DETERMINATION OF THE EFFECTS OF PHOTOCHEMICAL OXIDANTS AND/OR SO_2 ON YIELD OF NAVEL ORANGES

Interim Report

to the

California Air Resources Board

Contract No. A2-130-33

February 17, 1983 through June 16, 1985

C. Ray Thompson
Principal Investigator

Statewide Air Pollution Research Laboratory
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ABSTRACT

The ozone and sulfur dioxide sensitivity of California citrus trees is being tested using Valencia orange trees (Citrus sinensis). The trees were planted in soil at a newly developed research site on the Agricultural Experiment Station of the University of California, Riverside, on July 25, 1983. The site was extensively prepared before planting by testing the soil for nutrient concentrations, fumigating the soil for soil-borne pathogens, installing an underground irrigation system, and leveling the area. A new type of open-top field chamber was designed, constructed, and tested for use with the orange trees. The chamber system consisted of a 4.27 m diameter, 2.03 m high vinyl bubble over the tree canopy; a 0.91 m high fiberglass base; a fiberglass door; a blower box containing a 3/4 hp motor, axial blade fan, fiberglass particulate filters, and metal-activated charcoal filters; a sheet metal mixing duct between blower and chamber base; and a sheet metal diffusing panel inside the chamber in front of the air entrance port. The chambers were placed over the trees in late March, 1984 and the pollutant exposures were initiated on May 22, 1984. Twenty- eight chambers were constructed and placed over trees to provide four pollutant treatments with seven trees per treatment e.g. filtered air, ambient air, one-half filtered air, and filtered air plus 0.10 ppm SO_2. All treatments were continuous from the time of experiment initiation. There were seven chamberless outside control trees. None of the tree growth or physiological status parameters, e.g. leaf drop, stomatal conductance, net photosynthesis, and water potential; indicated any effects attributable to the different pollutant treatments. The chamber itself significantly increased leaf drop compared to outside trees. Small increases in leaf and air temperatures, and a small decrease in light intensity were found in the chambers compared to outside trees. No fruit were set on the chamber trees during the 1984-1985 growing period. Both chamber and outside trees had a large flower production during late winter 1985 which will provide the first definite indication of effects of the air pollutants on yield at the June 1986 harvest.

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DISCLAIMER

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I. INTRODUCTION

California is a major United States producer of citrus crops. Oranges are grown on about 200,000 acres of the state's most productive land (2). Major production is in Tulare, Fresno, Kern, Ventura and San Diego counties with lesser amounts in adjoining areas. Total annual production is in excess of 2.6 million tons valued at $360 million. Valencia oranges for juice account for approximately 46% of the volume produced. The areas of production presently have photochemical oxidants which probably reduce yields, but no studies are available which indicate the amount of economic losses.

During the late 1950's and early 1960's, Taylor, Thompson, and coworkers (13,15,16) studied the chronic (low level, long term) effects of photochemical oxidants which occur in the Los Angeles basin and/or fluoride on navel oranges and lemons. These studies showed reduced water use, reduced apparent photosynthesis, increased leaf drop, and very substantial reductions in yields of both crops due to photochemical oxidants. Losses of one-third to one-half of total production were recorded even though no easily observed injury occurred on the trees.

However, the sensitivity of the trees to ambient pollutants may have been different from that of outside trees as the experiment was conducted in closed, plastic covered greenhouses. The temperatures in the greenhouses on hot days exceeded outside temperatures by 4-5^{o}C. Light intensity was reduced and relative humidity increased in the greenhouses compared to outside trees. These environmental factors are known to affect the air pollutant sensitivity of plants, especially to O_3, the major component of photochemical "smog". A complicating factor was the fact that there was little or no overt injury on the trees, and that leaf drop occurs naturally from the evergreen trees. Thus, it was difficult to definitely assign the effects solely to the treatments.

The susceptibility of oranges to long-term low level "chronic" exposure to SO_2 is not known. Thomas (14) cited results of O'Gara who did one-hour exposures in small greenhouses in Utah with SO_2 on 100 crop, ornamental or forest species. He found citrus to be very resistant to acute foliar injury by SO_2 compared to the other species tested. Matsushima and Harada (7,8,9) found that exposures of three species of one-year old citrus with 1 and 5 ppm SO_2 for 2 hrs/day for 40 days caused no foliar injury. Later work showed Satsuma orange (Citrus unshiu) to have accelerated leaf drop after exposure with 5 ppm SO_2 for 2 hrs/day for 34 days. After spraying with Bordeaux mixture, leaf drop was accelerated following 13 days of exposure with SO_2. These studies also were done in closed greenhouses.

Thus, the previous long term studies of effects of photochemical oxidants citrus are suspect because of experimental methods and little work has been done with chronic effects of low levels of SO_2.

Currently, experimental procedures for measuring the effects of photochemical oxidants and SO_2 primarily make use of open top chambers (3). These chambers provide for environmental conditions which more nearly approach field exposure conditions than the greenhouse structures used for the original citrus research (15,16). Air flow, light intensity, relative humidity, and especially air temperature levels are much closer to field conditions in chambers than greenhouses. Methods for dispensing precisely measured levels of given pollutants are now available as are reliable instruments for monitoring pollutant concentrations. Recently, computer hardware and software also have become available to provide for rapid and accurate storing and analysis of pollutant data so that plant responses can be correlated to pollutant doses.

However, the open top field chamber systems previously in use were designed for exposure of herbaceous annual crops to air pollutants, especially as part of the National Crop Loss Assessment Network or NCLAN (4). These 3.0 m diameter, 2.43 m high chambers are not adequate for small trees of fruit bearing age. The air pollutant exclusion in open top chambers decreases with increasing height, which would provide for insufficient control of pollutant concentration in the tree canopy. Furthermore, the NCLAN design for open top chambers provides for air flow horizontally over the low canopy of a herbaceous crop. This direction of air flow would not provide for adequately high air flows to provide for high leaf boundary layer conductances in the tree canopy.

A UVEX plastic dome recently has been developed for use in controlling air temperature over spas during the winter. This dome has several characteristics which indicate its potential usefulness in constructing an exposure chamber for young trees especially: size, clarity and light transmission characteristics of the plastic, sectional construction for ease of transportation and construction, commercial accessibility, and relatively low cost. However, these domes had not been developed for use as plant exposure chambers.

Recently two instruments have been developed which can supplement the measurements used to quantify air pollution effects in the original citrus studies, i.e. leaf drop, leaf injury, fruit drop, and growth and yield of mature fruit (16). One recent instrument is the dual radioisotope porometer which measures photosynthesis and transpiration of leaves (1). The other is the steady state diffusion porometer for measuring water vapor transpiration and stomatal conductance of leaves simultaneously with measurements of light intensity, relative humidity, and temperature.

Thus a new citrus study was proposed to carefully determine the effects of long term, low-level exposures of air pollutants on citrus in California. A new type of open top field chamber was developed to provide for carefully controlled exposures of young trees. Valencia oranges were used to provide for information on this important crop. Specific research questions to be addressed were: (1) What are the effects of photochemical oxidants on oranges based on current levels found in the San Joaquin Valley and southern California? (2) How susceptible are oranges to chronic exposure to SO_2 such as would occur if additional emissions of of this gas occurred in the citrus producing areas of California? (3) Are Valencia oranges as sensitive to oxidants as navel oranges were found to be in the previous work? (4) What growth parameters are most useful in indicating the effects of air pollutants on oranges? (5) What parameters best indicate the physiological basis for injury to orange trees from air pollutants?

II. METHODS

A. Tree Culture

Originally navel orange trees (Citrus sinensis) were to have been used in this study. However, during the Spring of 1983 Valencia orange trees were chosen instead for the following reasons: (1) No grove of navel orange trees could be found on the University of California Experiment Station land. (2) It was determined that Valencia oranges would produce a crop every year versus alternate year bearing in navel oranges. Yield data only every other year with navel oranges would not be adequate for determination of yield effects from the air pollutants with navel oranges. (3) Newly established Valencia orange trees produce a crop several years sooner than newly established navel orange trees. Thus, air pollutant effects on yield could be determined sooner with Valencia oranges than with navel oranges. (4) There was no information available on the sensitivity of Valencia orange trees to air pollutants even though they are increasing in importance in California.

In June 1983 it also was determined that planting of a new small citrus grove specifically for this study was the best way to insure a uniform stand of trees for the exposures. No uniform stand of Valencia orange trees was found on the University of California Experimental Station that could be used for the exposures. The existing stands were of divergent rootstocks, had been inoculated with the Tristeza virus, a rootstock disease, and were not distributed in a pattern which would allow for placement of the exposure chambers over the trees.

Thus, young Valencia orange trees were purchased commercially for development of a new citrus grove. Forty-two two year old Valencia orange trees budded onto Troyer citrange rootstocks were purchased from Dollen Young Nurseries in Thermal, California. The trees were selected at the grower based on similar stem diameters of 0.032 m. Stem diameter is recognized as a useful covariate to account for some variability in statistical analysis of citrus growth and yield data (5, and personal communication, Carol Adams, University of California Cooperative Extension), and may be useful to determine oxidant effects on orange trees (10). The trees were delivered to the experimental site in Riverside in late June, 1983.

The new experimental grove was located on a roughly 0.34 ha triangular shaped site near existing air pollution research facilities on the University of California Agricultural Experiment Station (Figure 1). Prior to planting of the trees the soil was tested for nematode population by Dr. Seymore Van Gundy's Laboratory in the Nematology Department of the University of California, Riverside. Dr. Van Gundy indicated that the nematode population was very low e.g. an average of 0.54 per cm^3 of soil based on four samples. However, he still recommended soil fumigation with methyl bromide as a precautionary measure against any future nematode infestations. The soil was fumigated with methyl bromide in early July, 1983; and the trees were planted on July 25, 1983.

The soil also was tested for important plant nutrients. Ten samples were randomly taken from across the site and sent for analysis of conductivity, acidity, and potassium, phosphorous, zinc and sulfur concentration by the Agricultural Extension Laboratory at the University of California, Riverside. All parameters were near the range for normal citrus tree growth. Dr. Tom Embleton (Professor of Horticultural Science, Department of Botany and Plant Sciences, University of California, Riverside) indicated that the most important element that may cause a problem is zinc, as zinc deficiencies can occur on trees especially with a flush of new growth. He recommended a foliar spray with zinc when the major flush of growth had just expanded, possibly twice a year. To date the orange trees have been treated with a 455 ppm zinc and 335 ppm manganese spray.

The trees also received irrigation with a nutrient solution containing 57 g of nitrogen per tree as urea applied over six irrigations since planting. A total of approximately 40.4 gallons were used over the year with a urea concentration of 373 ppm. The trees were initially watered at regular intervals via furrow irrigation. Prior to placing the chambers over the trees an underground tubing irrigation system was installed. The system consisted of a hookup to the Agricultural Experiment Station irrigation water supply, liquid feed proportioner for fertilizer addition, polyvinylchloride main lines, separate lines to each tree, individual valves for each tree, and drip irrigation tubing in a circle under each tree. Later during the experiment the drip tubing was replaced with single sprinkler head. Early in 1985 the sprinkler heads were replaced by a single tube which released water into a circular furrow dug under the drip line of each tree. Two Irrometers® (one 0.31 m and one 0.61 m long)

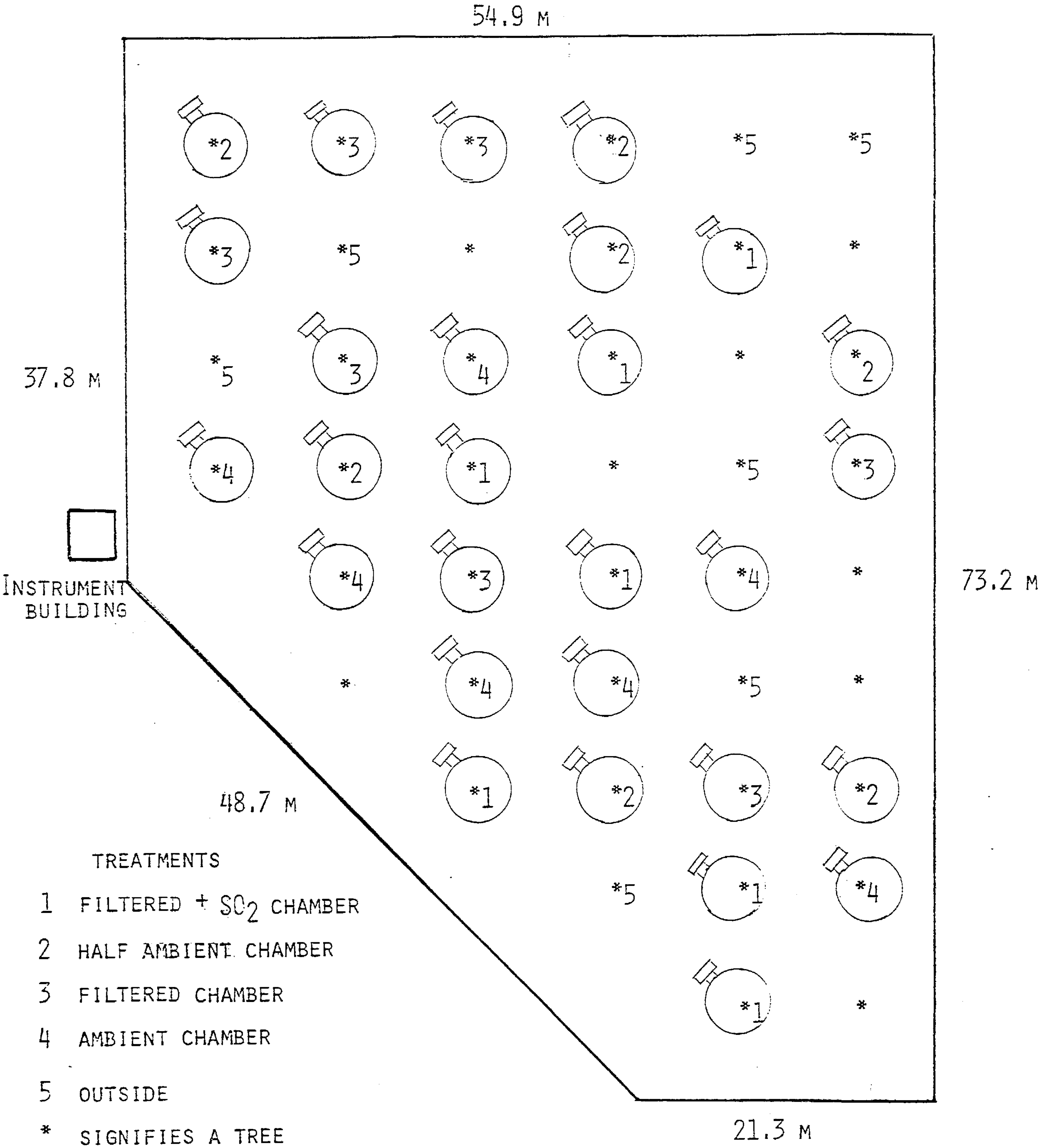


FIGURE 1. DIAGRAM OF CITRUS CHAMBER SITE AND EXPERIMENTAL DESIGN FOR TREATMENTS

Table 1. Bulk Weights for Leaves Dropped From Valencia Orange Trees Exposed to Oxidants or Sulfur Dioxide*

Treatment	Dates: 7/84 - 10/31/84	11/1/84 - 12/10/84	12/11/84 - 1/10/85	Total
		grams $tree^{-1}$		
Outside	27 ± 25 a	58 ± 63 a	54 ± 46 a	139
Ambient	86 ± 33 b	96 ± 83 ab	263 ± 142 b	445
Half Ambient	103 ± 64 b	174 ± 125 abc	339 ± 260 b	616
Filtered	104 ± 62 b	255 ± 139 c	357 ± 187 b	716
Filtered + SO_2	67 ± 35 ab	202 ± 101 bc	263 ± 117 b	532

*Values are means ± SD for seven trees. Means in a column followed by different letters are significantly different at $p<0.05$ using Duncan's Multiple Range Test.

were placed together under the drip line of the tree. The Irrometers were checked periodically and recorded weekly as an indicator of water use by the trees. The trees were irrigated if the 0.31 m Irrometers® read over 50 centibars.

The modes of irrigation were changed several times as the trees grew larger and more water had to be delivered. There was also an ongoing testing process to see which mode most efficiently delivered water in the desired location beneath the trees. Water is generally present only in a small area directly beneath the trees for only a few hours each week. This period is not long enough for any significant absorption of SO_2 within a chamber of this large volume.

B. Exposure System Construction

A large and relatively light weight open top field chamber was designed, constructed, tested, and fabricated as described in detail in Appendix A. The chambers were built in quantity at the Agricultural Experiment Station of the University of California, Riverside. The chamber used many of the basic design principles developed by Heagle et al. (3) and incorporated into the NCLAN chambers (4). However, because of its unique application for trees, the chamber structural characteristics are of original design.

Carbon monoxide dilution measurements (6) indicated that air flow into the chamber by the blower was approximately 56.63 m^3 min^{-1}. This provided for approximately 1.7 air exchanges per minute. Motors and fans of a higher capacity would increase the air flow into the chamber and number of air exchanges per minute. The combination of air filtering by the charcoal filters and air exclusion by preventing air incursion through the top of the chamber resulted in a filtered treatment with approximately 20% of the ambient O_3 concentration.

C. Pollutant Exposure and Air Monitoring

The pollutant exposures were continuous, except that the air flow over the trees was reduced by 67% between 20:00 and 06:00 daily via a Parajust Y speed controller. The pollutant exposure system for SO_2 consisted of a temperature controlled tank of liquid SO_2, mass flow controller, heatless air drier, and pollutant delivery lines. The oxidant exposure treatments of filtered, half-ambient, and ambient air, respectively, were achieved by totally, partially, and not filtering the air entering the chambers.

Air samples for pollutant analysis were drawn from the chambers via a pump. The sample lines from chambers and outside tree plots entered a 24 point sampling valve which sampled each line once every 120 minutes. Each air sample was drawn through both a Thermo Electron Model 43 SO_2 analyzer and Bendix Model 8002 O_3 analyzer for five minutes. Electronic signals from the analyzers were received by a Cyborg ISAAC computer interface and by a strip chart recorder. The interface transmitted the signals to an Apple II+ computer for processing. The computer retained the last minute of each five minute signal in its memory. Raw data from the computer was processed with summation and averaging programs developed by our research group.

The average SO_2 concentration was 0.092 ± 0.013 ppm between 08:00 and 20:00. This average is for 29 weekly values between 6/2/84 and 12/28/84, using data from all filtered air + SO_2 chambers. Seven of the input ports for the scanning valve were used to measure SO_2 concentration in the seven SO_2 chambers.

The average ozone concentrations for the oxidant treatments and outside trees are shown in Figure 2. The data is for between 08:00 and 20:00 with each sampling point recorded once every two hours. All seven chambers were sampled for the half ambient treatment, four of the seven chambers were sampled for the filtered and ambient treatments, and two outside plots were sampled for the outside treatment. All seven treatment trees could not be sampled for the filtered ambient and outside treatments as the sampling valve had only 17 of 24 input ports available to cover oxidant treatments. The sampling pattern emphasized the half ambient treatment because there can be variable loading of the charcoal filters with dirt or debris over time due to slight differences in the flow restriction into the filters caused by the blocking panels used to create the half ambient treatment. Thus, it was important to measure ambient oxidants in all seven half ambient chambers with the remaining 10 channels concentrating on the filtered and ambient chamber treatments.

Ozone concentrations were approximately the same in the ambient chambers as outside, indicating that the exposure system itself did not remove any appreciable ozone from the incoming air stream. Ozone was 50% of ambient in the half ambient chambers and 17% of ambient in the filtered chambers. Thus, the new design open top chambers and accompanying charcoal filters were efficient, resulting in an effect removal of 83% of the ambient oxidants from the air. This residual ozone likely resulted from a combination of slight incursion of ozone through the open top and a small amount of ozone not removed by the charcoal filters. The average ozone concentrations over the entire 6/2-12/28/84 period were 0.011 ± 0.006, 0.063 ± 0.038, 0.068 ± 0.041, and 0.033 ± 0.021 ppm, respectively, for the filtered, ambient, outside, and half ambient treatments. The standard deviations are for the 29 weekly averages.

D. <u>Environmental Measurement</u>

Important environmental parameters, i.e. light (quantum) intensity, leaf temperature, air temperature, and relative humidity were monitored both for chambers and outside tree plots. These measurements will be used to determine the occurrence of any variability in the environment between chambers and outside plots which could be associated with differences in tree responses to air pollutants. The measurements also will be used to

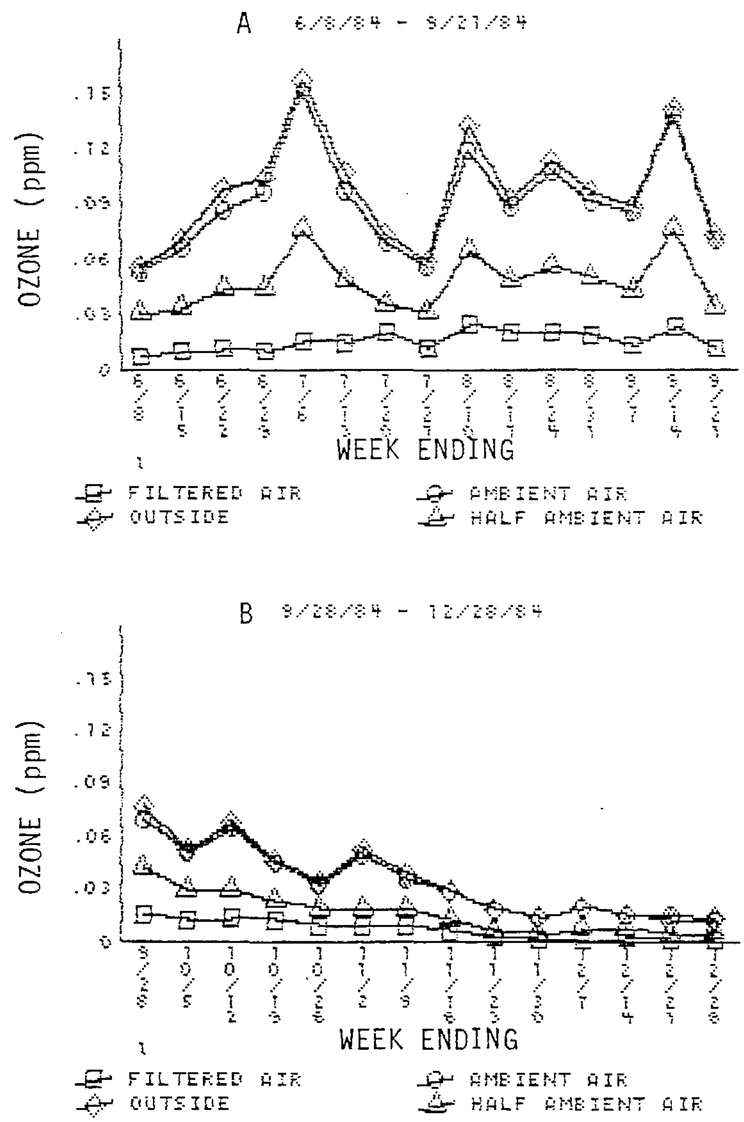


Figure 2. Average ozone concentrations for Valencia orange study. Data is for weeks ending on (A) 6/8-9/21/84, (B) 9/28-12/28/84. Data is average of six values between 08:00 and 20:00.

evaluate the environmental basis for any seasonal changes in tree responses.

Relative humidity was measured weekly for an outside area using the exposed cuvette of the LI-1600 porometer.

Quantum intensity was measured weekly as part of the stomatal conductance measurements using the quantum sensor attached to a Lambda Instruments Company LI-1600 Steady State Porometer. Measurements were taken in the plant canopy at the leaf position used for stomatal measurements.

Air temperature was measured continuously via fine wire thermocouples shielded within insulated cups and suspended within the canopies of trees. Air temperature was measured in the plant canopy and for an open outside area as a reference point. Air temperature also was measured weekly for an outside area using the exposed leaf thermocouple attached to the LI-1600 porometer.

Leaf temperature was measured continuously via fine wire thermocouples attached to the undersides of leaves with surgical tape. The signals from the thermocouples were read and processed by the computer. Leaf temperature also was measured weekly as part of the stomatal conductance measurements using the leaf thermocouple attached to the LI-1600 porometer.

E. Plant Response Measurement

Plant response measurements were made for physiological, growth and yield parameters. All measurements were on a per tree basis. Physiological measurements were stomatal conductance, water potential, and net photosynthesis. Stomatal conductance was measured weekly (09:30 to 11:30 on Fridays) using the LI-1600 porometer. Sample leaves were tagged and measured on successive weeks until the leaf senesced. At the beginning of the measurements leaves from the previous year were sampled. In August, 1984, after a flush of new growth had occurred for all trees, new young leaves were selected for both chamber and outside trees. New leaves were again selected for all trees in February, 1985, after many of the sample leaves had fallen from the trees.

Net photosynthesis was measured using a $^{14}CO_2/^{3}H_2O$ dual isotope porometer (1). Measurements were made in the late morning on February 4,

1985. Water potential was measured for whole leaves using a pressure bomb. The first sets of measurements were made in both the late morning and early afternoon on February 4, 1985. Additional net photosynthesis measurements will be made monthly after that date.

Tree growth was determined by measuring stem circumference just above the shoot/root graft union, tree height from soil line to top of canopy, trunk height from soil line to bottom of canopy, and diameter of the crown in both east-west and north-south directions. The measurements were made in December 1984, following the first summer of tree treatment.

F. Statistical Analysis

Statistical analysis was with procedures described by Snedecor and Cochran (12) and Steel and Torrie (13). Preliminary analysis of variance was by one-way analysis of variance with five treatments and seven observations per treatment. Duncan's Multiple Range Test was used to determine statistical differences between treatments. Further, more detailed comparisons will be made with the data using the experimental design shown below:

Source	df
Treatment	4
Chamber	1
Oxidants	2
Linear	(1)
Quadratic	(1)
SO_2	1
Error	30
Total	34

III. RESULTS AND DISCUSSION

A. Plant Response

1. Leaf Drop

The trees in the chambers had substantially greater growth than outside trees. The greater bulk leaf weight of leaves collected from chamber versus outside trees was evident during all three collection periods (Table 1). This leaf weight data represented relative leaf drop between treatments, with greater leaf weight indicating greater leaf drop. The total leaf drop after over 6 months of exposure was 3 to 4 fold greater for chamber than for outside trees. There were no differences in leaf drop between treatments in chambers, except for a possibly lower leaf drop in ambient than in filtered air chambers during the second collection period.

The greater leaf drop for chamber than for outside trees may have indicated either greater growth in general for chamber trees or more stress for chamber trees compared to outside trees. Citrus trees tend to lose both older and more recently developed leaves following growth flushes. In this study, there was more new growth in chambers than outside trees. Citrus trees also tend to lose leave with stresses such as heat, cold, or moisture stress. The chambers had slightly higher air and leaf temperatures than outside trees. However, whether environmental factors are related to the greater leaf drop in chambers remains to be determined.

Individual leaves from the outside trees tended to be heavier than from chamber trees, especially for the third collection period (Table 2). The increased weight was likely due to increased leaf thickness as the leaves were visibly smaller on outside versus chamber trees. Leaves from the chamber treatments all had similar weights. The morphological basis for the differences in leaf thickness will be investigated at a later date.

2. Stomatal Conductance

There were few differences in stomatal conductance between treatments over much of the experiment to date (Figure 3). During the early summer of 1984, there tended to be a higher conductance for outside than for chamber trees, with a significantly higher conductance for outside

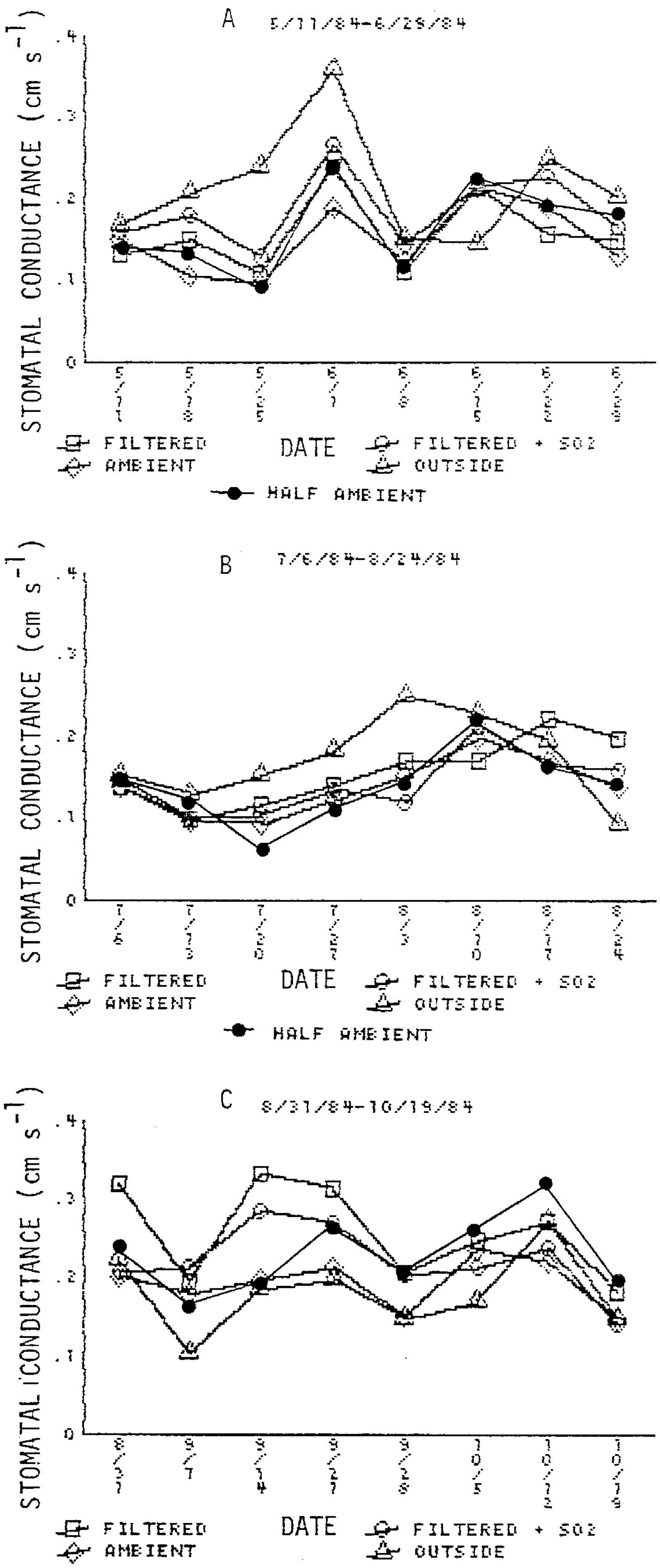
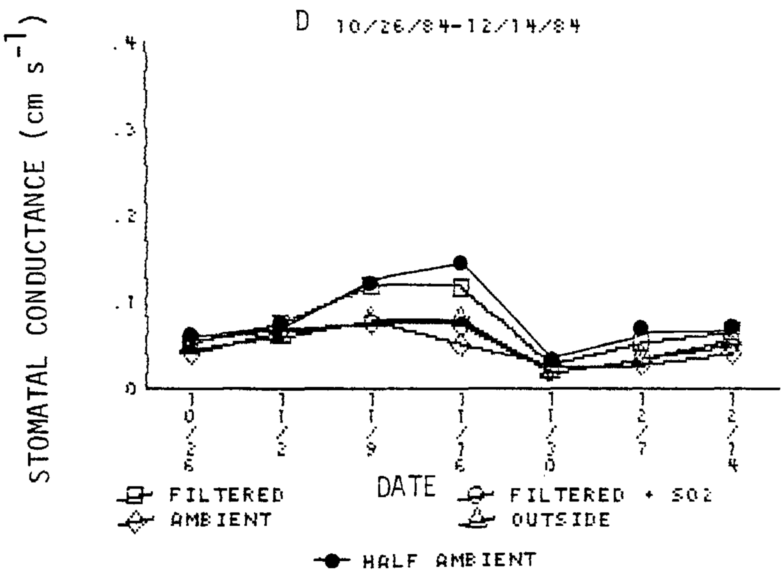


Figure 3. Stomatal conductance, Valencia Orange Study. Data is (A) 5/11-6/29/84, (B) 7/6-8/24/84, and (C) 8/31-10/19/84.



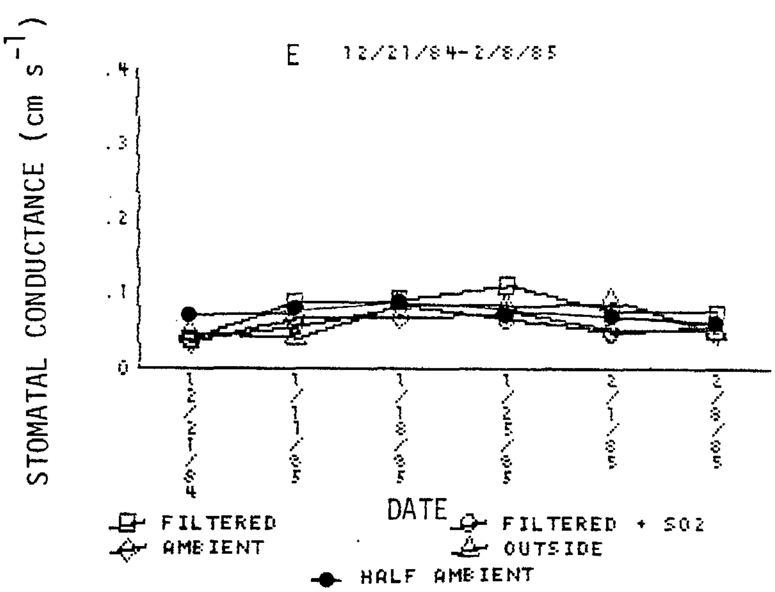


Figure 3 (continued). Stomatal conductance for (D) 10/26-12/14/84, and (E) 12/21/84-2/8/85.

Table 2. Individual Weights for Leaves Dropped From Valencia Orange Trees Exposed to Oxidants or Sulfur Dioxide*

Treatment	Dates 7/1/84 - 10/31/84	11/1/84 - 12/10/84	12/11/84 - 1/10/85
	grams leaf^{-1}		
Outside	0.25 ± 0.05 a	0.18 ± 0.04 a	0.24 ± 0.08 b
Ambient	0.22 ± 0.05 a	0.13 ± 0.03 a	0.17 ± 0.05 a
Half Ambient	0.24 ± 0.05 a	0.16 ± 0.07 a	0.14 ± 0.05 a
Filtered	0.23 ± 0.04 a	0.13 ± 0.03 a	0.15 ± 0.04 a
Filtered + SO_2	0.26 ± 0.04 a	0.17 ± 0.06 a	0.16 ± 0.08 a

*Values are means ± SD for seven trees based on a single measurement for 10 leaves. Means in a column followed by different letters are significantly different at $p<0.05$ using Duncan's Multiple Range Test.

trees on 5/25, 6/1, 7/20 and 8/3 (Figures 3A and B). During the late summer of 1984, there tended to be a higher conductance for filtered chamber trees than for other treatments (Figure 3C). This greater conductance for filtered trees may be associated with a lack of oxidants, which were especially high for ambient trees during this time. During the summer and early fall the conductances averaged approximately 0.10 to 0.25 cm s^{-1} for most treatments. In late fall and early winter stomatal conductances generally were less than 0.10 cm s^{-1} for most treatments and dates.

Overall, the seasonal differences in stomatal conductance between the treatments indicate potentially important interactions between the air pollutants and environmental conditions. More precise statistical analysis of the weekly data will be carried out to evaluate the stomatal responses.

3. Net Photosynthesis

Net photosynthesis was not affected by any of the pollutant treatments within chambers (Table 3). However, the measurements were made during the winter when the physiological activity of the trees is low and ozone concentrations are minimal (Figure 2). Net photosynthesis was significantly lower in the outside compared to ambient chamber trees. More critical measurements will be made when the physiological activity of the trees increases in the spring.

4. Leaf Water Potential

Leaf water potential also was not affected by any of the treatments (Table 3). Leaf water potential was lower in the afternoon than in the morning across all treatments. The lower afternoon potential was

Table 3. Net Photosynthesis and Leaf Water Potential for Valencia Orange Trees Exposed to Oxidants or Sulfur Dioxide*

Treatment	Net Photosynthesis ($\mu mol\ m^{-2}\ s^{-1}$)	Leaf Water Potential (MPa) 0930-1130	1330-1530
Outside	1.77 ± 0.71 a‡	-0.49 ± 0.17 a	-0.74 ± 0.11 a
Ambient	2.57 ± 0.72 b‡	-0.61 ± 0.21 a	-0.91 ± 0.08 a
Half Ambient	2.11 ± 0.84 b	-0.63 ± 0.15 a	-1.02 ± 0.38 a
Filtered	2.25 ± 1.04 b	-0.58 ± 0.24 a	-0.81 ± 0.26 a
Filtered + SO_2	2.12 ± 1.33 b	-0.54 ± 0.11 a	-0.81 ± 0.18 a

*Values are means ± SD for seven trees. Means in a column followed by different letters are significantly different at $p<0.05$ using Duncan's Multiple Range Test.
‡Significant difference in net photosynthesis between outside and ambient chamber trees based on 't' test.

likely related to the higher temperatures and lower humidity, and thus greater plant water stress than in the morning.

5. Growth

Tree growth tended to be greater in chambers than in outside plots for all response variables (Table 4). Crown diameter measured in both east-west and north-south directions was approximately 20-30% greater

Table 4. Relative Growth for Valencia Orange Trees Exposed to Oxidants or Sulfur Dioxide*

Treatment	Stem Circumference (m)	Tree Height (m)	Trunk Height (m)	Crown Diameter‡ E-W (m)	Crown Diameter‡ N-S (m)
Outside	0.16 ± 0.20 a	1.81 ± 0.14 a	0.41 ± 0.07 a	1.45 ± 0.25 a	1.37 ± 0.17 a
Ambient	0.17 ± 0.06 a	1.90 ± 0.08 a	0.47 ± 0.05 a	1.84 ± 0.17 b	1.87 ± 0.18 b
Half Ambient	0.17 ± 0.14 a	1.87 ± 0.13 a	0.43 ± 0.03 a	1.68 ± 0.23 ab	1.74 ± 0.29 b
Filtered	0.17 ± 0.14 a	1.91 ± 0.10 a	0.47 ± 0.06 a	1.74 ± 0.19 b	1.77 ± 0.15 b
Filtered + SO_2	0.16 ± 0.09 a	1.92 ± 0.11 a	0.44 ± 0.06 c	1.68 ± 0.20 ab	1.77 ± 0.18 b

*Measured in December 1984. Values are means ± SD for seven trees. Means in a column followed by different letters are significantly different at $p<0.05$ using Duncan's Multiple Range Test.
‡Crown diameter as measured in east-west (E-W) and north-south (N-S) directions.

for chamber trees than for outside trees. A similar trend toward greater tree growth in chambers than outside was evident from the stem circumference, tree height, and trunk height data, however, the differences between treatments were not statistically significant. There were no differences in tree growth between any of the treatments within chambers. The "chamber effect" on the orange trees that is suggested by this growth data will be carefully evaluated during the course of the study. Initial tree trunk diameter measurements are available for use as a possible covariate when evaluating treatment effects in future statistical analysis of the data.

B. Environmental Conditions

1. Relative Humidity

General relative humidity for the exposure site increased gradually between 10/19/84 and 2/8/84 (Figure 4A). The highest values were on 11/16/84 and 2/8/84 when humidity was over 40%. However, humidities were in general low within a general range of from 10 to 30%.

2. Quantum Intensity

Overall quantum (light) intensity for the exposure site varied between 500 and 1,500 umol m^{-2} s^{-1} between 10/19/84 and 2/8/84 (Figure 4B). The lower intensities were associated with cooler, cloudy days. No measurements were made for an empty chamber, however, intensities measured for trees in ambient chambers are slightly lower than intensities for outside trees.

Quantum intensity was slightly higher (approximately 10 to 20%) in outside plots than in chambers when quantum intensity was highest in May, June and July, 1984 (Figure 5A and B). This greater outside intensity is likely due to the smaller tree canopy and hence less shading of the porometer for outside versus chamber trees. Shading due to structural components of the chamber dome may play only a small role in the lower quantum intensity for chamber versus outside trees. Outside and chamber quantum intensities were approximately the same as the quantum intensity decreased later in the year (Figure 5C through E).

3. Air Temperature

Air temperature for the exposure site decreased between 10/19/84 and 2/8/85 (Figure 4C), based on the porometer data. The coolest days roughly corresponded to the days with the highest relative humidity and

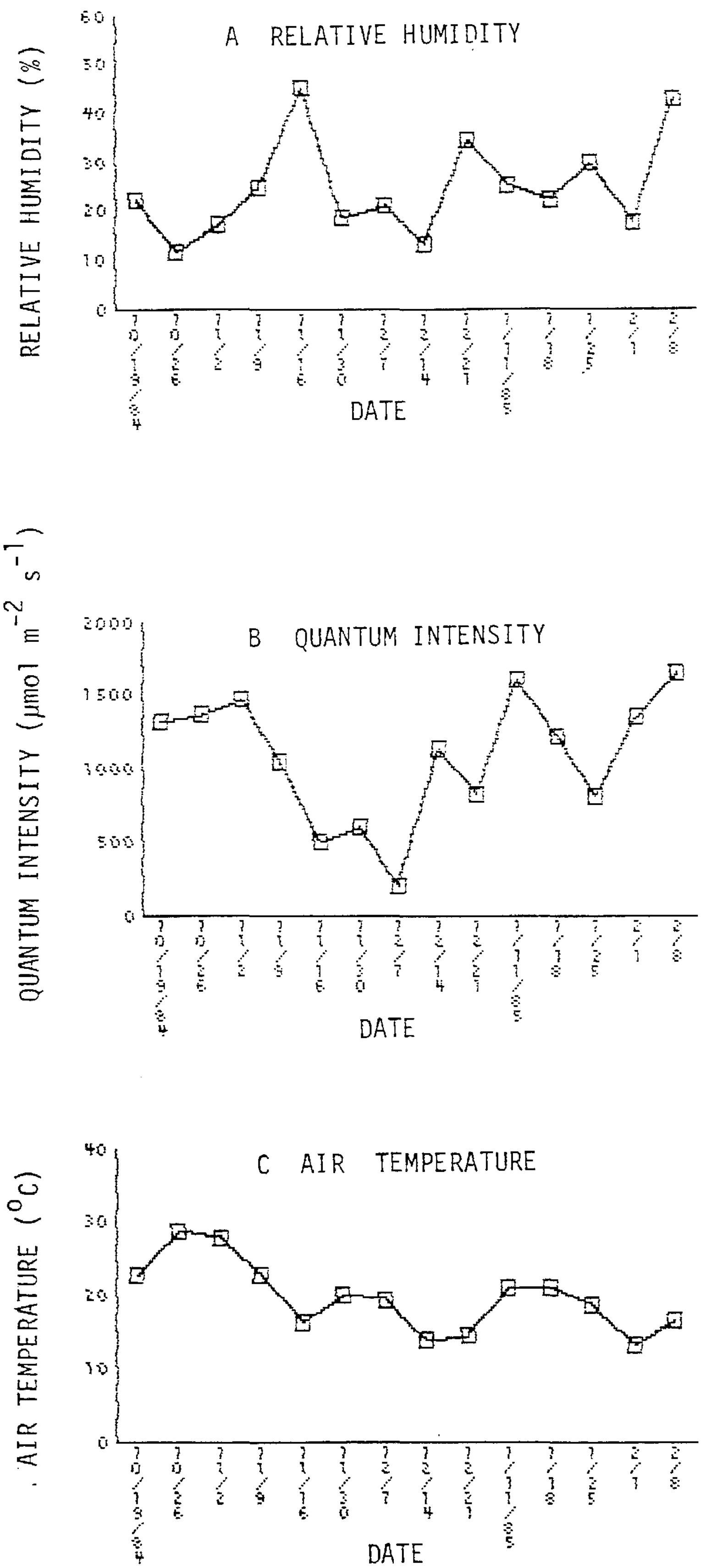


Figure 4. Environmental conditions as measured with the LI-COR 1600 porometer. (A) relative humidity, (B) quantum intensity, and (C) air temperature. Measures were made in an outside area adjacent to the chambers.

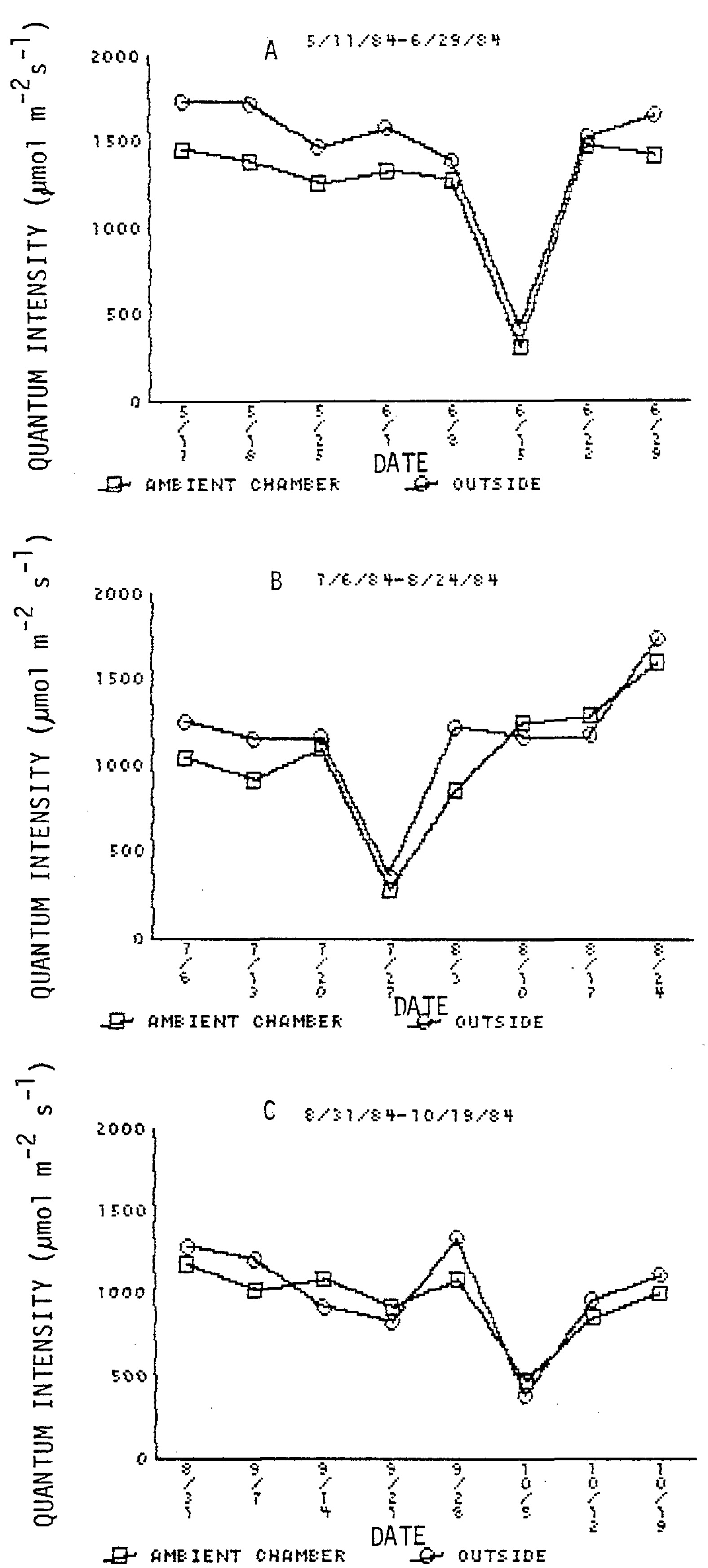
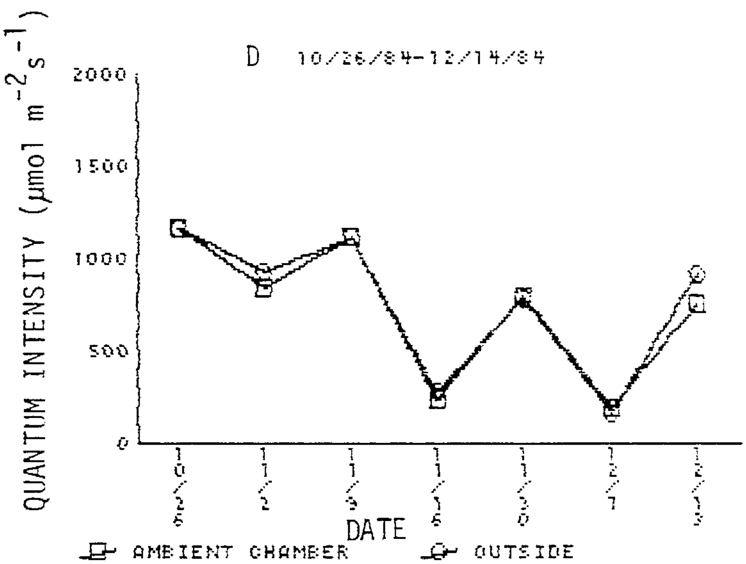


Figure 5. Quantum intensity for Valencia Orange Study. Data is for (a) 5/11-6/29/84, (B) 7/6-8/24/84, and (C) 8/31/-10/19/84.



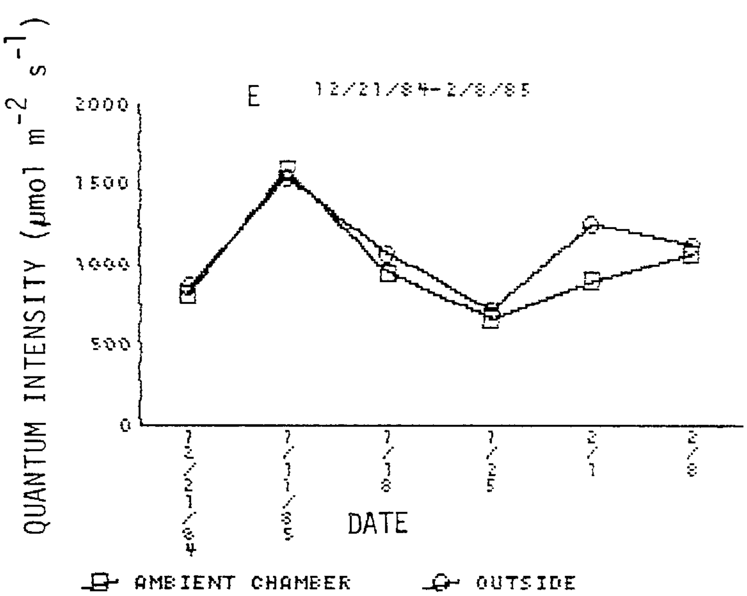


Figure 5 (continued). Quantum intensity for (A) 10/26-12/23/84, and (B) 12/21-2/8/84.

lowest quantum intensity. The continuous air temperature data for chambers and outside plots is being processed.

4. Leaf Temperature

Leaf temperature was consistently 1 to 2°C lower for outside trees than ambient air chamber trees, based on porometer measurements. The difference was greatest during May through September, 1984 (Figure 6A through C), and decreased in magnitude in fall and winter (Figure 6C through E). The continuous leaf temperature data for chamber and outside trees is being processed.

C. Applicability of These Findings

The study to date has not been conducted long enough to determine the effects of air pollutants on Valencia orange trees, but has established the basis by which those effects can be detected. A new type of open top field chamber was designed, tested and constructed for use with Valencia orange trees. This chamber could also be used with many other species of cultivated and native trees. The chamber has a minimal affect on the environment around the tree. The chamber also produced sufficient air flow to maintain normal gas exchange characteristics for the tree leaves, as measured by stomatal conductance.

The increased tree growth indicates either that small changes in environment can have a large change in plant growth, or that some environmental variable not measured may be affecting growth. It may not be specific average changes in light, temperature, etc. that may be increasing tree growth in the chambers. Rather, the generally more consistently even air movement in chambers compared to wide fluctuations in outside air movement may be encouraging the increased tree growth.

Despite the small extent of environmental modification in the chambers, tree growth was greater in the chambers than in outside plots. The increased growth was indicated directly by the larger crown diameters for chamber versus outside trees. Increased growth was shown indirectly by the greater leaf drop for chamber than outside trees, an indication that the chamber trees had produced greater growth flushes during the year. Their greater growth indicates that the air pollutant sensitivity may be different for chamber versus outside trees. However, the ambient air chamber trees will indicate this "chamber effect" so that it can be

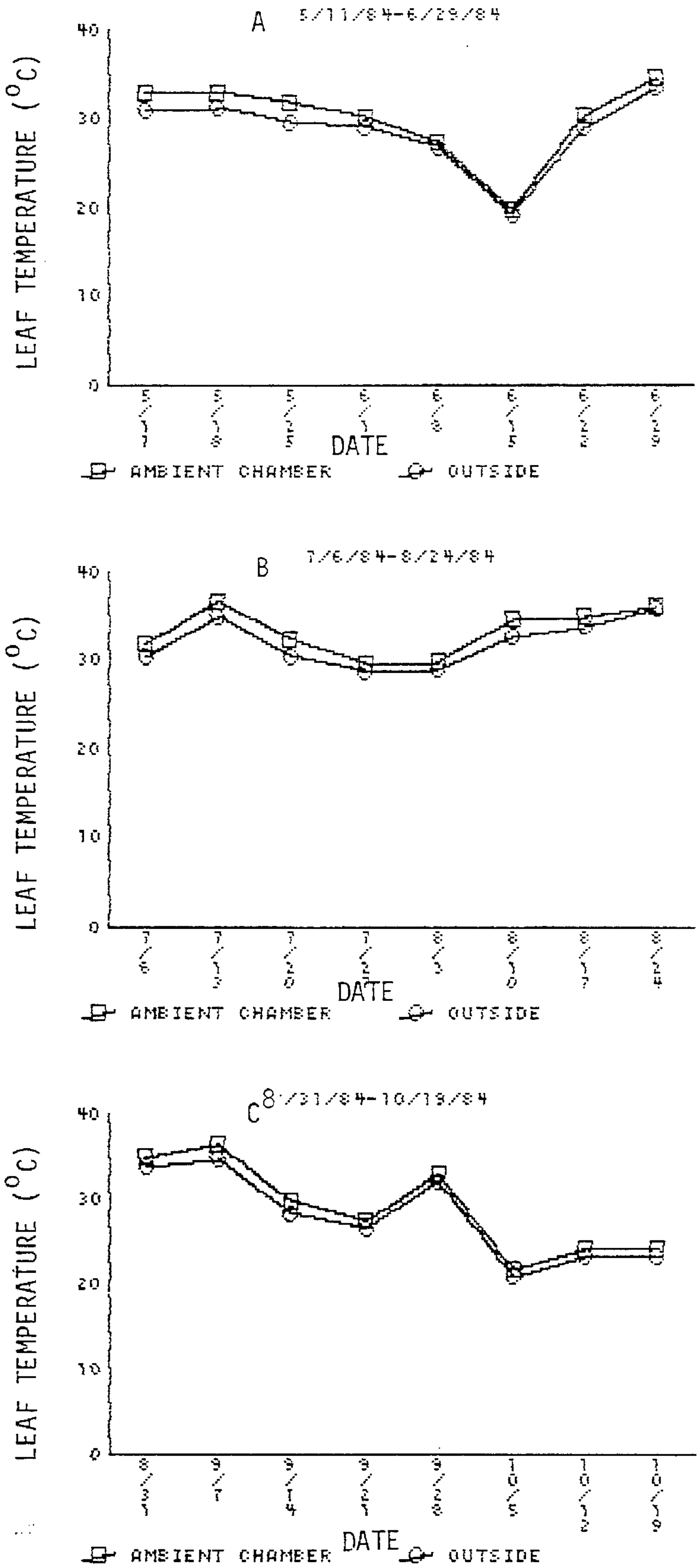
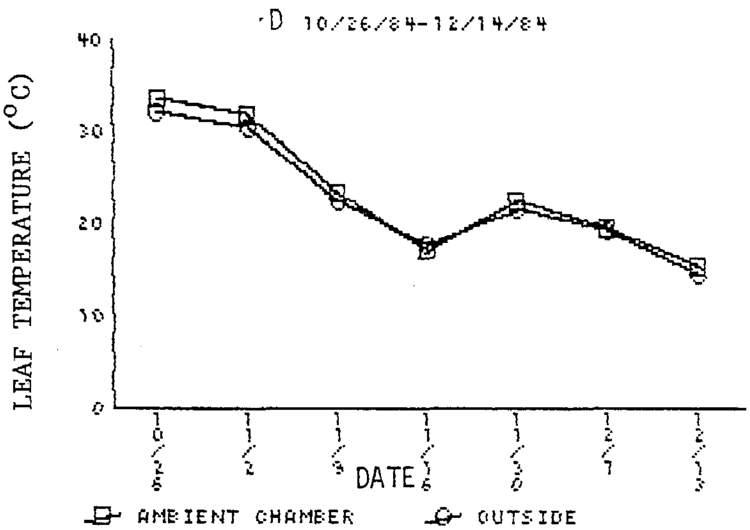


Figure 6. Leaf temperature for Valencia Orange Study. Data is for (A) 5/11-6/29/84, (B) 7/6-8/24/84, and (C) 8/31-10/19/84.



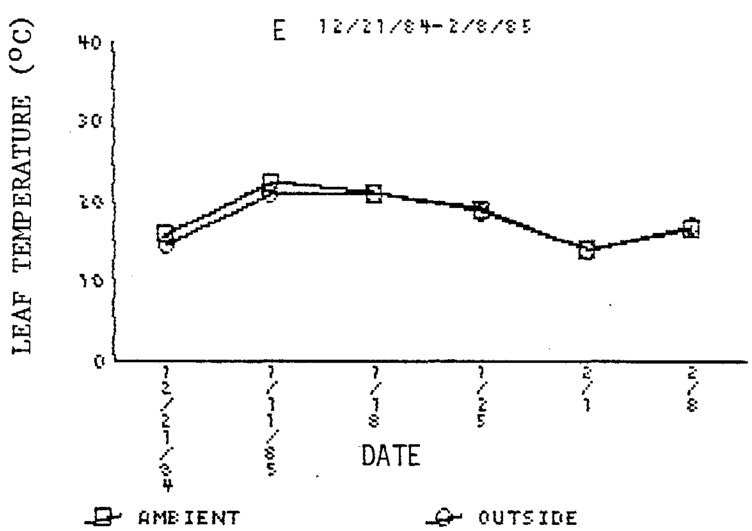


Figure 6 (continued). Leaf temperature for (D) 10/26-12/14/84, and (E) 12/21/84-2/8/85.

taken into consideration in evaluating the Valencia orange crop losses from either oxidants or SO_2.

Transplanting of trees to form a new grove for experimental purposes temporarily alters the bearing characteristics of citrus so that a crop is not produced until up to three years after planting. However, planting of the vigorously growing trees also provided the opportunity for determination of the effects of air pollutants on the growth of young trees. This altered growth likely has a significant impact on tree production in later years.

Thus, this study is providing both the experimental conditions and plant material for an in-depth determination of the effects of air pollutants on citrus. Additional years of research are needed to investigate the long term effects of oxidants or SO_2 on the physiology, growth and yield of Valencia oranges.

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APPENDIX A

Exposure System Construction

A large and relatively light weight open top field chamber was designed, constructed, tested, and fabricated in quantity at the Agricultural Experiment Station of the University of California, Riverside. The chamber used many of the basic design principles developed by Heagle et al. (1) and incorporated into the NCLAN chambers (2). However, because of its unique application for trees, the chamber structural characteristics are of original design.

Chamber. The chamber components; base and dome, were assembled separate from the air handling system at a remote site. When complete, the chambers were moved to the experimental site, lifted over the trees, and attached to the air handling system. The total volume of each chamber was approximately 33.41 m^3.

Base. Figure A-1 shows the chamber with finished base. The galvanized metal Rollform frame (Conley's Manufacturing and Sales, Pomona, CA), was made of 18 gauge galvanized sheetmetal which was shaped and bent in one manufacturing process. The rolled shape of the frame is shown in Figure A-2B. There were two 4.27 m diameter hoops per base, with each hoop comprised of two 13.7 m perimeter sections which overlapped by 0.31 m. The sections were joined on one side using pop rivets (Joint A in Figure A-3), and on the opposite side using bolts (Joint B in Figure A-3), so that final adjustments could be made when installing the dome top.

Ten 0.91 m high upright sections of galvanized steel were used to join the upper and lower hoops together (Figure A-1). Two uprights with the groove facing inward (Figure A-2A) were placed on either side of the door (Figure A-3). The remaining 8 uprights were installed at intervals of approximately 1.27 m around the perimeter of the base. The joints between the horizontal and vertical framing members were cut to specifications and pop rivets were used for fastening (Figure A-2A). A 0.77 m wide by 0.91 m high section of sheetmetal was placed between the hoops opposite the door (Figure A-3). A 0.53 m diameter hole was made in the center of this piece of sheetmetal as a portal for the mixing baffle of the blower assembly.

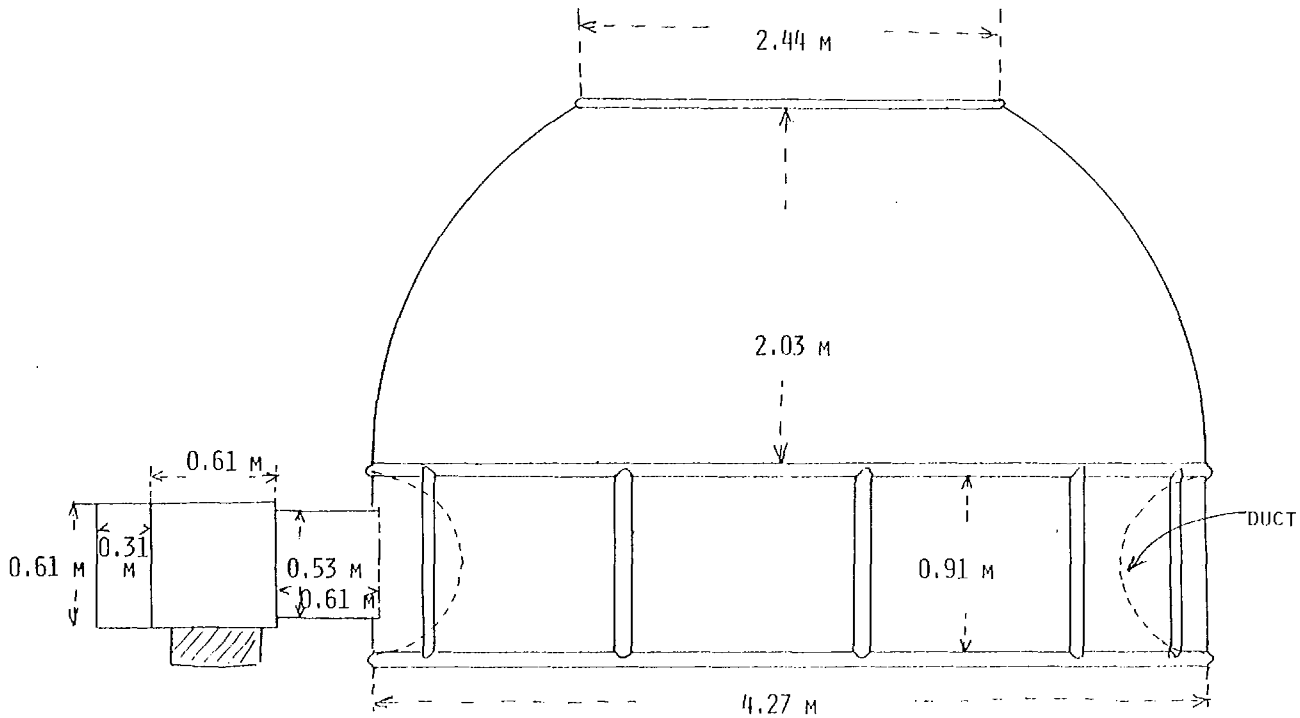
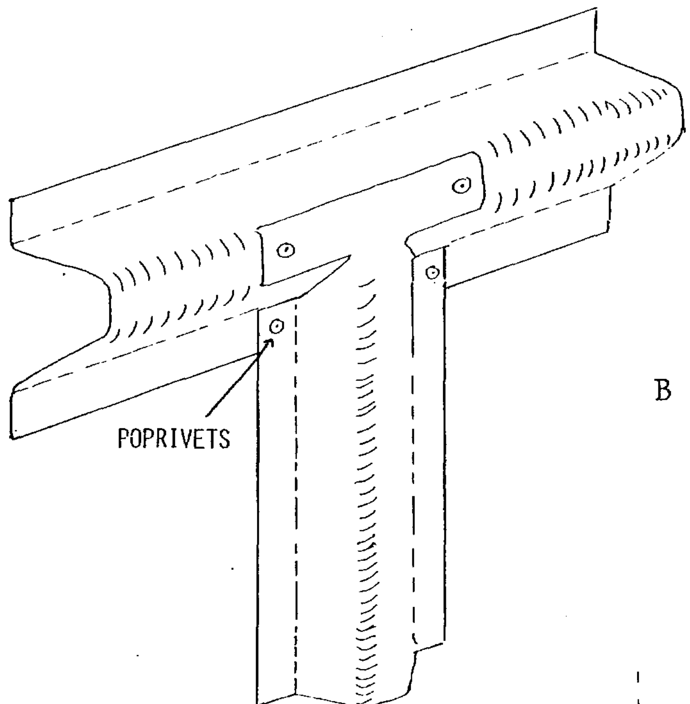


Figure A-1. Dimensions of open top field chamber developed for use with Valencia orange trees.

A Side View



B Cross Section

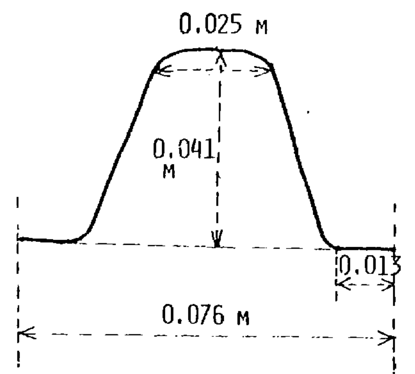


Figure A-2. Side view (A) and cross section (B) of rolled galvanized steel frame for orange tree open top chamber.

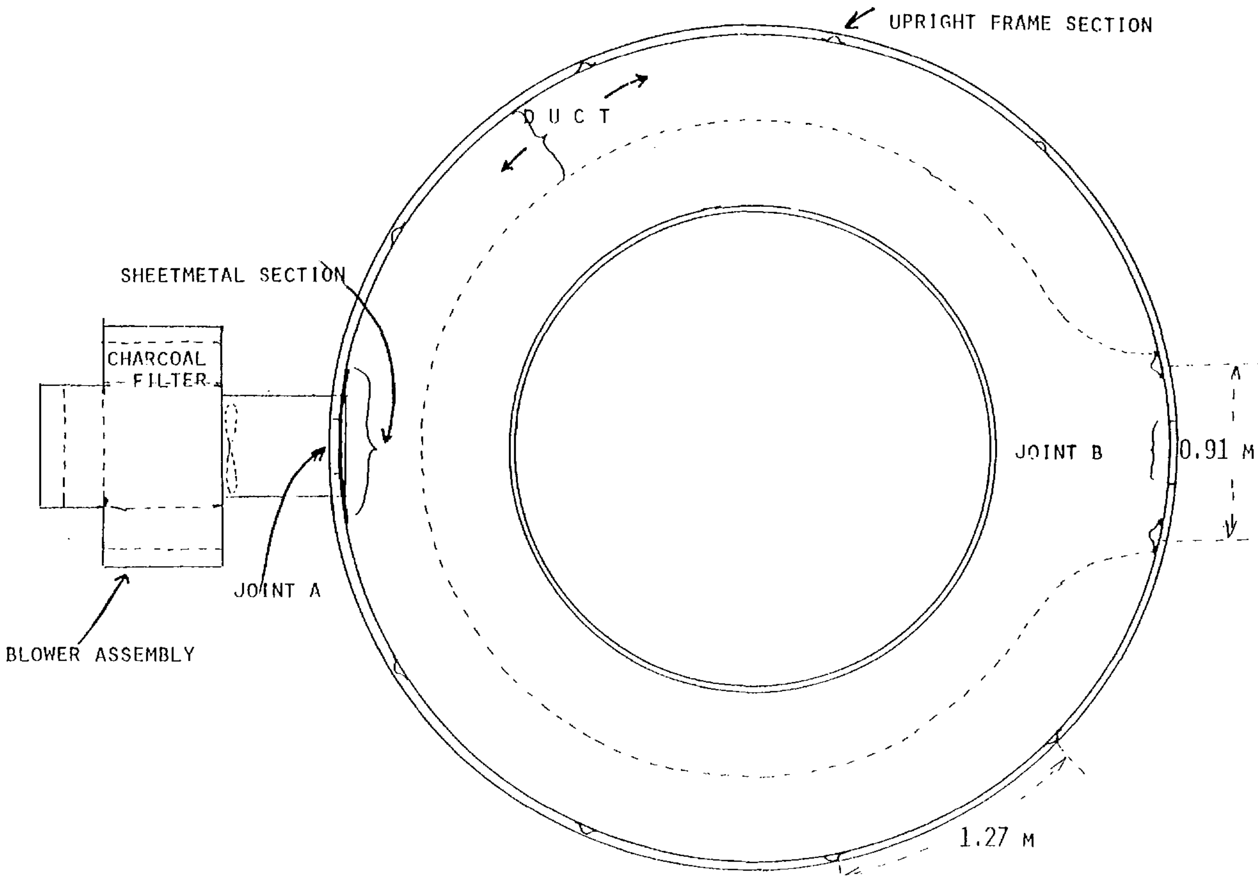


Figure A-3. Cross section of chamber and air handling system for orange open top field chamber.

Corrugated fiberglass panels were connected to the rest of the base assembly using pop rivets as shown in the lower part of Figure A-4. An opening 0.91 m wide opposite the blower entrance, was left to serve as a door. The fiberglass was positioned so that the folds were attached outward from the base. The panels were originally 2.90 m wide by 1.31 m high, but were cut to fit the space between the hoops, and to leave an angle at the top corresponding to the angle of the frames. When needed, panels were joined together using clear silicone sealant (Silicon Construction 1200 Sealant, General Electric #SCS 1201).

Doors in the bases consisted of fiberglass panels attached to the left side of the door opening and overlapping the right side by 0.25 m (Figure A-3). Poprivets and silicone sealant were used to attach the doors on the left side (Figure A-4). Velcro® strips were originally used to attach the door on the right side, with opposing strips attached with silicone sealant to the base and inside of the door. The doors were further secured with two springs crossing the door after severe winds blew out the doors in January 1985. The springs were attached at upper and lower positions on the left side of the door, crossed each other, and were attached to hooks at the lower and upper sides, respectively, of the right side of the door.

Dome. The dome was manufactured in kit form and sold under the names of "Solarium Dome" or "Spa Dome" (Solarium Incorporated, Troy, Michigan). For the citrus chambers, 10 panels were purchased per dome, and the advertized doors and top were not acquired. The panels are of 0.003175 m thick "UVEX"® plastic manufactured by the Eastman Kodak Company. This plastic was tested for ultraviolet transmission characteristics using a spectroradiometer and was found to transmit light in the 350 to beyond 800 nm wavelength range. Assembly of the panels produced a 4.27 m diameter, 2.03 m high dome with a 2.44 m diameter circular perforation in the top (Figure A-1).

The dome panels were attached to the upper hoop of the base as shown in Figure A-5. The uprights had been inserted in the base, but not the fiberglass walls or sheet metal panel. A bead of silicone sealant was applied to the upper flange of the frame to seal the dome-frame junction. A strap of metal 0.003175 m thick x 0.0191 m wide, pre-drilled at 0.20 m intervals, was wrapped around the base of the dome panel, opposite

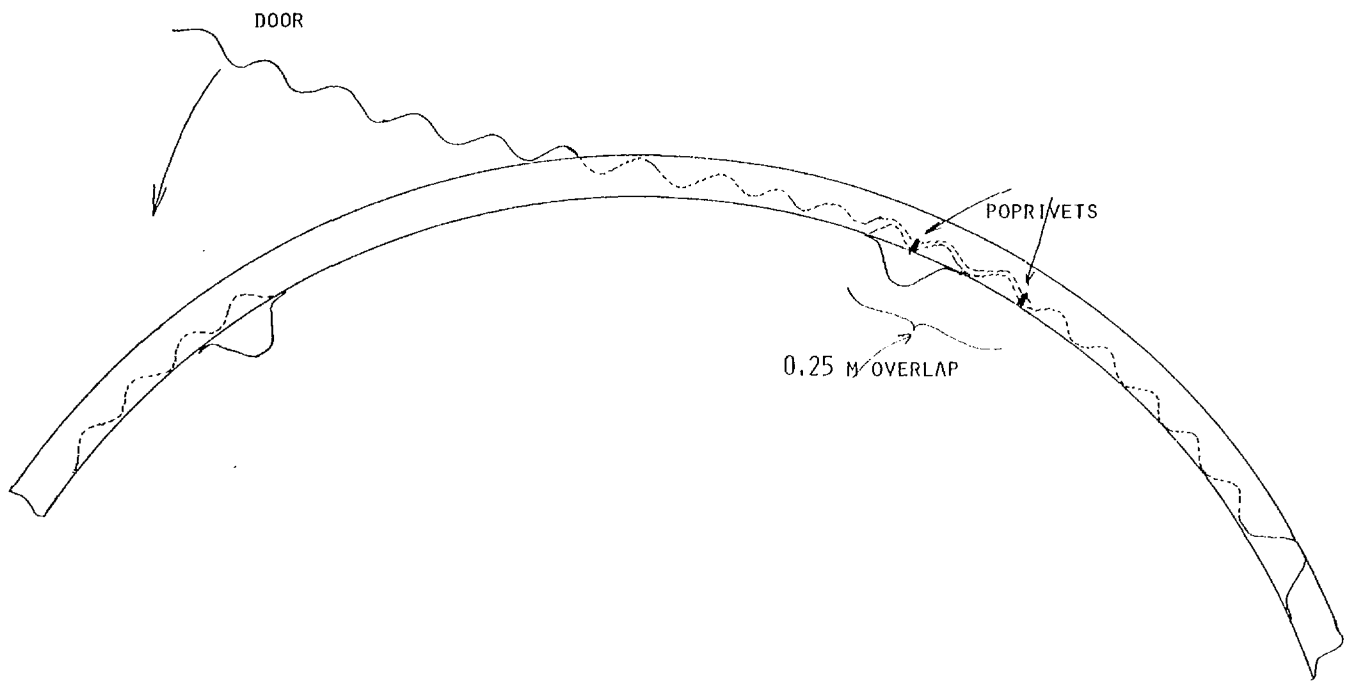


Figure A-4. Design for corrugated fiberglass door for orange open top field chamber.

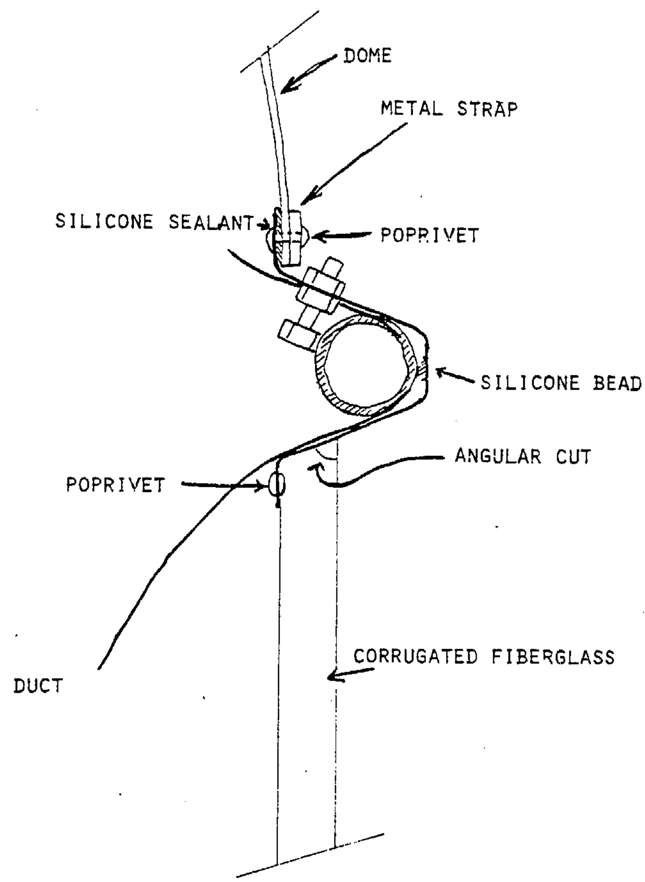


Figure A-5. Design for attaching dome panels and base panels to upper rolled galvanized metal hope of orange open top field chamber.

the silicone bead. Poprivets were than used to secure the panel to the frame.

The first panel was attached to the dome while being held upright from the inside of the chamber. The next panel also was held upright and attached to the frame, and then popriveted to the preceding panel along the vertical seam. The third panel was then held upright and attached to the frame and second panel. After installation of the third panel the dome became increasingly rigid and did not need much support during attachment of panels. The order of panel installation was alternating left and right starting at the door (Position B on Figure A-3). Joint A was temporarily fastened with bolts at the start of dome construction. The bolts were removed immediately before securing the last panel, and the hoop width adjusted slightly to allow the panel to fit tightly between the adjacent panels. Poprivets were then used to secure the last panel. After completion of the dome the fiberglass panels and sheet metal panel were attached to the base. A 0.0254 m diameter thin wall metal hoop was fitted into the upper edge of the dome to provide added rigidity to the structure (Figure A-1). The hoop was secured to the panels with self-drilling sheet metal screws.

Duct. The air from the blower initially was distributed in the chambers through an inflatable duct (Figure A-1). The duct extended from either side of the door around the periphery of the chamber (Figure A-3). The duct was made of a single 4 mill polyethylene plastic sheet, approximately 5.18 m long and 1.78 m wide when laying flat. When inflated the duct was a semicircle approximately 1.40 m wide and 0.46 m deep. A bead of silicone sealant was applied to the inside groove of the frame before installing the plastic to increase the friction between the plastic and frame and thus avoid slipage. The duct was attached to the inside grooves of the upper and lower hoops of the base (Figure A-6). At the top 0.13 m of sheeting was pulled through the groove, and at the bottom 0.26 m of vinyl was pulled through. A 0.0229 m diameter circular piece of class 200 polyvinylchloride pipe was than placed within both the upper and lower grooves to secure the plastic (Figure A-6). The pipe fit well into the channel shaped hoops. Bolts were added every 0.61 m to press the pipe into the channel. At each side of the door opening the duct was closed

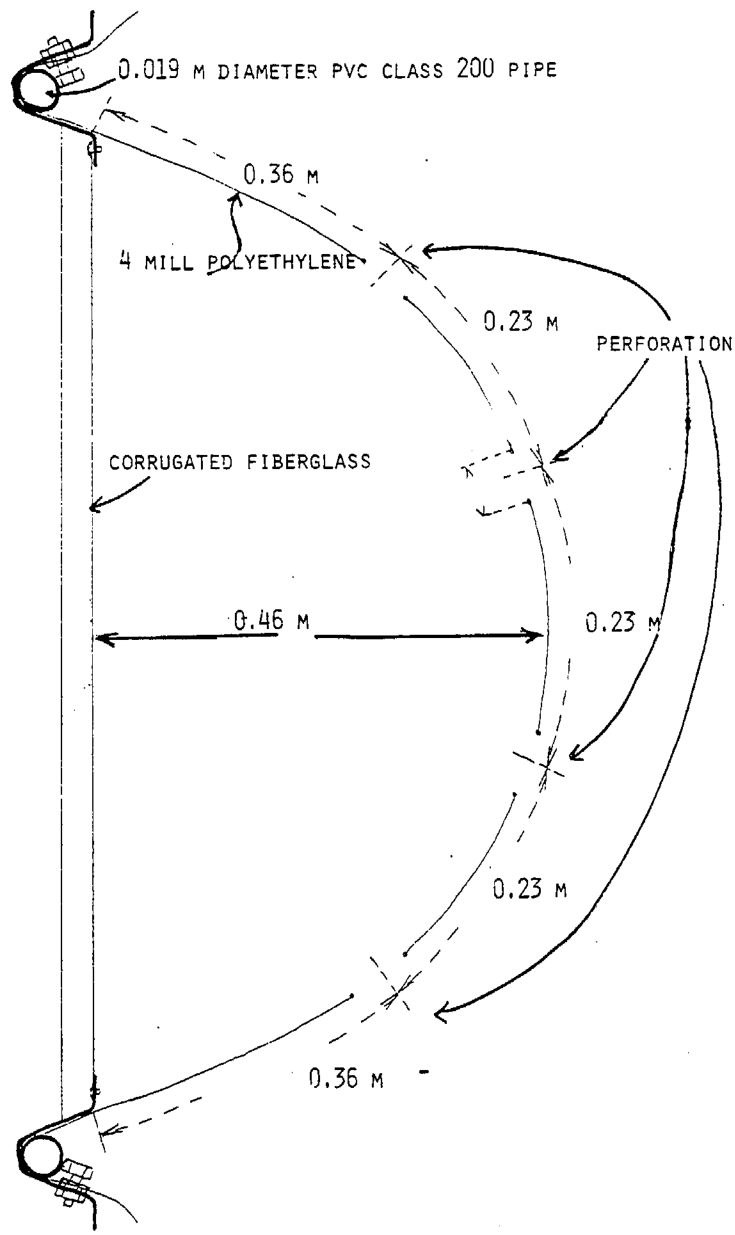


Figure A-6. Design for attaching vinyl plastic duct to upper and lower galvanized metal hoops of the orange open top field chamber.

off and attached with a Tubelock aluminum extrusion (Conley's Manufacturing and Sales, Pomona, California).

The perforations (0.051 m diameter) in the duct were arranged in 4 horizontal rows starting 0.36 m from the top and bottom, with 0.23 m between and within rows. The holes were cut after the duct had been placed inside the chamber, using an electrically heated nichrome wire loop.

During the fall of 1984 the ducts began to deteriorate within the chambers. The ducts had been in place approximately one-half year. Large holes began to form in the ducts, beginning at the perforations and spreading across the duct. Temporary repairs were made by taping the tears with duct tape. Replacing the ducts was estimated to cost approximately $65.00 per chamber. Thus, an alternative method was investigated for providing for air flow into the chambers.

The duct was replaced with a single sheet metal baffle directly opposite the blower hole. The baffle had 0.076 m diameter holes in 3 horizontal and 6 vertical rows. This baffle directed the incoming air at the tree canopy. Air mixing within the chamber with this single baffle was approximately the same as mixing with the circular duct. This was documented with carbon monoxide.

Air Handling System. The air handling system consisted of a sheet-metal housing, fan, particulate and gaseous pollutant filters, and a cylinder containing baffles (Figures A-1 and A-2). Air was blown into the chamber by a 0.51 m diameter propeller fan (Peerless Model PVH 20), driven by a three-fourths hp , 3 phase 230 volt, 60 HZ AC motor (Reliance Electric Company, Duty Master Motor). The fan was installed in a housing fabricated from 20 gauge galvanized sheetmetal. It was designed to accept three 0.61 m high x 0.61 m wide x 0.23 m deep filter cannisters (Cambridge Activated Carbon Air Filter Model 45 FB-35). For the filtered treatments, the three cannisters were filled with activated charcoal granules [Cambridge Activated Carbon 6-12 mesh (3.33 mm x 1.40 mm) coconut grit charcoal]. For the half-ambient treatment the cannisters were half filled with charcoal, and for the ambient treatment the cannisters were empty. Each filter filled with charcoal allowed a flowrate of 28.32 m^3 min^{-1}. Using 3 filters the maximum flow through the system would be 84.95 m^3

min^{-1}. Fiberglass furnace filters were placed exterior to the cannisters to exclude particulates.

Use of 3 phase motors allowed for use of a variable frequency speed controller (Parajust Y by Parametrics, Orange, CT). The speed controller provided the ability to automatically adjust the motor speed and thus air flow rate simultaneously for all chambers. The controller was used to decrease the motor speed between 20:00 and 06:00, resulting in decreased air flow over the trees at night compared to the day. This resulted in more natural diurnal air flow conditions, and saved approximately 37% in electric power costs.

A 0.53 m diameter, 0.61 m long cylindrical sheetmetal duct was inserted between the blower box and chamber base (Figures A-1 and A-2). Four crescent shaped baffles were placed inside the duct perpendicularly to the vortex of the air flow. This greatly improved air mixing without air flow rate losses.

Carbon monoxide dilution measurements (3) indicated that air flow into the chamber by the blower was approximately 56.63 m^3 min^{-1}. This provided for approximately one air exchange per minute. Motors and fans of a higher capacity would increase the air flow into the chamber and number of air exchanges per minute. The combination of air filtering by the charcoal filters and air exclusion by preventing air incursion through the top of the chamber resulted in a filtered treatment with approximately 20% of the ambient ozone concentration.

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