10.7 ± 2.7
	Dinuba	3.3 ± 1.1	4.1 ± 1.9	2.7 ± 1.0
	Hanford	6.4 ± 1.7	7.2 ± 1.8	4.0 ± 1.3
	Five Points	14.6 ± 0.9	14.9 ± 1.4	14.8 ± 2.0

[a]Means ± standard deviation for six single plant replicates, three from each of two replicate plots.

APPENDIX D

COMPARISON OF DIFFERENT STATISTICAL ANALYSES FOR LINT YIELD AT HANFORD SITE

The cotton harvest data from the Hanford site were analyzed according to five different models to determine the effect of the model on detection of statistically significant differences between the charcoal-filtered and nonfiltered air treatments. Each site had four chambers, two charcoal-filtered and two nonfiltered; and two outside plots. Within each chamber or outside plot there were two center rows which were harvested. The two rows were designated A and B, with A and B always occurring on the same side of the chamber or outside plot at each site.

The five models were used because the data could be evaluated differently depending on the how the two rows of cotton in each of the chambers and outside plots were treated, and on whether the chambers and outside plots were grouped into blocks. The five analysis of variance models are shown below (note - an * indicates a significant difference at $p<0.05$):

Model #1
(Groups and Rows Treated as Blocks)

Source	df	p Value
Row	1	0.778
Block	1	0.149
Air	2	0.095
Filt. vs. Nonf.	(1)	0.049 *
Nonf. vs. Out.	(1)	0.125
Error (Plot)	2	
Error B	5	
Total	11	

Model #2
(Groups Treated as Blocks, Rows as Split-Plots)

Source	df	p Value
Block	1	0.149
Air	2	0.095
Filt. vs. Nonf.	(1)	0.049 *
Nonf. vs. Out.	(1)	0.125
Error (Plot)	2	
Row	1	0.875
Row x Air	2	0.424
Error B	3	
Total	11	

Model #3
(No Blocks, Rows Treated as Split-Plots)

Source	df	p Value
Air	2	0.145
Filt. vs. Nonf.	1	0.068
Nonf. vs. Out.	1	0.199
Error (Plot)	3	
Rows	1	0.825
Row x Air	2	0.424
Error B	3	
Total	11	

Model #4
(Groups Treated as Blocks, no Split-Plots)

Source	df	p Value
Block	1	0.149
Air	2	0.095
Filt. vs. Nonf.	(1)	0.049 *
Nonf. vs. Out.	(1)	0.125
Error (Plot)	2	
Error B	6	
Total	11	

Model #5
(No Blocks, No Split Plots)

Source	df	p Value
Air	2	0.145
Filt. vs. Nonf.	1	0.068
Nonf. vs. Out.	1	0.199
Error (Plot)	3	
Error B	6	
Total	11	

These models indicate that the use of blocks increased the ability of the analysis to detect a significant difference in cotton lint yield due to ozone exposure (filtered vs. nonfiltered air comparison). The p values went from 0.068 without blocks as shown in Models 3 and 5 (barely nonsignificant at $p<0.05$), to 0.049 with blocks as shown in Models 1, 2 and 4 (barely significant at $p<0.05$). Thus we have retained use of the blocks in this analysis for all sites. However, we recognize that the use of the blocks was arbitrary and that they were possibly not necessary. The study originally was set up so that one representative of each treatment was in the same general area of the field at each site, which indicated blocking. However, there was not necessarily any reason for the blocks in terms of position of rows or obvious differences in soil type between the blocks. Furthermore, the outside plots at Dinuba and Hanford were in slightly different locations compared to the other two treatments in the blocks.

Similarly, we harvested cotton in two rows, primarily to have more cotton samples than if both rows were harvested together per chamber. However, we also kept the A and B rows on the same side in each chamber or outside plot in an attempt to detect any positional effect due to the chambers, and to account for it in the analysis of variance. We originally treated the rows as blocks in the analysis of variance (Model #1). This was not necessarily incorrect, however, it would be more appropriate to treat the rows as split-plots (Models #2 and 3). The rows could also be treated simply as random samples in each plot (as shown in Models #4 and 5), primarily because there should not be any directional effect for the outside plots. In any event, the procedure for analyzing the row data had no effect on the results from the air treatments, which are the only results of interest in this study.

Considering all of the above, we settled on Model #2 because it incorporated the blocks and treated the rows as split plots for the yield data. The other response parameters, injury, mapping, quality, stomatal conductance, transpiration were analyzed according to the same model but with modification of the Error B term depending on how observations were made in each plot. Use of Model #2 with the blocks resulted in detection of a significant difference (at $p<0.05$) in cotton yield between filtered and nonfiltered chambers at Hanford while use of models without blocks did not detect the difference. At Dinuba, use of Model #2 resulted in detection of a significant difference between filtered and nonfiltered chambers at $p<0.05$, whereas use of models without blocks actually resulted in detection of a difference at $p<0.01$. Thus, use of models without blocks was actually better at Dinuba. For Shafter and Five Points no significant difference between filtered and nonfiltered chambers was found using models either with or without blocks.

Finally, the detection of a "significant" difference between treatments usually is determined at the $p<0.05$ probability level due to a longstanding convention in agricultural research. However, as indicated by this analysis, the indication of the probability level may be more important for establishing the likelihood that a difference between treatments is real, than merely the indication of whether or not the probability was greater than less than 0.05.

APPENDIX E

TREATMENT MEANS FOR RESPONSE PARAMETERS

FROM ANTIOXIDANT SITES

Table E-1	Treatment means for SJ2 and GC510 cotton at Five Points site.
Table E-2	Treatment means for SJ2 and GCSW cotton at Shafter site.
Table E-3	Statistical analysis for non-spray controls vs. surfactant.
Tables E-4 through E-7	Treatment means for non-spray controls vs. surfactant for both cultivars and sites.

Table E-1. Treatment Means for Cotton at Five Points Site[a]

Parameter	SJ2		GC510	
	Surfactant	Ozoban	Surfactant	Ozoban
Plant Height (m)	1.25 ± 0.08	1.19 ± 0.10	1.04 ± 0.08	1.09 ± 0.05
Plants (#)	12 ± 2	11 ± 2	12 ± 2	12 ± 2
Open Bolls (#)	175 ± 17	159 ± 18	165 ± 21	173 ± 10
Open Bolls (g)	1154 ± 110	1110 ± 119	1026 ± 108	1079 ± 71
Green Bolls (#)	21 ± 12	25 ± 7	4 ± 4	3 ± 3
Green Bolls (g)	460 ± 299	592 ± 170	89 ± 76	56 ± 51
Mature Bolls (#)	18 ± 10	23 ± 6	4 ± 3	3 ± 3
Mature Bolls (g)	263 ± 309	323 ± 297	10 ± 36	12 ± 26
Young Bolls (#)	3 ± 4	2 ± 2	0.3 ± 0.9	0.4 ± 0.9
Young Bolls (g)	197 ± 273	269 ± 330	78 ± 75	44 ± 53
Lint Weight (g)	436 ± 44	419 ± 42	404 ± 46	426 ± 31
Seed Weight (g)	709 ± 66	682 ± 74	610 ± 67	638 ± 36
Open Bolls/Plant	15 ± 2	14 ± 2	14 ± 3	15 ± 2
Injury- Upper (%)	29 ± 24	20 ± 11	40 ± 20	50 ± 28
Injury- Lower (%)	42 ± 21	37 ± 15	43 ± 17	58 ± 29

[a]Values are means ± SD for a 2 m length of row for height, # plants, boll weights and numbers, and seed and lint weights; with 12 observations, two from each of six plots; except for injury with 24 observations, four from each of six plots.

Table E-2. Treatment Means for Cotton at Shafter Site[a]

Parameter	SJ2		GC510	
	Surfactant	Ozoban	Surfactant	Ozoban
Plant Height (m)	1.02 ± 0.13	0.94 ± 0.04	1.02 ± 0.08	1.02 ± 0.10
Plants (#)	20 ± 2	21 ± 2	18 ± 4	20 ± 4
Open Bolls (#)	157 ± 21	162 ± 18	173 ± 12	161 ± 27
Open Bolls (g)	845 ± 120	880 ± 97	963 ± 59	899 ± 151
Green Bolls (±)	8 ± 7	2 ± 3	3 ± 3	3 ± 3
Green Bolls (g)	114 ± 115	24 ± 35	53 ± 49	52 ± 48
Mature Bolls (±)	6 ± 7	1 ± 2	2 ± 3	3 ± 2
Mature Bolls (g)	105 ± 111	10 ± 26	19 ± 39	31 ± 51
Young Bolls (#)	1 ± 1	1 ± 1	1 ± 1	1 ± 1
Young Bolls (g)	9 ± 9	13 ± 26	34 ± 46	21 ± 24
Lint Weight (g)	310 ± 49	325 ± 38	366 ± 28	346 ± 59
Seed Weight (g)	533 ± 73	553 ± 60	590 ± 34	546 ± 92
Open Bolls/Plant	8 ± 1	8 ± 1	10 ± 2	8 ± 2
Injury- Upper (%)	36 ± 27	45 ± 32	33 ± 22	30 ± 15
Injury- Lower (%)	71 ± 24	80 ± 22	56 ± 18	55 ± 18

[a]Values are means ± SD for a 2 m length of row for height, # plants, boll weights and numbers, and seed and lint weights; with 12 observations, two from each of six plots; except for injury with 24 observations, four from each of six plots.

Table E-3. Results from Statistical Analysis for No-Spray Controls vs. Surfactant for Antioxidant Study, Surfactant Test[a]

Parameter	Five Points			Shafter		
	Surf.	Cultivar	S x C	Surf.	Cultivar	S x C
Plant Height (m)	ns	***[d]	ns	ns	ns	ns
No. Plants	ns	ns	ns	ns	ns	ns
No. Open Bolls	ns	ns	*[b]	ns	*[c]	ns
Wt. Open Bolls (g)	ns	**[d]	ns	ns	**[c]	ns
Wt. Lint (g)	ns	*[d]	ns	ns	***[c]	ns
Wt. Seed (g)	ns	***[d]	ns	ns	*[c]	ns
No. Green Bolls	ns	***[d]	ns	*[e]	ns	ns
Wt. Green Bolls (g)	ns	***[d]	ns	*[e]	ns	ns
No. Mature Bolls	ns	***[d]	ns	*[e]	ns	ns
Wt. Mature Bolls (g)	ns	***[d]	ns	ns	ns	ns
No. Young Bolls	ns	*[d]	*[f]	*[e]	ns	*[b]
Wt. Young Bolls (g)	ns	**[d]	ns	ns	ns	ns
No. Open Bolls/Plant	ns	ns	ns	ns	*[c]	ns

[a]Based on two-way analysis of variance. A "ns" indicates no significant difference at $p<0.05$; a *, **, or *** indicates a significant effect at $p<0.05$, 0.01, or 0.005, respectively. The surfactant indicates the difference between the surfactant and no-spray control treatment. The S x C interaction indicates the surfactant vs. control comparison for each treatment.

[b]Significant interaction for surfactant-GC510 vs. control.

[c]GC510>SJ2.

[d]SJ2>GC510.

[e]Surfactant>control.

[f]Significant interaction for surfactant-SJ2 vs. control.

Table E-4. Treatment Means for SJ2 Cotton at Five Points Site, Surfactant Test[a]

Parameter	Surfactant	Ozoban	Control
Plant Height (m)	1.20 ± 0.05	1.18 ± 0.08	1.23 ± 0.10
Plants (#)	12 ± 2	12 ± 2	11 ± [illegible]
Open Bolls (#)	175 ± 17	163 ± 19	168 ± 23
Open Bolls (g)	1158 ± 131	1136 ± 121	1141 ± 165
Green Bolls (#)	18 ± 11	26 ± 7	11 ± 7
Green Bolls (g)	370 ± 223	608 ± 153	256 ± 184
Mature Bolls (#)	15 ± 7	24 ± 6	10 ± 7
Mature Bolls (g)	269 ± 250	335 ± 290	205 ± 199
Young Bolls (#)	3 ± 5	2 ± 3	1 ± 1
Young Bolls (g)	101 ± 76	274 ± 350	51 ± 107
Lint Weight (g)	438 ± 53	427 ± 43	429 ± 64
Seed Weight (g)	710 ± 77	701 ± 73	699 ± 100
Open Bolls/Plant	15 ± 1	14 ± 2	16 ± 2

[a]Values are means ± SD for a 2 m length of row for height, # plants, boll weights and numbers, and seed and lint weights; with eight observations, two from each of four plots.

Table E-5. Treatment Means for GC510 Cotton at Five Points Site, Surfactant Test[a]

Parameter	Surfactant	Ozoban	Control
Plant Height (m)	1.07 ± 0.11	1.10 ± 0.05	1.08 ± 0.13
Plants (#)	12 ± 2	11 ± 2	12 ± 1
Open Bolls (#)	155 ± 17	172 ± 9	173 ± 14
Open Bolls (g)	985 ± 104	1061 ± 72	1042 ± 86
Green Bolls (#)	3 ± 2	2 ± 2	1 ± 2
Green Bolls (g)	66 ± 36	39 ± 31	21 ± 28
Mature Bolls (#)	3 ± 2	2 ± 2	1 ± 1
Mature Bolls (g)	0	7 ± 14	7 ± 20
Young Bolls (#)	0	1 ± 1	1 ± 1
Young Bolls (g)	66 ± 36	32 ± 33	14 ± 16
Lint Weight (g)	386 ± 44	418 ± 31	410 ± 33
Seed Weight (g)	583 ± 61	630 ± 38	629 ± 53
Open Bolls/Plant	14 ± 2	16 ± 2	15 ± 2

[a]Values are means ± SD for a 2 m length of row for height, # plants, boll weights and numbers, and seed and lint weights; with eight observations, two from each of four plots.

Table E-6. Treatment Means for SJ2 Cotton at Shafter Site, Surfactant Test[a]

Parameter	Surfactant	Ozoban	Control
Plant Height (m)	0.99 ± 0.14	0.94 ± 0.05	0.99 ± 0.13
Plants (#)	19 ± 2	20 ± 2	20 ± 3
Open Bolls (#)	157 ± 24	158 ± 21	154 ± 11
Open Bolls (g)	855 ± 122	860 ± 93	832 ± 52
Green Bolls (#)	5 ± 7	3 ± 3	1 ± 1
Green Bolls (g)	73 ± 108	36 ± 37	14 ± 20
Mature Bolls (#)	4 ± 7	2 ± 3	1 ± 1
Mature Bolls (g)	67 ± 105	16 ± 31	6 ± 17
Young Bolls (#)	1 ± 2	1 ± 1	0.3 ± 0.5
Young Bolls (g)	6 ± 8	20 ± 30	8 ± 10
Lint Weight (g)	315 ± 51	315 ± 35	303 ± 20
Seed Weight (g)	537 ± 73	544 ± 58	521 ± 35
Open Bolls/Plant	8 ± 1	8 ± 1	8 ± 1

[a]Values are means ± SD for a 2 m length of row for height, # plants, boll weights and numbers, and seed and lint weights; with eight observations, two from each of four plots.

Table E-7. Treatment Means for GC510 Cotton at Shafter Site, Surfactant Test[a]

Parameter	Surfactant	Ozoban	Control
Plant Height (m)	0.99 ± 0.08	1.00 ± 0.08	0.99 ± 0.06
Plants (#)	18 ± 4	20 ± 4	21 ± 2
Open Bolls (#)	173 ± 11	160 ± 29	176 ± 118
Open Bolls (g)	978 ± 39	887 ± 167	946 ± 112
Green Bolls (#)	4 ± 3	3 ± 3	0
Green Bolls (g)	56 ± 57	44 ± 33	0
Mature Bolls (#)	3 ± 3	2 ± 3	0
Mature Bolls (g)	24 ± 45	22 ± 55	0
Young Bolls (#)	1 ± 1	0.3 ± 0.5	0
Young Bolls (g)	33 ± 51	22 ± 26	578 ± 71
Lint Weight (g)	372 ± 18	344 ± 65	360 ± 40
Seed Weight (g)	599 ± 24	536 ± 102	578 ± 71
Open Bolls/Plant	10 ± 2	8 ± 2	9 ± 1

[a]Values are means ± SD for a 2 m length of row for height, # plants, boll weights and numbers, and seed and lint weights; with eight observations, two from each of four plots.

APPENDIX F

CULTIVAR MEANS FOR INJURY AND YIELD FROM CULTIVAR TRIAL SITES

Table F-1. Parameter Means for Cotton Cultivar Trial at Wasco Site[a]

Cultivar	% Leaf Injury		Lint Yield
	Upper	Lower	kg/ha
Acala GC-260	20 ± 8	85 ± 13	4442
Acala GC-356	10 ± 0	40 ± 14	4549
Acala GC-510	20 ± 8	58 ± 15	4534
Acala GC-714	0	18 ± 10	4452
Acala SJ2	0	35 ± 13	4621
CB 2	15 ± 6	83 ± 5	4333
CPCSD C-32	23 ± 5	88 ± 10	4436
CPCSD C-37	13 ± 5	75 ± 13	4425
CPCSD C-4164	30 ± 8	85 ± 6	4899
CPCSD C-4226	25 ± 10	90 ± 8	5040
CPCSD C-4272	15 ± 6	40 ± 8	4491
DPL 6	13 ± 5	58 ± 17	4327
Westlake 10	8 ± 5	28 ± 5	4267

[a]Values are means ± SD for four observations. To convert lint yield to lbs./acre multiply by 0.184.

Table F-2. Parameter Means for Cotton Cultivar Trial at Porterville Site[a]

Cultivar	% Leaf Injury		Lint Yield
	Upper	Lower	kg/ha
Acala GC-260	18 ± 10	63 ± 10	5906
Acala GC-356	20 ± 8	65 ± 13	5612
Acala GC-510	23 ± 5	80 ± 0	5400
Acala GC-714	35 ± 6	85 ± 13	6260
Acala SJ2	30 ± 8	98 ± 5	4937
CB 2	25 ± 13	83 ± 13	5563
CPCSD C-32	45 ± 6	88 ± 10	5508
CPCSD C-37	25 ± 6	98 ± 5	5617
CPCSD C-4164	13 ± 5	55 ± 6	6004
CPCSD C-4226	15 ± 6	78 ± 5	6232
CPCSD C-4272	3 ± 5	45 ± 6	6434
DPL 6	10 ± 8	48 ± 10	6439
Westlake 10	5 ± 6	35 ± 6	5508

[a]Values are means ± SD for four observations. To convert lint yield to lbs./acre multiply by 0.184.

Table F-3. Parameter Means for Cotton Cultivar Trial at Hanford Site[a]

Cultivar	% Leaf Injury		Lint Yield
	Upper	Lower	kg/ha
Acala GC-260	20 ± 11	83 ± 5	7022
Acala GC-356	25 ± 6	55 ± 13	6875
Acala GC-510	5 ± 6	30 ± 8	7060
Acala GC-714	10 ± 0	25 ± 6	6978
Acala SJ2	35 ± 6	33 ± 5	6668
CB 2	5 ± 6	68 ± 5	6766
CPCSD C-32	10 ± 0	58 ± 10	7239
CPCSD C-37	8 ± 5	43 ± 5	7266
CPCSD C-4164	8 ± 5	20 ± 0	7756
CPCSD C-4226	20 ± 8	70 ± 14	7958
CPCSD C-4272	5 ± 6	20 ± 0	7125
DPL 6	20 ± 0	73 ± 10	6907
Westlake 10	23 ± 5	45 ± 6	6445

[a]Values are means ± SD for four observations. To convert lint yield to lbs./acre multiply by 0.184.

Table F-4. Parameter Means for Cotton Cultivar Trial at West Side Site[a]

Cultivar	% Leaf Injury		Lint Yield
	Upper	Lower	kg/ha
Acala GC-260	5 ± 6	23 ± 5	6798
Acala GC-356	3 ± 5	23 ± 5	6624
Acala GC-510	5 ± 6	20 ± 0	6641
Acala GC-714	10 ± 0	30 ± 8	6608
Acala SJ2	25 ± 6	53 ± 10	6292
CB 2	40 ± 8	73 ± 15	5971
CPCSD C-32	13 ± 5	28 ± 5	6145
CPCSD C-37	10 ± 0	25 ± 6	6820
CPCSD C-4164	13 ± 5	35 ± 6	7495
CPCSD C-4226	5 ± 6	23 ± 5	8094
CPCSD C-4272	13 ± 5	25 ± 10	7207
DPL 6	8 ± 5	20 ± 0	7103
Westlake 10	8 ± 5	23 ± 5	6396

[a]Values are means ± SD for four observations. To convert lint yield to lbs./acre multiply by 0.184.

Table F-5. Parameter Means for Cotton Cultivar Trial at Madera Site[a]

Cultivar	% Leaf Injury Upper	% Leaf Injury Lower	Lint Yield kg/ha
Acala GC-260	8 ± 5	23 ± 5	7326
Acala GC-356	3 ± 5	13 ± 5	6956
Acala GC-510	0	8 ± 5	7315
Acala GC-714	0	15 ± 6	7272
Acala SJ2	8 ± 5	20 ± 0	7827
CB 2	23 ± 10	35 ± 6	7642
CPCSD C-32	0	58 ± 10	7000
CPCSD C-37	0	3 ± 5	7201
CPCSD C-4164	0	5 ± 6	7365
CPCSD C-4226	3 ± 5	15 ± 6	8165
CPCSD C-4272	0	0	7299
DPL 6	0	0	7343
Westlake 10	0	0	6722

[a]Values are means ± SD for four observations. To convert lint yield to lbs./acre multiply by 0.184.

Table F-6. Parameter Means for Cotton Cultivar Trial at Merced Site[a]

Cultivar	% Leaf Injury		Lint Yield
	Upper	Lower	kg/ha
Acala GC-260	23 ± 5	43 ± 10	7941
Acala GC-356	10 ± 8	33 ± 10	8230
Acala GC-510	10 ± 0	33 ± 10	7707
Acala GC-714	3 ± 5	18 ± 5	7811
Acala SJ2	35 ± 6	20 ± 0	8878
CB 2	23 ± 5	58 ± 5	8007
CPCSD C-32	13 ± 5	40 ± 0	7762
CPCSD C-37	0	20 ± 8	7745
CPCSD C-4164	0	10 ± 0	8088
CPCSD C-4226	18 ± 5	35 ± 6	8437
CPCSD C-4272	15 ± 6	30 ± 8	7707
DPL 6	8 ± 5	33 ± 10	7892
Westlake 10	10 ± 0	25 ± 10	7348

[a]Values are means ± SD for four observations. To convert to lbs./acre multiply by 0.184.

Table F-7. Parameter Means for Cotton Cultivar Trial at Firebaugh Site[a]

Cultivar	% Leaf Injury		Lint Yield
	Upper	Lower	kg/ha
Acala GC-260	25 ± 6	---	8458
Acala GC-356	43 ± 5	---	7702
Acala GC-510	30 ± 0	---	8279
Acala GC-714	45 ± 6	---	8638
Acala SJ2	---	---	6989
CB 2	48 ± 10	---	7724
CPCSD C-32	33 ± 5	---	7696
CPCSD C-37	38 ± 5	---	8317
CPCSD C-4164	23 ± 5	---	8453
CPCSD C-4226	23 ± 5	---	9014
CPCSD C-4272	33 ± 5	---	8850
DPL 6	33 ± 5	---	9035
Westlake 10	35 ± 6	---	7865

[a]Values are means ± SD for four observations. To convert lint yield to lbs./acre multiply by 0.184.

Table F-8. Parameter Means for Cotton Cultivar Trial at Maricopa Site[a]

Cultivar	Lint Yield kg/ha
Acala GC-260	5982
Acala GC-356	5753
Acala GC-510	6080
Acala GC-714	5704
Acala SJ2	6047
CB 2	6183
CPCSD C-32	5601
CPCSD C-37	5786
CPCSD C-4164	6885
CPCSD C-4226	6771
CPCSD C-4272	6238
DPL 6	6325
Westlake 10	5830

[a]Values are means ± SD for four observations. To convert lint yield to lbs./acre multiply by 0.184.

Table F-9. Parameter Means for Cotton Cultivar Trial at Shafter Site[a]

Cultivar	% Leaf Injury	
	Upper	Lower
Acala 1517-7	38 ± 5	78 ± 5
Acala GC-260	28 ± 5	68 ± 10
Acala GC-356	8 ± 5	23 ± 5
Acala GC-510	15 ± 6	43 ± 15
Acala GC-714	15 ± 6	58 ± 10
Acala SJ2	38 ± 10	100 ± 0
CB 2	28 ± 5	75 ± 13
CPCSD C-32	13 ± 5	35 ± 13
CPCSD C-37	13 ± 5	40 ± 8
CPCSD C-4164	3 ± 5	23 ± 5
CPCSD C-4226	10 ± 0	33 ± 10
CPCSD C-4272	15 ± 6	68 ± 10
Coker 139	43 ± 13	90 ± 8
DPL 6	13 ± 5	43 ± 10
DPL 50	65 ± 13	98 ± 5
Paymaster 14	55 ± 6	98 ± 5
Westlake 10	8 ± 5	20 ± 8

[a]Values are means ± SD for four observations. There was no yield data as the site was not part of the cultivar trials.

Table F-10. Parameter Means for Cotton Cultivar Trial at Stratford Site[a]

Cultivar	% Leaf Injury	
	Upper	Lower
Acala GC-510	8 ± 5	43 ± 10
Acala GC-800	8 ± 5	53 ± 13
Acala GC-806	0	45 ± 13
Acala SJ2	35 ± 6	83 ± 5
C-4789	20 ± 8	65 ± 10
C-4892	8 ± 5	53 ± 26
CB 9	0	20 ± 8
CB 10	10 ± 0	38 ± 10
DP 878	13 ± 5	33 ± 10
WC-3	25 ± 13	58 ± 19
WLF 18	5 ± 6	33 ± 13

[a]Values are means ± SD for four observations. Their is no cotton lint yield data because this site was not part of the cultivar trials.

APPENDIX G

ABSTRACT FOR PAPER PRESENTED AT 1988 MEETING

OF AMERICAN SOCIETY OF AGRONOMY

ANAHEIM, CALIFORNIA

DECEMBER 1, 1988

ABSTRACT FORM — AGRONOMY ABSTRACTS

American Society of Agronomy — Crop Science Society of America — Soil Science Society of America

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Air Pollution Effects on Cotton in the San Joaquin Valley.

D. OLSZYK*, G. KATS, R. BASSETT, S. JOHNSON, T. KERBY, D. MILLHOUSE, AND B. ROBERTS, Univ. of California and BASF Company, Dinuba, CA

An intensive study to determine the effects of photochemical oxidant air pollution (primarily O_3) was conducted on cotton (Gossypium hirsutum L.) in California's San Joaquin Valley during the 1988 growing season. Effects were assessed (1) by using charcoal filtered and nonfiltered open-top field chambers and cv. SJ2 cotton at sites with different ambient O_3 concentrations: Dinuba, Five Points, Hanford, and Shafter; (2) with antioxidant sprays to represent filtered air for SJ2 and GC510 cotton at Five Points and Shafter; and (3) by comparing yields and injury for cultivars planted in trials in different areas of the valley with different ambient O_3 concentrations. Plant responses measured included leaf injury and yield. A gradient in O_3 concentrations was found between the chamber sites, with Dinuba having the highest O_3 and Five Points the lowest. Other data collected during 1988 will be presented. This multifaceted approach to investigate the effects of O_3 on cotton will help to determine whether estimated losses based on controlled experiments are actually occurring under differing field conditions.

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APPENDIX H

PAPER INCLUDED IN 1989 ANNUAL CALIFORNIA COTTON REPORT

EFFECTS OF SMOG ON COTTON IN THE SAN JOAQUIN VALLEY

David Olszyk, Gerrit Kats, and Chris Reagan
Contributors: Dick Bassett, Stephanie Johnson, Tom Kerby
Dave Millhouse, Bruce Roberts

Air pollution has been suspected as affecting cotton in the San Joaquin Valley for over 20 years. Photochemical oxidant smog is of primary interest, with ozone being the most toxic component of smog as far as plants are concerned. In the early 1970's Drs. Bob Brewer and George Ferry from the University of California Kearney Agricultural Center at Parlier evaluated the effects of ambient smog on SJ1 cotton. The study was conducted at Parlier, Hanford, Cotton Center, and Five Points in the valley. Plants were grown in either a clean air (charcoal-filtered) or smoggy air (nonfiltered) closed plastic greenhouse at each site. Plants growing in smoggy air yielded 20-30% less raw cotton than plants in clean air at Parlier, Hanford, and Cotton Center. However, at Five points plants in smoggy air produced only 6% less cotton than plants in clean air. In later studies at Parlier, Dr. Brewer also demonstrated a large yield loss for SJ2 cotton growing in smoggy air vs. clean air.

In the early 1980's Drs. Clif Taylor and Pat Temple from the Statewide Air Pollution Research Center at the University of California, Riverside, conducted studies where SJ2 cotton was exposed to ozone at the U.S.D.A. Cotton Research Station at Shafter. The experiments were conducted in large (10 foot across) open-top chambers which carefully controlled the ozone concentrations around the plants. Based on those studies equations were established which predicted cotton yield losses based on ozone concentrations at different locations in the valley. The estimated losses ranged from <10% near Five Points to >20% near Fresno and Bakersfield, compared to the potential yields in clean air. The size of the estimated losses in both the Brewer and Ferry as well as Taylor and Temple studies indicated that smog may be causing a substantial problem for cotton in the San Joaquin Valley.

However, while the previous experiments were carefully conducted, uncertainty still persists whether such large estimated losses actually are occuring in fields across the San Joquin Valley because of the many variable conditions which can affect the response of crops to ozone. Ozone concentrations vary across the valley, as do soil types, environmental conditions, management practices, and many other factors. In addition, the closed or the open-top field chambers used for the exposures and very careful control of soil moisture in individual chambers may have influenced plant responses. Furthermore, SJ1 is no longer grown, and while SJ2 remains the predominant cultivar, GC 510 is increasing in importance and other cultivars may also be grown in the future.

Therefore, to verify the earlier results and to see how the estimated losses are affected by current environmental and management conditions across the valley a new cotton study was initiated in 1988. The objectives of the study were 1) to determine the percentage reduction in yield for sites with different ozone concentrations, 2) to determine if ozone effects could be documented by using a chemical to protect the plants as well as by using chambers, and 3) to determine the yields of cotton cultivars across the valley to see if relative yields were related to ozone concentrations. This wide-ranging study involved the valuable cooperation of many individuals including private growers, the BASF Chemical Company, U.S.D.A. and University of California- Riverside researchers, and University of California statewide and county Cooperative Extension personnel.

Field-Chamber Experiments

This part of the study used open-top field chamber experiments at four sites; the U.S.D.A. Cotton Research Station at Shafter in Kern County, the Dean Grabow farm near Hanford in Kings County, the BASF Research Station near Dinuba in Tulare County, and the University of California West Side Field Station near Five Points in Fresno County. At each site a field of SJ2 cotton was planted and grown using normal management practices for that area. Four open-top field chambers were placed over cotton in the field at each site; two with charcoal-filters to remove ozone and represent clean air, and two without charcoal-filters to represent regular or "nonfiltered" air in the area. The chambers were approximately 10 feet in diameter and eight feet high with metal frames and covered with clear plastic to allow light to enter. In addition, there were two open-plots without chambers ("ambient air") to detect any effects of the chambers themselves on the plants. The chambers were over the plants from approximately mid-June to mid-September when defoliant was applied to the fields in preparation for harvest. Only the middle 6.6 feet of each of the central two rows of cotton in the chambers were harvested. This provided two subplots for each of the two plots per treatment.

As expected, ambient ozone concentrations varied among the four sites (Figure 1). Across the mid-June to Mid-September period ozone concentrations were highest at Dinuba southeast of the Fresno urban area and lowest at Five Points on the west side of the valley. Concentrations at Shafter and Hanford were mid-way in between. Many indicators of injury to leaves, as well as plant development, growth and yield were measured in the study, but lint weight was of primary concern. As shown in Figure 2, cotton lint weights were lower in the nonfiltered or "smog affected" chambers than in the charcoal- filtered chambers or "clean air" at all four sites. The largest percentage yield loss was 34% at Dinuba, which had the highest average ozone concentrations. There was a 20% loss at Shafter and a 16% loss at Hanford, but only a 13% loss at Five Points which had the lowest ozone concentrations. Only the losses at Dinuba and Hanford were statistically significant, that is to say, outside the difference possibly due to normal variation expected between different small plots of cotton.

(INSERT FIGURE 1 HERE)

Figure 1. Ozone concentrations at four sites in the San Joaquin Valley. The averages are for daylight mid-day hours, 9 a.m.-4 p.m. from mid-June through mid-September, 1988 (from mid-July for Dinuba)

(INSERT FIGURE 2 HERE)

Figure 2. Cotton lint yields for 1988 air pollution study at four San Joaquin Valley sites.

As shown in Figure 2, the general yields at Hanford and Five Points were reasonably high, and equivalent to approximately 2.9 and 3.3 bales of cotton per acre, respectively for the ambient plots. In contrast, the ambient plot yield for Shafter was only 2.1 bales, possibly likely due to a nitrogen deficiency in the field. This nitrogen deficiency may have been accentuated in the chambers, resulting in the low yield especially for the nonfiltered air plants. In addition the large amount of variability between plots made it difficult to determine if the yield loss due to ozone was statistically significant. The ambient plot yield for Dinuba was very low at 1.3 bales, probably due to a combination of problems including the necessity to replant the field in late Spring due to the rains and cold weather, pests, and water stress. All of these problems seemed to be accentuated by the chambers and possibly by ozone, resulting in the vary low yields in the nonfiltered chambers at this site. However, the existence of these multiple stresses at Dinuba also indicated that ozone may exacerbate the adverse effects of other factors on cotton yield at some sites.

Non-Chamber Assessment

The second part of this study involved the use of an antioxidant chemical to see if the effects of ozone on cotton could be verified without the use of the field chambers. If successful, this would provide a tool for assessing the effects of ozone on cotton in many different locations. The antioxidant (sodium erythrobate, i.e. Ozoban[R] donated by the Pfizer Chemical company) has been believed to alter the effects of ozone in leaves, thus representing a "clean air" situation. The cultivar GC 510 as well as SJ2 was used for this study, with research sites at Shafter (medium-high ozone) and Five Points (low ozone). Plants were sprayed at a rate of 2,000 ppm for the antioxidant applied with a surfactant once per week for eight weeks from mid-June to mid-August. Control plants were sprayed only with the surfactant. There were six plots per treatment per cultivar at each site. Each plot included four 8.8 foot long rows of cotton, with only the middle 6.6 feet of the central two rows of each plot was harvested. This provided two subplots for each of the six plots per treatment.

The antioxidant had no affect on cotton lint yields for either cultivar at either site. As shown in Figure 3, cotton plants sprayed with the antioxidant had similar yields as control plants for either SJ2 or GC 510 at either Shafter or Five Points. This means that either a) the chemical was working but ozone was not affecting the cotton at either site or for either cultivar, b) the chemical was working but either the concentration or frequency of application was not appropriate to prevent ozone effects to the cotton, or 3) the chemical did not affect the sensitivity of cotton plants to ozone under the conditions used in this study. Explanation 3) is the most likley in this case as both the open-top field chamber experiments and presence of ozone injury symptoms on cotton at Shafter indicated that ozone was affecting the cotton, especially SJ2. The antioxidant concentration was quite high and frequency of application often enough to affect the sensitivity of grapes to ozone in a previous study, thus it should have been adequate to affect cotton if indeed it was active in this species.

(INSERT FIGURE 3 HERE)

Figure 3. Cotton lint yields with antioxidant treatments at Shafter and Five Points during 1988.

The cultivar GC 510 had a significantly higher lint yield, and greater growth than SJ2 at Shafter when data are averaged across the control and antioxidant treatments. In contrast SJ2 had a higher lint yield (though not statistically significant), and greater growth than GC 510 at Five Points. This relatively lower growth of SJ2, which is believed to be more susceptible to ozone than GC 510, at Shafter compared to Five Points could be associated with the higher ozone concentrations at Shafter. However, differences in soils and climate between the two sites, as well as well as the nitrogen deficiency at Shafter but not Five Points may also have been largely responsible for the relative yields between SJ2 and GC 510 in the two areas of the valley.

Cultivar Comparison

The cultivar comparison study evaluated injury and yield for 13 cultivars of cotton growing at nine cultivar test sites. The tests were carried out by Dr. Dick Bassett at the U.S.D.A. Cotton Research Station at Shafter, and sponsored by the Acala Cotton Board. The sites were near Merced in Merced County, Madera in Madera County, Firebaugh and Five Points in Fresno County, Hanford in Kings County, Porterville in Tulare County, and Maricopa, Shafter and Wasco in Kern County. Leaves were rated for percentage of leaf area exhibiting yellowing (chlorosis) or tissue death (necrosis) on the upper leaves and on the lower leaves of the plants. The rating occurred over the first three weeks or September, 1988, with sites rated from south to north across the valley.

The injury ratings indicated that SJ2 tended to have severe injury at nearly all sites, ranking in the top four cultivars in terms of injury for six of the eight sites: Shafter, Porterville, Hanford, Five Points, Madera, and Merced. Only at Wasco did SJ2 rank near the botton in terms of injury. Injury was not rated for Firebaugh and Maricopa. Injury was greater at southern sites than at northern sites. However, it could not be determined whether this difference in injury was due to higher ozone concentrations in the south, or due to other factors such as earlier maturing in the southern areas of the valley. Yield data are still being processed. When all of the cultivar trial data are complete yields across the valley will be compared to estimated ozone concentrations at the different trial sites.

Conclusions

The data from this study should be considered preliminary as they are still being processed and must be approved by the Air Resources Board before being published in a Final Report later in 1989. However, all three objectives were successfully addressed and provided the following preliminary conclusions.

(1) This study was successful in demonstrating reductions for SJ2 cotton due to ozone, with the reductions significant at sites with higher ambient ozone concentrations. The yield reductions appeared to be exacerbated by other stresses at Dinuba and Shafter, and by the open-top chambers themselves at those two sites.

(2) The antioxidant chemical used in this study apparently had no effect on injury or yield losses from ambient ozone for cotton. Therefore, it was not possible to use a protectant chemical in this study to verify the cotton yield losses from ambient ozone found in the open-top field chamber studies.

(3) The most widely grown cotton cultivar, SJ2, tended to have more injury than other cultivars at most sites surveyed. The injury also tended to be greater at southern than northern San Joaquin Valley sites. This pattern of injury coincides with the suspected greater ozone sensitivity for SJ2 than other cultivars and higher ozone concentrations at other sites. However, earlier maturity for this cultivar may also be responsible for the greater injury. The cultivar yield data will be used to more fully determine relative responses of the cultivars across the valley.

Plans for 1989

Many aspects of this project will be repeated in 1989 in order to definitively determine the effects of ozone on cotton. The field chamber experiments will be repeated at four sites, but using three instead of two chambers per treatment per site in order to improve our chances of detecting any statistically significant effects of ozone on yield. The same sites will be used in 1989 as in 1988, except for Hanford where another field nearby the 1988 field will be used. The cultivars SJ2 and GC 510 will again be compared at Five Points and Shafter. Data from Dr. Bassett's cotton variety trials from 1989 will also be evaluated.

Acknowledgments

The support of the Air Resources Board for this study under contract No. A733-088 is greatly appreciated. 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 commercial products, their sources, or their use is not to be construed as either an actual or implied endorsement of such products.

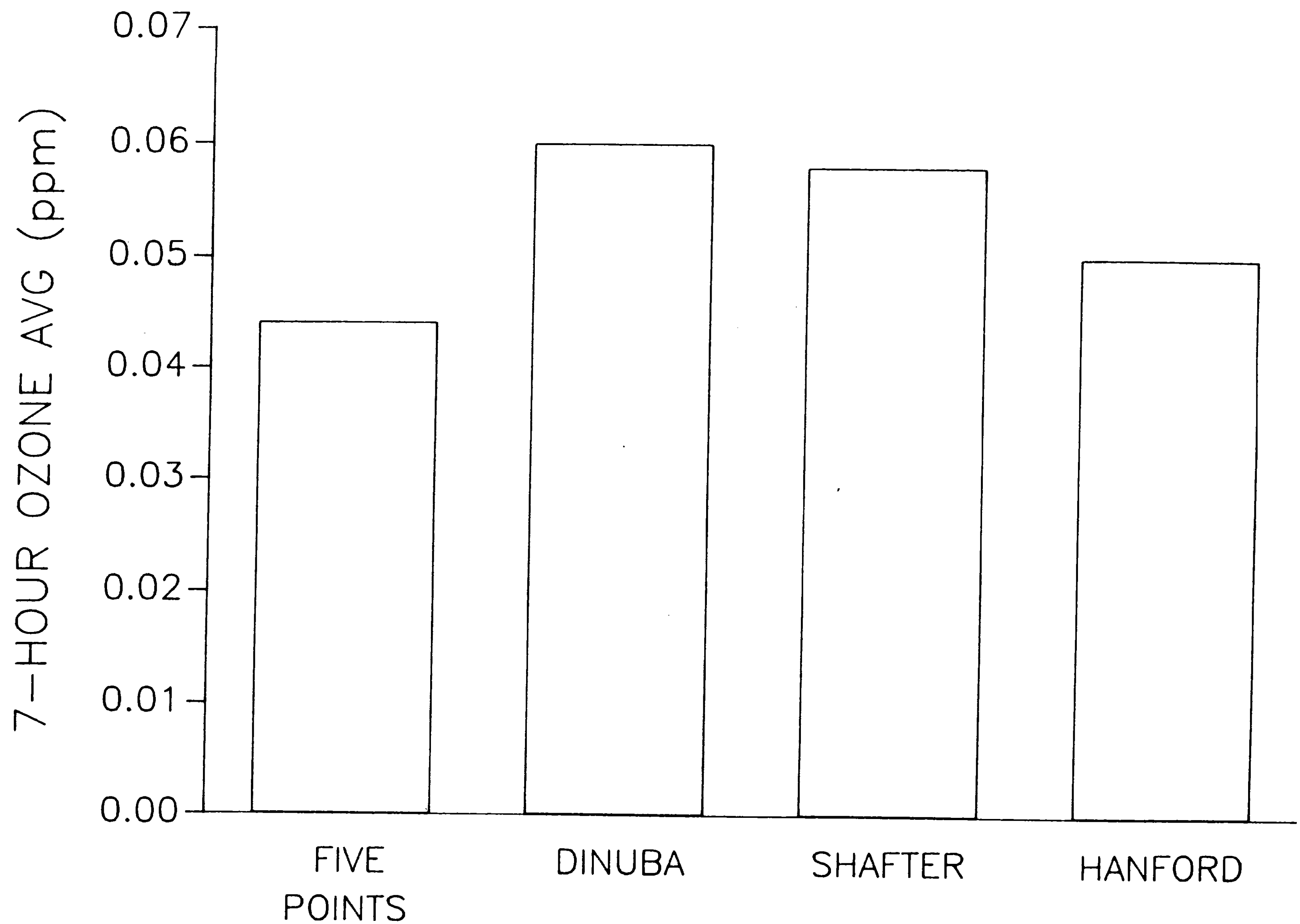

Figure 1. **Ozone concentrations at four sites in the San Joaquin Valley. The averages are for daylight mid-day hours, 9 a.m.-4 p.m. from mid-June through mid-September, 1988 (from mid-July for Dinuba).**

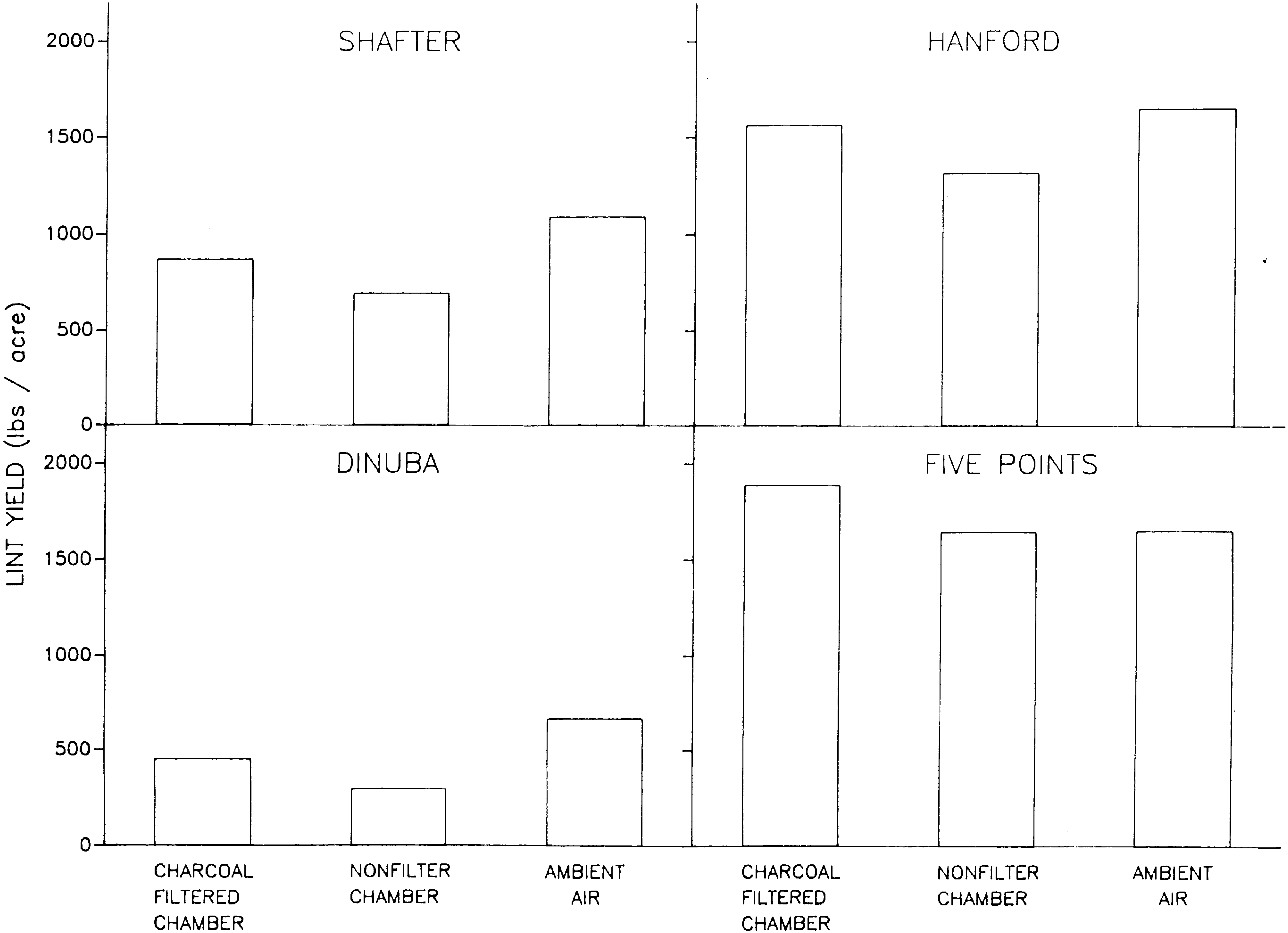

Figure 2. Cotton lint yields for 1988 air pollution study at four San Joaquin Valley sites.

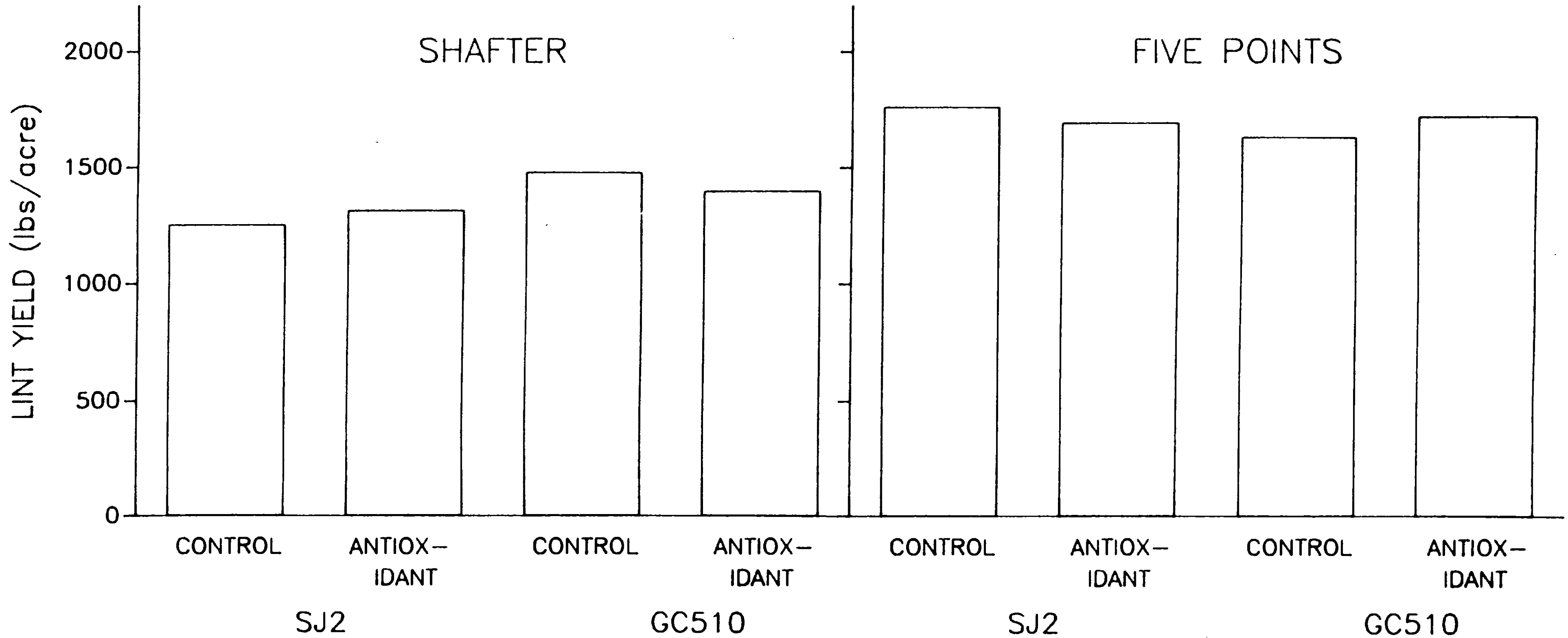

Figure 3. Cotton lint yields with antioxidant treatments at Shafter and Five Points during 1988.