

The Effects of Ozone and SO₂ on
Processing Tomato Yields and Quality

Prepared for California Air Resources Board
Final Report on ARB Contract A4-071-33
March 1, 1986

Robert F. Brewer
Project Leader

Rulon Ashcroft
Leonard Herrera
Staff Research Associates

ABSTRACT

Two varieties of processing tomatoes, UC-204-B and E-6203 were exposed to four levels of ozone and two levels of SO₂ in plastic covered open top chambers at Parlier, California. Ozone concentrations were based on ambient levels in the area and were .25, .50, 0.90 and 1.5 times ambient levels. Six hours per day, four days per week a SO₂ concentration of 0.1 ppm was maintained in the SO₂-added experiments by metering in anhydrous SO₂ gas from a cylinder. Treatments were maintained from June 10 until August 26 when the chambers were removed to facilitate fruit harvest.

The entire tomato vine with fruit attached was cut off at ground level prior to picking off all of the fruit. Upon removal the fruit was sorted into three categories: "reds", "greens", and "rots", which were weighed separately. One preweighed bin containing approximately 25 kg of ripe (red) fruit was counted to determine mean fruit weight as an indication of mean fruit size. Ten pound subsamples of ripe fruit representing each variety from each subplot were obtained and delivered to the U.C. Davis Tomato Quality Laboratory for standard quality tests.

Results of yield measurements indicated a 20% reduction in vine weights and 27% reduction in weight of good red fruit by vines receiving ambient ozone as compared with similar vines receiving filtered air. Exposure to SO₂ reduced vine growth approximately 7% and red fruit production approximately 8% as compared with no SO₂ exposure. Increasing the ozone level to 1.5 times ambient reduced yields an additional 15% but did not reduce vine weights, an indication the high ozone may be affecting flower production and/or pollination.

Fruit quality data from the Tomato Quality Laboratory indicated that soluble solids (Brix) and viscosity were reduced as ozone levels increased. Exposure to 0.1 ppm SO₂ tended to increase solids somewhat but had no significant effect on other quality criteria.

ACKNOWLEDGEMENTS

The advice and assistance of the following people and organizations is gratefully acknowledged:

1. Dr. Kent B. Tyler, Extension Vegetable Crops Specialist, Kearney Agricultural Center, Parlier, California.
2. Donald May, Vegetable Crops Farm Advisor, Fresno County.
3. Mitzi Aguirre, Tomato Quality Laboratory, University of California, Davis.
4. Teri K. Wolcott, Department of Food Science and Technology, University of California, Davis.

DISCLAIMER STATEMENT

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

TABLE OF CONTENTS

| | <u>Page No.</u> |
|--|-----------------|
| ABSTRACT | 2 |
| ACKNOWLEDGEMENTS | 4 |
| DISCLAIMER STATEMENT | 4 |
| TABLE OF CONTENTS | 5 |
| LIST OF FIGURES | 6 |
| LIST OF TABLES | 7 |
| SUMMARY AND CONCLUSIONS | 8 |
| RECOMMENDATIONS | 9 |
| INTRODUCTION | 10 |
| OBJECTIVES | 12 |
| EXPERIMENTAL DESIGN | 12 |
| CULTURAL PRACTICES AND GROWING CONDITIONS | 16 |
| RESULTS AND DISCUSSION | 22 |
| Yield Data | |
| Fruit Quality | |
| REFERENCES CITED | 31 |
| APPENDIX | |
| A. Lab Results for 1985 Tomato Variety Trials | 32 |
| B. Map of California Showing Processing Tomato Acreage | 33 |

LIST OF FIGURES

| | <u>Page No.</u> |
|--|-----------------|
| Figure 1. Layout of individual tomato rows in relation to air ducts. | 13 |
| Figure 2. Layout of 1985 tomato experiment. | 15 |
| Figure 3. Ozone profiles, June 21, 1985. | 17 |
| Figure 4. Ozone profiles, August 9, 1985. | 18 |

LIST OF TABLES

| | <u>Page No.</u> |
|--|-----------------|
| Table 1. 1983 and 1984 California tomato acreage. | 10 |
| Table 2. Atmospheric treatments in plastic chambers. | 14 |
| Table 3. SO ₂ dosages received by tomatoes, 1985. | 19 |
| Table 4. Ozone dosages received by tomatoes, 1985. | 20 |
| Table 5. Peak ozone concentrations, May-August, 1985. | 21 |
| Table 6. Fruit yields and vine weights, UC-204-B variety. | 23 |
| Table 7. Fruit yields and vine weights, E-6203 variety. | 24 |
| Table 8. Response of processing tomatoes to O ₃ and SO ₂ . | 25 |
| Table 9. Quality tests results on UC-204-B. | 26 |
| Table 10. Quality test results on E-6203. | 27 |
| Table 11. Effects of O ₃ and SO ₂ on quality criteria. | 28 |

SUMMARY AND CONCLUSIONS

Vine weights and fruit yields of two varieties of processing tomatoes, UC-204-B and E-6203, were significantly reduced by ambient oxidant concentrations present at Kearney Agricultural Center, Parlier, California. Exposure to 0.1 ppm SO₂ six hours per day, four days per week also reduced vine and fruit production, but to a much lesser extent than did ambient oxidants. Fruit quality was reduced by increasing levels of ozone, but SO₂ in the concentration used in this experiment had little effect except a slight increase in total solids. The quality differences found, although statistically significant, were not of sufficient magnitude to render the tomatoes unacceptable, although they may be less desired by the processors.

It can be concluded, therefore, that ambient levels of ozone present in the San Joaquin Valley can be detrimental to processing tomato production and quality. Further deterioration of present air quality would probably produce even greater losses in yields and fruit quality. Exposure to SO₂ concentrations of 0.1 ppm for not more than 24 hours per week could result in moderate yield losses but fruit quality would not suffer.

RECOMMENDATIONS

1. Processing tomato acreage in California should be protected by assuring ambient oxidant and SO₂ concentrations do not reach the levels found damaging in this study. At Parlier ambient oxidants would have to be reduced by approximately one-third to accomplish this goal. If the present ozone standard of 0.1 ppm was not exceeded, as it usually is, damage would probably be minimal.
2. The two varieties of processing tomatoes used in this study are considered industry standards representing approximately 45% of the planted acreage but there are over twelve popular varieties with no one other variety accounting for more than 20% of the acreage. It is difficult to estimate how representative these two varieties are of the whole group. A second study using several other varieties would answer this question.
3. The fact that SO₂ in concentrations approximating 0.1 ppm for six hours per day caused measurable crop loss points up the fact that present air quality standards would not protect crops from such exposures - in fact they could receive twice the daily dose which they received in these experiments without exceeding the 24 hour standard of 0.05 ppm. Lowering the standard to 0.05 ppm for six instead of 24 hours would provide the protection.

INTRODUCTION

Processing tomatoes are an important crop in the great Central Valley of California with over 90 percent of the United States production occurring in the area. Approximately 250,000 acres are planted per year with a value of approximately 300 million dollars. Much of the acreage planted to tomatoes is in areas subject to significant air pollution. Oxidants, primarily ozone (O₃) produced photochemically in the atmosphere from unsaturated hydrocarbons and oxides of nitrogen, are the principal pollutants, but sulfur dioxide (SO₂) produced by coal and oil-burning industries may also be a problem in agricultural areas downwind from industrial installations. Table 1 lists the principal tomato-growing counties of California and the acreage involved. Appendix B is a map of California showing the distribution of processing tomatoes grown in the state in 1984.

Table 1. 1983 and 1984 processing tomato acreage in various areas of California*.

| <u>County</u> | <u>Harvested Acreage</u> | |
|---------------|--------------------------|-------------|
| | <u>1983</u> | <u>1984</u> |
| †Colusa | 11,900 | 13,400 |
| Contra Costa | 4,550 | 5,400 |
| †Fresno | 60,500 | 65,850 |
| †Kern | 4,500 | 4,550 |
| †Merced | 7,700 | 4,460 |
| Monterey | 1,600 | 1,560 |
| †Sacramento | 5,400 | 5,150 |
| San Benito | 6,600 | 5,900 |
| †San Joaquin | 26,400 | 22,880 |
| Santa Clara | 2,950 | 1,900 |
| Solano | 11,400 | 13,600 |
| †Stanislaus | 10,000 | 12,250 |
| †Sutter | 16,000 | 16,500 |
| †Yolo | 50,100 | 49,450 |
| Others | 13,900 | 16,850 |

* Source - California Principal Crop and Livestock Report, 1984.

† California Great Central Valley Counties.

Tomatoes are considered relatively sensitive to oxidant-type air pollution with some varieties more sensitive than others (Reinert, 1969, 1972; Oshima et al., 1977a). Results of a two year study of the response of Murrieta processing tomatoes to O_3 , SO_2 and their mixtures conducted by Temple et al. (1985) near Tracy, California (San Joaquin County) as part of the National Crop Loss Assessment Network (NCLAN) program indicated only 4.4% crop loss due to ambient oxidants in 1982 and no loss attributable to ambient O_3 in 1981. There was no response to SO_2 in concentrations up to 0.12 ppm 7 hours per day, 7 days per week and there was no interaction between the two pollutants. A previous study by Oshima and associates (1977b) using fresh market tomatoes growing in 57 liter (15 gal) cans at thirteen field locations in the South Coast Air Basin of California indicated that increasing ozone dose was responsible for a significant reduction in fruit size. Fruit quality criteria other than size were not evaluated in these studies, however. A study of the effects of ozone fumigations on crop composition by Pippen et al. (1975) indicated changes in fruit composition of tomatoes exposed to ozone. Results of their studies, which included five other vegetables, indicated reductions in tomato soluble solids, and vitamins C and B_1 with increasing ozone exposure.

Fruit quality, especially soluble solids, is extremely important in the case of processing tomatoes, with canners and processors contracting on a solids basis and refusing tomatoes with low solids (Tyler and May, 1985). Recent trials conducted by Tyler and May have shown that yields of many of the newer processing tomato varieties respond positively to nitrogen and phosphorus application, and soluble solids are increased by application of nitrogen in amounts formerly considered more than adequate.

OBJECTIVES

The objectives of this study were to determine the effects of realistic concentrations of ozone (O_3) and sulfur dioxide (SO_2) on vegetative growth, fruit yields and fruit quality of two varieties of processing tomatoes.

EXPERIMENTAL DESIGN

Two varieties of processing tomatoes, UC-204-B and E-6203, were direct seeded into prepared beds on April 18, 1985. After germination on or about May 1 the seedlings were thinned to allow approximately 16 plants per row or 48 plants of each variety per plot. In half the replications variety UC-204-B was planted in the east bed and in the southern half of the middle bed (A's in Fig. 1) while E-6203 was planted in the west bed and the north half of the middle bed. In the remaining replications the order was reversed with UC-204-B planted in the west bed and the north half of the middle bed (B's in Fig. 1). After final thinning, on May 28, the plastic chambers were placed over the plots and the blowers started on May 29, 1985. Treatments involving additions of SO_2 or O_3 were begun on June 10 and June 14, respectively. The treatments used are listed in Table 2.

In addition to the treatments imposed on the various chamber-enclosed plots, there were two outside or non-enclosed plots which served as indicators of the chamber effect, which can be significant with some crops and some seasons.

Figure 2 shows the layout of the various plots within the experimental area. The ozone generator was housed in the tool storage shed to the west of the equipment shelter which housed the air sampling and recording equipment.

Table 2. Atmospheric treatments to which tomatoes were exposed in plastic chambers, 1985.

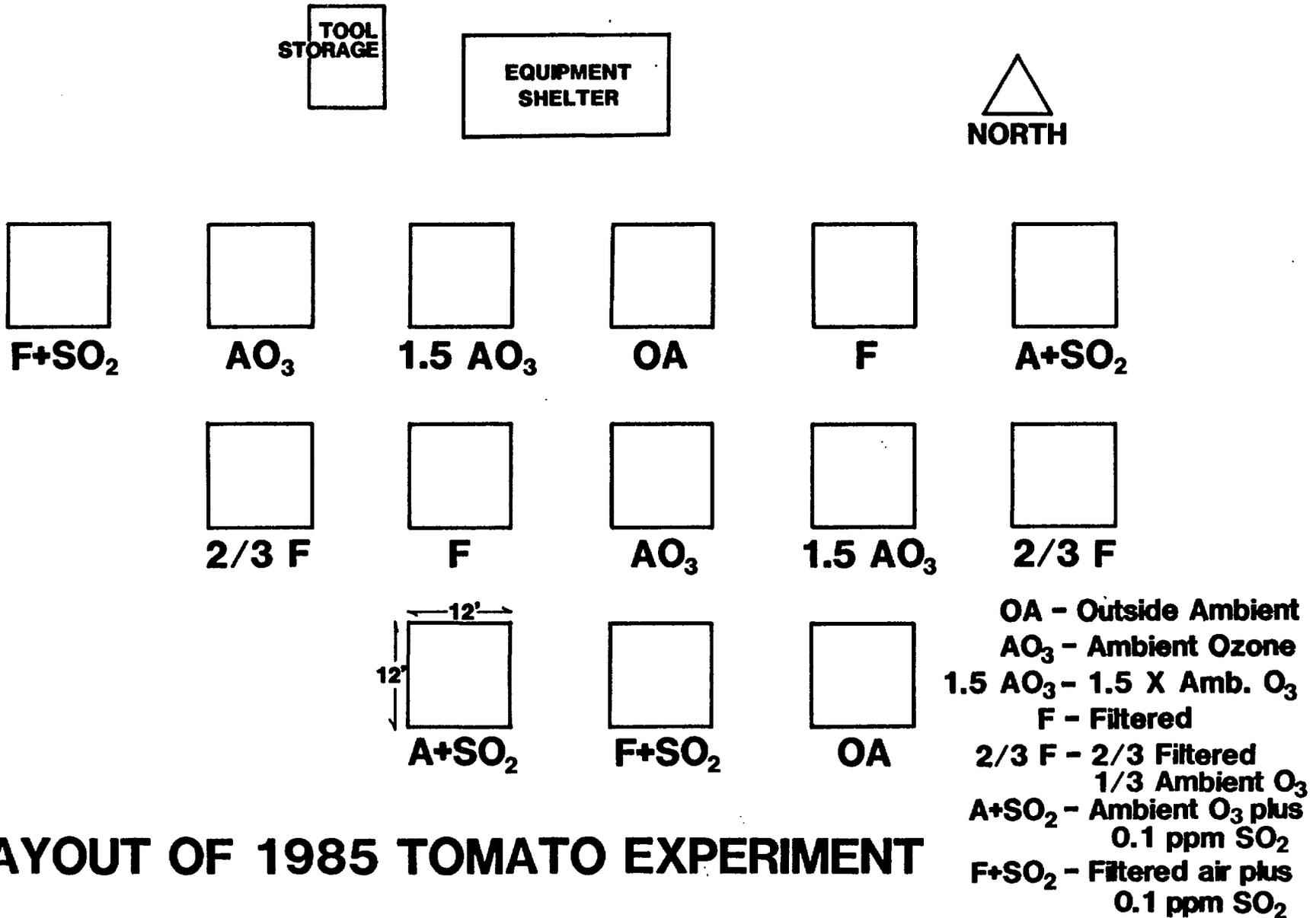
| <u>Treatment</u> | <u>Description</u> | <u>Ozone Level*</u> | <u>SO₂ Concentration</u> |
|------------------|--------------------------------------|---------------------|-------------------------------------|
| 1 | Ambient Air | .90 Ambient | None** |
| 2 | Filtered Air | .25 Ambient | None |
| 3 | 2/3 Filt., 1/3 Amb. Air | .50 Ambient | None |
| 4 | 1.5 Amb. O ₃ Air | 1.50 Ambient | None |
| 5 | 0.1 ppm SO ₂ in Amb. Air | .90 Ambient | 0.1 ppm 6 h/d, 4 d/wk |
| 6 | 0.1 ppm SO ₂ in Filt. Air | .25 Ambient | 0.1 ppm 6 h/d, 4 d/wk |

* Relative to outside ambient air.

** Ambient levels of SO₂ at Parlier were always below the limit of detection (.01 ppm).

The enclosed plots (treatments 1 through 6) were equipped with plastic-covered open top chambers. These plastic chambers, used previously on several crops, were igloo-shaped with twelve foot square bases and 9.5 foot circular openings nine feet above the plot surface. Filtered or non-filtered air was distributed at the floor of the chambers by partially submerged perforated plastic air ducts. Motorized blowers were adjusted to provide approximately 2200 ft³ of air per minute, sufficient to change the enclosed air volume twice per minute. Blowers on chambers fitted with charcoal filters were operated at a higher speed than those on chambers receiving ambient air to compensate for the greater negative static pressure created by the filters. Air flow patterns within the chambers were measured with a hot wire anemometer and blower-filter performance was monitored by inclined oil tube manometers. Changes in static pressure as indicated by the manometers were found to be an excellent early warning indicator of failing motors, loose drive belts and plugged air filters.

Fig. 2



LAYOUT OF 1985 TOMATO EXPERIMENT

CULTURAL PRACTICES AND GROWING CONDITIONS

To assure that results would be representative of field conditions cultural practices and growing conditions were kept as similar to commercial practices as possible within the limitations of the growth chambers and plots. Nitrogen, phosphorus and potassium fertilizers were added to each plot in amounts deemed necessary by the results of soil analyses. Sulfur in the form of calcium sulfate (gypsum) was added to each plot before rototilling to preclude its addition as SO_2 having a beneficial effect due to sulfur deficiency in the soil. Uniform irrigation was provided by dual-wall drip tubing laid hole down between the rows of tomatoes on the raised bed.

Air and soil temperatures within the plots were monitored continuously using copper-constantan (Type T) thermocouples. Relative humidity, light intensities and air movement were measured periodically to insure that conditions were uniform from chamber to chamber and not too unlike outside conditions. Frequent cleansing of the plastic chamber walls with a soft sponge dipped in special cleaning solution kept the plastic walls transparent and minimized dust buildup due to "static cling."

Six hours per day (usually 10:00 a.m. to 4:00 p.m.), 4 days per week anhydrous sulfur dioxide (SO_2) gas, in amounts necessary to maintain the desired concentration of 0.1 ppm, was metered into the airstreams ahead of the motorized blowers on chambers receiving treatments 5 and 6. A Teco SO_2 analyzer measured the actual SO_2 concentrations within the plant zone, and they were recorded on a roll chart potentiometric recorder.

Ozone concentrations were continuously monitored with a Dasibi ozone analyzer and recorded with a second potentiometric recorder. Figures 3 and 4 show typical O_3 concentrations on two days in 1985. Tables 3 and 4 contain

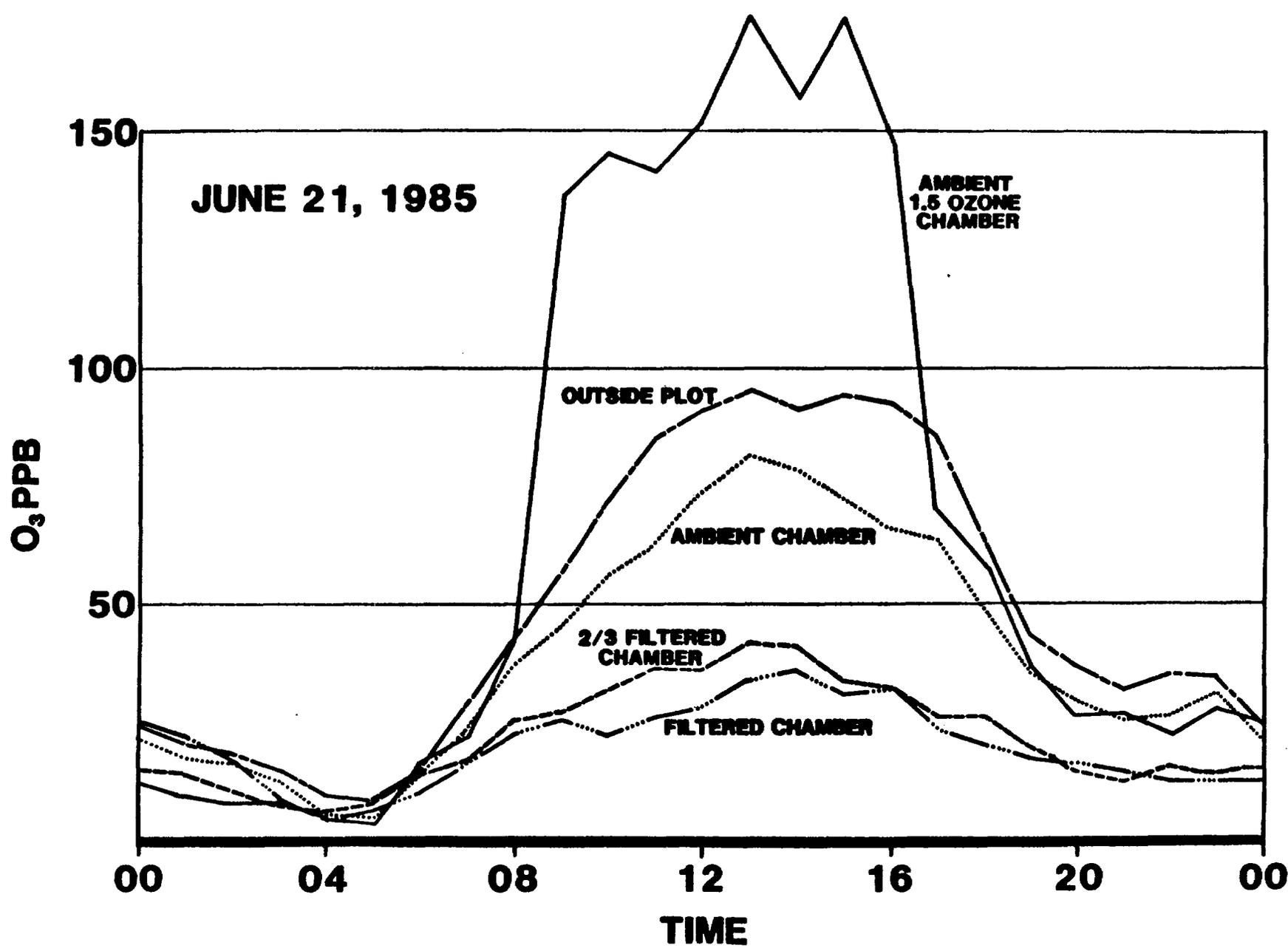


Figure 3. Typical O₃ concentration profiles as measured on June 21, 1985.

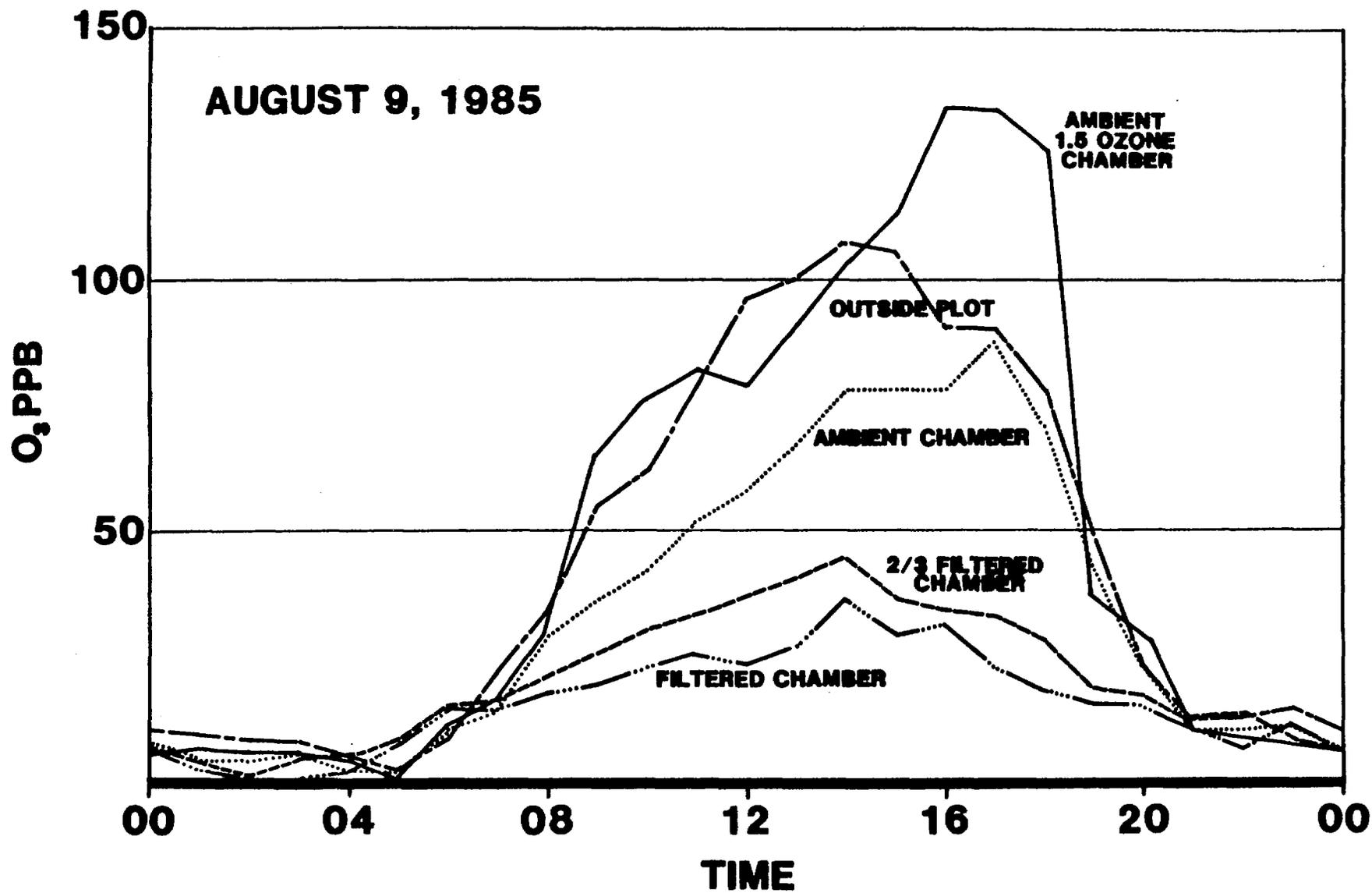


Figure 4. Typical O₃ concentration profiles for the various treatments as measured on August 9, 1985.

Table 3. Sulfur dioxide (SO₂) dosages received by tomatoes, 1985. Doses are based on concentrations measured in the chambers and expressed as parts per hundred million hours (pphm-hrs). Where dose values are listed as "0", no SO₂ was added and ambient concentrations, if present, were below the threshold of detection (.01 ppm) with our equipment.

| <u>Treatment</u> | SO ₂ Dosages | | | | <u>Total</u> |
|---------------------------------|-------------------------|--------------|-------------|-----------------|--------------|
| | <u>May</u> | <u>June*</u> | <u>July</u> | <u>August**</u> | |
| 1 Ambient Air | 0 | 0 | 0 | 0 | 0 |
| 2 Filtered Air | 0 | 0 | 0 | 0 | 0 |
| 3 2/3 Filtered, 1/3 Ambient Air | 0 | 0 | 0 | 0 | 0 |
| 4 1.5 Ambient O ₃ | 0 | 0 | 0 | 0 | 0 |
| 5 Ambient plus SO ₂ | 0 | 720 | 1080 | 840 | 2640 |
| 6 Filtered plus SO ₂ | 0 | 720 | 1080 | 840 | 2640 |
| 7 Outside | 0 | 0 | 0 | 0 | 0 |

* SO₂ generators started June 10.

** SO₂ generators shut off August 26.

listings of the monthly and seasonal SO₂ and O₃ doses, respectively, to which the tomatoes were exposed. Daily peak ambient ozone concentrations to which the tomatoes were exposed are shown in Table 5. Because they were achieved by filtering, the relative ozone concentrations for ambient, filtered and 2/3 filtered were relatively constant. The 1.5 ambient treatment was achieved by adding electrically generated ozone five days per week between the hours of 8:00 a.m. and 6:00 p.m. Ozone additions were manually adjusted hourly based on the prevailing ambient O₃ concentration and the amount required to achieve the 1.5 ambient dose. Because ozone levels over 0.2 ppm (200 pphm) seem to

Table 4. Ozone (O₃) doses based on three thresholds of 0.5, 5.0 and 10.0 pphm O₃ to which tomatoes were exposed in 1985. Dose values are in pphm-hrs.

| <u>Treatment</u> | <u>Description</u> | <u>May*</u> | <u>June**</u> | <u>July</u> | <u>August</u> | <u>Total</u> |
|------------------|----------------------------|-------------|---------------|-------------|---------------|--------------|
| | (<u>> 0.5 pphm</u>) | | | | | |
| 1 | Ambient Air | 2733 | 2479 | 2507 | 2100 | 9819 |
| 2 | Filtered Air | 2566 | 828 | 858 | 715 | 4967 |
| 3 | 2/3 Filtered, 1/3 Ambient | 2617 | 1489 | 1504 | 1256 | 6866 |
| 4 | 1.5 Ambient O ₃ | 2733 | 3433 | 3992 | 3343 | 13501 |
| 5 | Ambient + SO ₂ | 2733 | 2479 | 2507 | 2100 | 9819 |
| 6 | Filtered + SO ₂ | 2566 | 828 | 858 | 715 | 4967 |
| 7 | Outside Plots | 2805 | 3158 | 3218 | 2688 | 11869 |
| | (<u>> 5.0 pphm</u>) | | | | | |
| 1 | Ambient Air | 1084 | 907 | 863 | 743 | 3597 |
| 2 | Filtered Air | 990 | 19 | 3 | 16 | 1028 |
| 3 | 2/3 Filtered, 1/3 Ambient | 1024 | 157 | 131 | 126 | 1438 |
| 4 | 1.5 Ambient O ₃ | 1084 | 1617 | 2275 | 1904 | 6880 |
| 5 | Ambient + SO ₂ | 1084 | 907 | 863 | 743 | 3597 |
| 6 | Filtered + SO ₂ | 990 | 19 | 3 | 16 | 1028 |
| 7 | Outside Plots | 1138 | 1274 | 1255 | 1058 | 4725 |
| | (<u>> 10 pphm</u>) | | | | | |
| 1 | Ambient Air | 40 | 87 | 44 | 53 | 224 |
| 2 | Filtered Air | 38 | 0 | 0 | 0 | 38 |
| 3 | 2/3 Filtered, 1/3 Ambient | 38 | 0 | 0 | 0 | 38 |
| 4 | 1.5 Ambient O ₃ | 40 | 726 | 1137 | 938 | 2841 |
| 5 | Ambient + SO ₂ | 40 | 87 | 44 | 53 | 224 |
| 6 | Filtered + SO ₂ | 38 | 0 | 0 | 0 | 38 |
| 7 | Outside Plots | 42 | 142 | 105 | 94 | 383 |

* Seedling emergence began May 1, but there were few true leaves until May 10.

** Orec ozonator started 6/14/85. Filters installed 5/29/85.

produce acute rather than chronic toxicity symptoms on some crops, ozone concentrations over 0.2 ppm were avoided unless ambient levels exceeded 0.15 ppm, a situation which never occurred during these experiments.

Table 5. Peak ambient ozone concentrations measured during experiment with processing tomatoes, 1985. Concentrations are in pphm and represent one hour means.

| <u>Day</u> | <u>May</u> | <u>June</u> | <u>July</u> | <u>August</u> | <u>Day</u> | <u>May</u> | <u>June</u> | <u>July</u> | <u>August</u> |
|------------|------------|-------------|-------------|---------------|------------|------------|-------------|-------------|---------------|
| 1 | 8.5 | 5.9 | 12.8 | 8.0 | 16 | 7.6 | 12.0 | 9.1 | 9.3 |
| 2 | 8.0 | 4.3 | 11.1 | 8.3 | 17 | 11.5 | 14.7 | 10.6 | 7.9 |
| 3 | 8.8 | 7.5 | 9.9 | 10.5 | 18 | 11.1 | 14.8 | 10.3 | 8.0 |
| 4 | 7.7 | 8.2 | 10.9 | 12.1 | 19 | 9.6 | 10.9 | 8.6 | 7.0 |
| 5 | 10.2 | 8.9 | 10.2 | 11.2 | 20 | 7.0 | 8.8 | 8.6 | 9.1 |
| 6 | 10.2 | 9.0 | 10.7 | 9.0 | 21 | 5.0 | 9.9 | 10.3 | 10.8 |
| 7 | 11.3 | 9.1 | 7.7 | 10.0 | 22 | 5.5 | 10.6 | 10.1 | 9.0 |
| 8 | 10.0 | 9.7 | 9.6 | 9.2 | 23 | 3.9 | 10.4 | 9.4 | 12.3 |
| 9 | 9.1 | 9.9 | 11.1 | 12.1 | 24 | 7.1 | 9.3 | 11.2 | 12.6 |
| 10 | 9.8 | 14.1 | 9.9 | 13.3 | 25 | 8.8 | 9.9 | 11.3 | 12.1 |
| 11 | 8.5 | 10.7 | 9.2 | 8.3 | 26 | 7.5 | 9.2 | 10.6 | 10.0 |
| 12 | 6.6 | 13.7 | 11.5 | 10.6 | 27 | 6.6 | 10.1 | 10.6 | - |
| 13 | 5.3 | 13.7 | 10.4 | 8.4 | 28 | 6.8 | 9.3 | 9.2 | - |
| 14 | 9.5 | 11.7 | 9.4 | 9.1 | 29 | 9.2 | 8.1 | 7.3 | - |
| 15 | 7.8 | 11.5 | 10.7 | 10.2 | 30 | 10.4 | 10.1 | 7.9 | - |
| | | | | | 31 | 7.1 | - | 5.9 | - |

RESULTS AND DISCUSSION

Both varieties grew very well in the growth chambers, although vegetative growth was somewhat greater in the outside plots due to a lack of walls which restricted spreading of the enclosed plants. Mild foliar chlorosis and some necrosis appeared on foliage in plots receiving the 1.5 ambient O₃ and SO₂ treatments. Some difficulty maintaining adequate moisture during very hot periods was experienced in plot 1 (receiving treatment 6) as had been the case in previous experiments with cotton. Evidently the subsoil below 24 inches is so coarse below this plot that moisture storage is limited. This plot was reworked to a depth of 24 inches in 1979 in an attempt to correct this situation, but replacing the 12 to 24 inch subsoil layer did not completely solve the problem.

The blowers were turned off on August 26, 1985 and harvesting begun. The vines were cut off at ground level, all of the fruit were removed, and the fruit were then sorted into three categories - red fruit, green fruit and cull fruit (mostly due to splitting or rot). Each of the varieties were harvested separately. No attempt was made to pick individual vines because they were so badly intertwined. After removing the fruit the green vines were weighed, as were the three lots of fruit (reds, greens and rots). One approximately 25 kg bin of ripe fruit was hand counted to establish average fruit weight as an indicator of fruit size. Ten pound subsamples of ripe fruit representing each variety from each plot were taken for laboratory analysis. This subsample was kept refrigerated between picking and delivery to the Tomato Quality Lab at U.C. Davis. Harvest data for variety UC-204B are summarized in Table 6. Similar data for variety E-6203 are in Table 7.

Table 6. Fruit yields and fresh vine weights of UC 204B variety tomatoes exposed to various air treatments, 1985. Values are treatment means per plot.

| Treatment description | Vine weight (kg) | Fruit Yields (kg) | | | | |
|----------------------------|---------------------|-------------------|---------------------|--------------|--------|---------------|
| | | Red (R) | Green (G) NS* | Rots (Rt) | R+G | R,G+Rt NS* |
| 1 Ambient | 33.0cd** | 36.8c | 26.4 | 9.1b | 63.2ab | 72.3 |
| 2 Filtered | 41.7a | 59.9ab | 26.8 | 9.0b | 86.8a | 95.8 |
| 3 2/3 Filt. 1/3 Amb. | 39.1ab | 63.4a | 20.4 | 8.8b | 83.9a | 92.7 |
| 4 1.5 Ambient | 35.1cd | 34.6c | 16.7 | 10.9b | 51.5b | 62.4 |
| 5 Ambient+SO ₂ | 29.3d | 46.9b | 14.3 | 7.5b | 61.2ab | 68.7 |
| 6 Filtered+SO ₂ | 36.8bc | 55.0ab | 15.8 | 8.3b | 70.8a | 79.1 |
| 7 Outside plots | 37.3bc | 46.7b | 26.0 | 17.9a | 72.7a | 90.7 |

* Analysis of variance indicated differences due to treatment were not significant at 95% confidence level.

** Mean values not sharing the same subscript letter are significantly different at 5% level using Duncan's Multiple Range Test.

All of the yield and fruit quality data were subjected to an analysis of variance and then, if the variance due to treatment was significant, to Duncan's multiple range test to determine ranking.

Table 7. Fruit yields and fresh vine weights of E-6203 variety processing tomatoes exposed to various air treatments, 1985.

| <u>Treatment description</u> | <u>Vine weight (kg)</u> | <u>Fruit Yields (kg)</u> | | | | <u>R,G+Rt</u> |
|------------------------------|-----------------------------|--------------------------|----------------------|----------------------|------------|---------------|
| | | <u>Red (R)</u> | <u>Green (G)</u> | <u>Rots (Rt)</u> | <u>R+G</u> | |
| | | | | | | NS* |
| 1 Ambient | 33.4ab** | 52.4bc | 27.5a | 9.6b | 79.9a | 89.5 |
| 2 Filtered | 35.4a | 64.3ab | 16.2b | 9.1b | 80.5a | 89.6 |
| 3 2/3 Filt. 1/3 Amb. | 29.9abc | 65.1ab | 14.8b | 11.6b | 79.8a | 91.5 |
| 4 1.5 Ambient | 25.4d | 38.4c | 9.2b | 10.8b | 47.6b | 58.5 |
| 5 Ambient+S0 ₂ | 27.9cd | 49.5bc | 10.9b | 9.2b | 60.4ab | 69.7 |
| 6 Filtered+S0 ₂ | 26.4cd | 40.3c | 15.8b | 8.2b | 56.1ab | 64.3 |
| 7 Outside plots | 30.9abc | 74.7a | 14.1b | 16.2a | 88.8a | 105.1 |

* Analysis of variance indicated differences due to treatment were not significant at 5% level.

** Mean values not sharing the same subscript letter are significantly different at 5% level using Duncan's Multiple Range Test.

It is very evident from an analysis of the above data that ambient ozone concentrations had a much greater impact on processing tomato production than did the S0₂ exposures utilized in these experiments. Table 8 presents a summary of the responses to O₃ and S0₂ expressed as a percentage of the production in the chambers receiving filtered air or no S0₂. This comparison lumps the two varieties together and includes data from all plots receiving the level of O₃ or S0₂ indicated except that data from the high ozone plots are not averaged in the no sulfur added values.

It is difficult to directly compare the results of this study with the previous study with "Murrieta" variety processing tomatoes conducted by Temple et al. near Stockton in 1981 and 1982. The 20.5% crop loss, which they

Table 8. Response by two varieties of processing tomatoes to differences in O_3 and SO_2 concentrations. Percent loss values are relative to production in filtered air in the case of O_3 and to no SO_2 added in case of SO_2 . Values in parentheses in bottom row represent are the values with data from chamber one excluded.

| Factor | Level | Vine weight % loss | Tomato Production | |
|--------|-------------|-----------------------|---------------------|-----------------------|
| | | | Red fruit % loss | Total fruit % loss |
| O_3 | .25 Ambient | 0 | 0 | 0 |
| | .50 Ambient | 10 | 2 | 1 |
| | Ambient | 20 | 26 | 19 |
| | 1.5 Ambient | 21 | 43 | 35 |
| SO_2 | None* | 0 | 0 | 0 |
| | 0.1 ppm** | 15 (7) | 26 (2) | 21 (8) |

* SO_2 concentrations always below detectable level of .01 ppm.

** Concentration maintained 6 hours per day, 4 days per week.

reported for 1982 with their highest ozone level, (1.5 times ambient) would agree with our 21% crop reduction with ambient air because Parlier ozone concentrations are generally about 50% higher than those reported for Modesto. Our finding that 0.1 ppm SO_2 reduced vine weights 7 to 15% and fruit production 8 to 21% contrasts with their failure to measure an effect on tomatoes at SO_2 concentrations as high as 0.12 ppm, but did measure effects at .23 ppm. These differences in response by tomatoes may be due to differences in variety, or in other environmental conditions such as sulfur content of the soil, humidity, or air temperatures.

It is interesting to note that although fruit production was approximately 17% less with the high ozone treatment than with ambient ozone, vine weights were approximately the same. This would suggest that high ozone levels may be limiting flower production and/or pollination. It may also be causing abortion of pollinated flowers, which seems to be the case often times with cotton. A comprehensive study of ozone levels as they influence blossom production and set would answer this question.

Fruit Quality

Results of fruit quality determinations made on samples taken to the Tomato Quality Laboratory, University of California, Davis are summarized in Table 9 and 10 for varieties UC 204B and E6203, respectively.

Table 9. Results of quality determinations made on UC 204B fruit samples from various air pollution treatments, 1985.

| <u>Treatment Description</u> | <u>Fruit size^{1/}</u> NS | <u>Brix</u> NS | <u>pH</u> NS | <u>Citric acid</u> NS | <u>Agtron color index*</u> NS | <u>Viscosity</u> NS | <u>WIS/TS^{2/}</u> NS |
|------------------------------|--------------------------------------|-------------------|-----------------|--------------------------|----------------------------------|------------------------|----------------------------------|
| 1 Ambient | 29.0 | 4.45 | 4.20 | 5.05 | 25.8 | 5.24 | .157 |
| 2 Filtered | 29.0 | 4.40 | 4.37 | 4.65 | 30.9 | 5.15 | .152 |
| 3 2/3 Filt. 1/3 Amb. | 25.0 | 4.55 | 4.24 | 5.10 | 25.6 | 5.23 | .137 |
| 4 1.5 Amb. O ₃ | 27.5 | 4.00 | 4.29 | 5.10 | 25.9 | 4.62 | .140 |
| 5 Amb.+SO ₂ | 24.5 | 4.40 | 4.24 | 5.45 | 27.4 | 5.27 | .152 |
| 6 Filt.+SO ₂ | 24.0 | 5.10 | 4.21 | 5.50 | 26.3 | 5.89 | .143 |
| 7 Outside | 26.0 | 4.45 | 4.20 | 4.75 | 23.8 | 5.30 | .167 |

* Color index equals $\frac{\text{Green color intensity}}{\text{Red color intensity}} \times 48$

^{1/} Number of fruit per 2 kg sample.

^{2/} Ratio of water insoluble solids to total solids.

NS - Analysis of variance indicated differences due to treatment were not significant at 5% level.

Table 10. Results of quality determinations made on E6203 variety fruit samples from various air pollution treatments, 1985.

| <u>Treatment Description</u> | <u>Fruit size</u> ^{1/} NS | <u>Brix</u> NS | <u>pH</u> NS | <u>Citric acid</u> | <u>Agtron color index</u> * NS | <u>Viscosity</u> NS | <u>WIS/TS</u> ^{2/} NS |
|------------------------------|---------------------------------------|-------------------|-----------------|--------------------|-----------------------------------|------------------------|-----------------------------------|
| 1 Ambient | 25.5 | 4.70 | 4.37 | 4.62a** | 24.3 | 5.55 | .161 |
| 2 Filtered | 29.5 | 4.95 | 4.46 | 4.15c | 19.8 | 6.04 | .132 |
| 3 2/3 Filt. 1/3 Amb. | 27.5 | 4.80 | 4.44 | 4.27bc | 21.3 | 5.51 | .135 |
| 4 1.5 Amb. O ₃ | 28.0 | 4.30 | 4.48 | 4.57ab | 18.7 | 4.91 | .130 |
| 5 Amb.+SO ₂ | 28.5 | 5.15 | 4.44 | 4.35abc | 18.7 | 6.01 | .152 |
| 6 Filt.+SO ₂ | 31.0 | 5.30 | 4.46 | 4.62a | 19.8 | 6.04 | .132 |
| 7 Outside | 28.0 | 4.85 | 4.44 | 4.22c | 20.6 | 5.64 | .148 |

* Color index equals $\frac{\text{Green color intensity}}{\text{Red color intensity}} \times 48$

** Means not sharing the same subscript letter are significantly different at 5% level using Duncan's Multiple Range Test.

1/ Number of fruit per 2 kg sample.

2/ Ratio of water insoluble solids to total solids.

NS - Analysis of variance indicated differences due to treatment were not significant at 95% confidence level.

Although there seem to be indications of responses in fruit quality to air pollution, only a few of the mean differences in Tables 9 and 10 were found statistically significant in an Analysis of Variance of the data from individual varieties. Only two replications per treatment places extreme stress on the requirements for statistical significance. When the data from both varieties were pooled, as has been done in Table 11, the number of replications are doubled (or tripled in some cases) and the differences between means required for statistical significance are reduced substantially.

A comparison of tomato fruit quality in our experimental plots with similar data from the field can be made by referring to data published by the

U.C. Davis Dept. of Food Science and Technology for the 1985 Tomato Variety Trials (Appendix A). All of the values found in our samples lie within the range of values reported by the U.C. Davis group and therefore would be acceptable. The lack of acid, red color and low viscosity associated with high ozone (1.5X A) would all be considered less desirable, even though within the acceptable range.

It would appear from an analysis of the data in Table 11 that high ozone and 0.1 ppm SO₂ can influence soluble solids (Brix), ozone reducing the solids; SO₂ increasing them. High ozone also reduced viscosity, an important indicator of processing behavior. Neither ozone level, within the ranges used in this experiment, or SO₂ had any significant impact on product consistency as indicated by the ratio of water insoluble solids to total solids. Both

Table 11. The effects of ozone and sulfur dioxide on quality criteria of processing tomatoes - combination of data for two varieties E6203 and UC 204B) and all plots receiving a given O₃ or SO₂ level.

| <u>Factor</u> | <u>Level</u> | <u>Fruit size</u> NS | <u>(Brix)</u> | <u>pH</u> | <u>Citric acid</u> NS | <u>Agtron color</u> | <u>Viscosity</u> | <u>WIS/TS</u> |
|-----------------|--------------|-------------------------|---------------|-----------|--------------------------|---------------------|------------------|---------------|
| Ozone | .25 Ambient | 29.2 | 4.68b | 4.37b | 4.73 | 26.70a | 5.35a | .136 |
| | .50 Ambient | 26.2 | 4.67b | 4.34b | 4.68 | 23.45ab | 5.37a | .136 |
| | Ambient | 26.9 | 4.67b | 4.31b | 4.87 | 24.05ab | 5.52a | .161 |
| | 1.5 Ambient | 27.7 | 4.15c | 4.88a | 4.78 | 22.30b | 4.77b | .135 |
| SO ₂ | None* | 27.8 | 4.64b | 4.41ab | 4.65 | 23.67ab | 5.40a | .142 |
| | 0.1 ppm** | 29.9 | 4.99a | 4.34b | 4.98 | 23.05ab | 5.81a | .150 |

* SO₂ concentrations always below detectable level of 0.01 ppm.

** SO₂ concentration of 0.1 ppm maintained 6 hours per day, 4 days per week.

NS - Analysis of variance indicated treatment differences were not significant at 5% level. Means not sharing the same subscript letter were significantly different at 5% level using Duncan's Multiple Range Test.

soluble solids (Brix) and WIS/TS ratios have been found to correlate with the tendency of homogenized catsups and tomato pastes to separate upon standing (Marsh, Wolcott and Merson, 1986). A processing tomato product with higher viscosity is preferred for catsup and paste production because less energy is required to achieve the desired consistency.

An analysis of the combined data presented in Table 11 indicates significant impacts of both ozone and SO₂ on several parameters effecting tomato fruit quality. Brix (soluble solids) was reduced by ozone at the 1.5 ambient level and increased by exposure to 0.1 ppm SO₂. Viscosity was also reduced by the high ozone level. The results of the WIS/TS consistency tests are difficult to assess because there is no clear correlation with O₃ or SO₂ concentrations. The TS (total solids) represents the complete solids content determined by drying the tomato serum to dryness in a microwave oven-balance device. The SS (soluble solids) is similarly determined by drying a previously centrifuged sample. The WIS (water insoluble solids) is equal to the difference between TS and SS, and the WIS/TS ratio is found using the formula:

$$\text{WIS/TS} = \frac{100 \times (\text{TS} - \text{SS})}{\text{TS}}$$

Ambient levels of ozone and the addition of 0.1 ppm SO₂ six hours per day four days per week seemed to increase the WIS/TS ratio. Fruit from the high ozone treatment (1.5 x Ambient O₃), however, were not significantly different in this respect from the fruit from filtered and 2/3 filtered treatment plots. A combination of the viscosity and WIS/TS ratio has been found to be an accurate indicator of the tendency for tomato serum to separate upon standing. The higher the viscosity and/or the WIS/TS ratio the less tendency there is for

the serum to separate and the less the serum must be concentrated by cooking or evaporation to obtain a stable product such as catsup or tomato paste.

It was previously mentioned that heavy applications of nitrogen fertilizers can increase both yields and soluble solids in processing tomatoes. Presumably, then, heavier than usual applications of nitrogen could be used to offset the observed reductions in soluble solids (Brix) associated with high ozone levels.

REFERENCES

1. Reinert, R. A., D. T. Tingey and H. B. Carter. 1969. Varietal sensitivity of tomato and radish to ozone. *HortScience* 4:189.
2. Reinert, R. A., D. T. Tingey and H. B. Carter. 1972. Sensitivity of tomato cultivars to ozone. *J. Amer. Soc. Hort. Sci.* 97:149 & 151.
3. Temple, Patrick J., Kris A. Surano, Randall G. Mutters, Gail E. Bingham and Joseph H. Shinn. 1985. Air Pollution Causes Moderate Damage to Tomatoes. *California Agriculture*, Vol. 39, Nos. 3 & 4, p. 21-22.
4. Oshima, R. J., P. J. Braegelmann, D. W. Baldwin, V. Van Way and O. C. Taylor. 1977. Responses of five cultivars of fresh market tomato to ozone: A contrast of cultivar screening with foliar injury and yield. *J. Amer. Soc. Hort. Sci.*, 102(3):286-289.
5. _____ . 1977. Reduction of tomato fruit size and yield by ozone. *J. Amer. Soc. Hort. Sci.*, 102(3):289-293.
6. Pippen, E. L., A. L. Patter, V. G. Randall, K. C. Ng, F. W. Reuter, A. I. Morgan, Jr., and R. J. Oshima. 1975. Effect of ozone fumigation on crop composition. *J. Food Sci.* 40:672-676.
7. Tyler, K. B. and D. M. May. 1986. Research points way to high tomato solids. California-Arizona Farm Press.
8. Marsh, G. L., T. K. Wolcott, and R. L. Merson. 1986. (Results of) 1985 Processing Tomato Variety Trials. University of California, Davis, Department of Food Science and Technology. 25 pp.

1985 Tomato Variety Trials
Lab Results for Unheated Juice

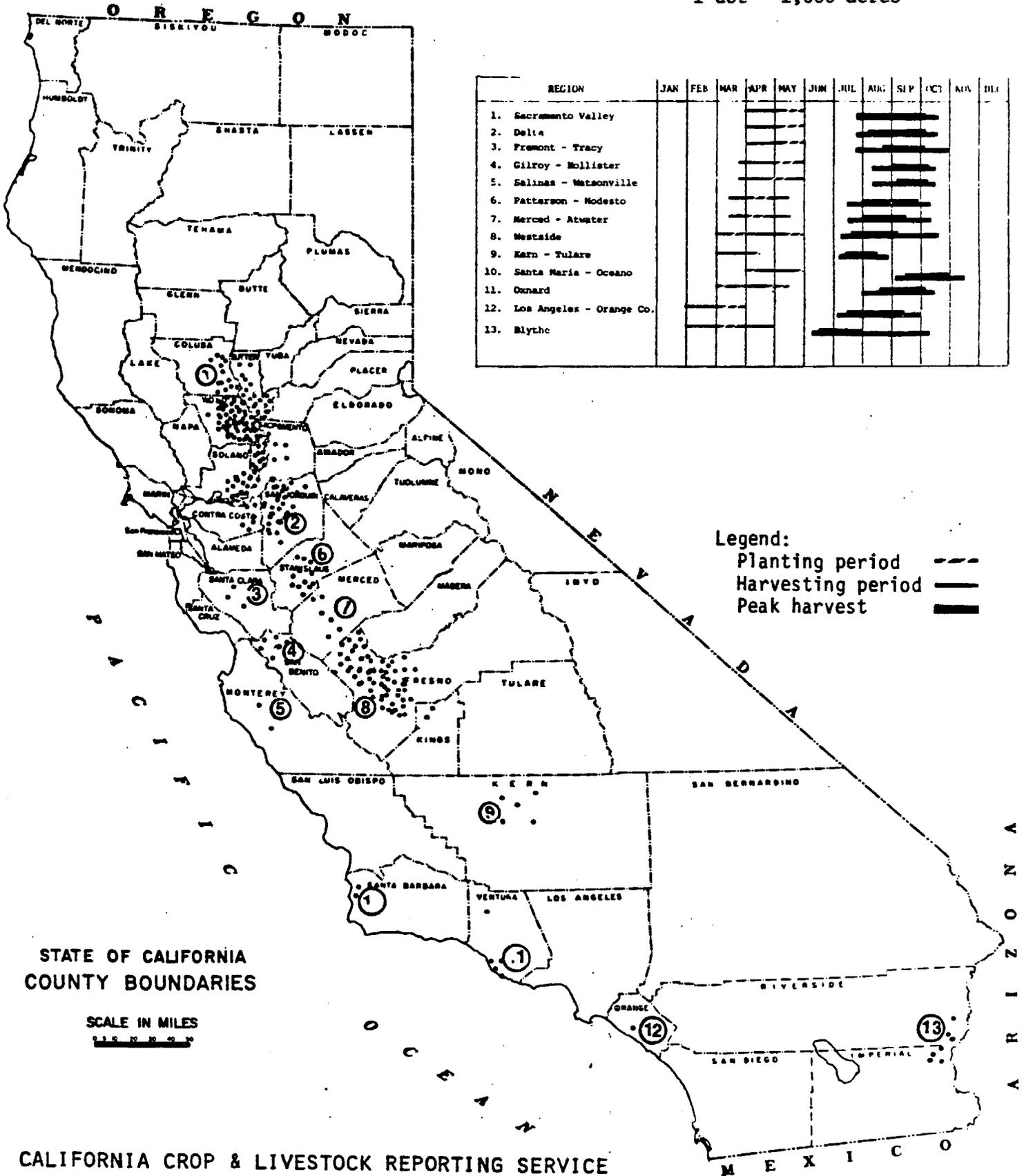
| Variety | Total Solids (%) | Soluble Solids Serum | Agtron E5M Color Index | pH | Total Acid (% citric) | WIS/TS | Serum Viscosity |
|----------------|------------------|----------------------|------------------------|------|-----------------------|--------|-----------------|
| FM 789 | 4.90 | 4.40 | 34.5 | 4.21 | 0.36 | 0.149 | 4.50 |
| SR 443 | 5.18 | 4.70 | 33.0 | 4.26 | 0.34 | 0.159 | 4.34 |
| PGI 1101 | 6.07 | 5.60 | 31.0 | 4.30 | 0.42 | 0.151 | 4.70 |
| Nema 1200 | 5.69 | 5.20 | 31.5 | 4.25 | 0.38 | 0.133 | 3.16 |
| Peto 343 | 6.28 | 5.55 | 30.5 | 4.15 | 0.36 | 0.128 | 4.13 |
| Nema 1400 | 5.92 | 5.40 | 31.0 | 4.30 | 0.39 | 0.144 | 4.29 |
| <u>E6203</u> | 6.13 | 5.45 | 29.0 | 4.33 | 0.40 | 0.161 | 5.67 |
| FM 785 | 6.44 | 5.90 | 32.0 | 4.28 | 0.43 | 0.155 | 4.21 |
| GS 1131 | 5.77 | 5.00 | 31.0 | 4.20 | 0.43 | 0.162 | 5.52 |
| Murrieta | 6.43 | 5.70 | 30.0 | 4.27 | 0.39 | 0.152 | 5.46 |
| HM 3075* | 6.01 | 5.40 | 31.0 | 4.12 | 0.43 | 0.149 | 7.90 |
| <u>UC 204C</u> | 5.75 | 5.15 | 29.0 | 4.24 | 0.39 | 0.165 | 6.86 |

* formerly Diego

From Marsh G. L., T. K. Wolcott, and R. L. Merson. 1986. (Results of) 1985 Processing Tomatoes Variety Trials. University of California, Davis, Department of Food Science and Technology. 25 pp.

TOTAL ACREAGE = 249,835

1 dot = 1,000 acres



STATE OF CALIFORNIA
COUNTY BOUNDARIES

SCALE IN MILES
0 10 20 30