Final Report to the
California Air Resources Board
(Research Contract A7-141-30)

THE IMPACT OF SULFUR DIOXIDE ON A PROCESSING TOMATO STRESSED WITH CHRONIC AMBIENT OZONE

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ABSTRACT

This study was designed to identify growth and yield responses of VF 145B-7879 processing tomato plants from ambient ozone and varying SO_2 exposures. The definition of possible interactions between the two gases was of greatest interest. A 3 x 3 factorial Anova design was therefore used to detect potential interactive responses.

Only sulfur dioxide exposures significantly affected yield reduction in this study. Both the ozone and O_3 x SO_2 terms were not significant in the Anova analysis. When the O_3 x SO_2 interaction term was partitioned to further scrutinize possible interactive effects, only a single complex interaction was weakly significant. The SO_2 quadratic-O_3 quadratic term was statistically significant (.05 level) but questionable in biological terms because of the nonuniformity of yield data in the two SO_2 treatments.

Intermittent SO_2 exposures of 10 and 20 pphm reduced marketable yields (weight of red and breaker fruit) of tomato by 16 and 20%, respectively. However, there was no statistical basis to separate the 16 and 20% reductions and they must be regarded as equivalent. SO_2 exposures did not influence fruit quality parameters (e.g., pH, pulp color).

Ozone did not influence tomato yield or quality in the factorial design, but foliar injury was observed in plants exposed in chambers to 25% filtered to 75% nonfiltered ambient air. Commercial yields from ambient plots, not enclosed in exposure chambers and independent of the factorial design, were reduced 66% when compared to the 100% filtered ambient air treatment. Plant dry weight, fruit pulp color and fruit size were also deleteriously influenced in ambient plot tomatoes. The ambient ozone dose during this study was 11,671 pphm-hrs. In Riverside, characterized by high ambient ozone and low SO_2 levels, the three highest ambient SO_2 and ozone one-hour average concentrations were 5, 6 and 8 pphm and 23, 27 and 28 pphm, respectively.

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CONCLUSIONS

Adverse effects of ozone in the the total oxidant complex in ambient air were detected only on the ambient air treatments where tomato plants were grown outside the Teflon covered chambers. The reduced commercial yield of 66%, reduced fruit size and plant dry weight may be attributed largely to the total ozone dosage of 11,671 pphm-hrs but it should be recognized that other factors unknown to us may have played an important role in the plant response. The dosage (concentration x time) of ozone was by design considerably less in the chambers than in ambient air and the peak concentrations were also lower with correspondingly lower hourly averages. On three dates reported in Table 16, one-hour ambient concentrations were 27, 23 and 28 pphm, respectively, while none of the chambers exceeded 17 pphm. The possibility that peak concentrations may have equal or greater influence on plant response than total dose must be considered.

The limitation of evaluating adverse plant response to the ambient treatment may also be related to differences in the chamber environment compared to the nonenclosed treatment. Air temperatures were comparable between these treatments but the mean relative humidity was less outside the chambers. Although it was concluded that photosynthetically active radiation transmission into the chambers was not a limiting factor, the fact that the mean flux for the ambient treatment was about 15% greater than the mean flux in the chambers may have influenced plant response to the ozone treatment.

Intermittent exposure to 10 and 20 pphm SO_2 decreased commercial yield. The fumigated levels were substantially higher than ambient SO_2 levels which could be characterized by the three highest one-hour values of 5, 6 and 8 pphm. The plant response to SO_2 treatment in these experiments should not be compared directly with the federal secondary standard.

The federal standard is based on a 3-hour average and the treatments in this experiment were 10 or 20 pphm for 6 hours on 5 successive days with at least 4 instances when the treatment continued for 24 hours. However, it should be noted that concentrations (40 pphm) during this experiment did not exceed either the primary or secondary federal SO_2 ambient air quality standards.

RECOMMENDATIONS

Further studies with VF 145B-7879 tomato should be run to more clearly define the response of this cultivar to SO_2 exposures. This particular cultivar was selected because of its importance to the tomato industry of California but studies with other cultivars should be run since the genetic variability of tolerance to ozone is well-known.

Future experiments with VF 145B-7879 tomato should include a treatment with 100% nonfiltered air within the Teflon chambers. Such a treatment would help to substantiate the finding reported here that a marked decrease in yield and plant growth was truly due to the ozone dosage or concentration and was not unduly influenced by the chambers. Experiments with 100% nonfiltered air would also help to determine if periodic peak concentrations exceeding about 20 pphm are critical in the production and growth reduction responses. It may well be that plant response was related as much or perhaps more to the incidents during a particular stage of growth when ozone exceeded some critical concentration than to the dose during the growing season.

The range of experimental parameters used in factorial designs should encompass peak concentrations and/or dosages which insure a measurable response to make the design effective for analysis. Experiments of the type reported here should have one treatment of ozone within the chambers that would assure measurable reduced growth and production or reduced fruit quality even though the focus is on determining the response to realistic dosages. If it is unlikely that ambient concentrations or dosages will be sufficient to produce such response, the addition of synthesized ozone at intervals should be considered.

SUMMARY

The basic 3 x 3 factorial design using 100, 75 and 50% filtered to nonfiltered ambient air and 0, 10 and 20 pphm SO_2 with two replications of each treatment was used to study the response of VF 145B-7879 tomato plants to SO_2 and ozone. This design was used for Factorial Analysis of Variance of the response data.

To define the ozone dose response, results from the factorial design were supplemented by data from two replicates which received 25% filtered to 75% nonfiltered ambient air and two ambient air treatments that were not enclosed in chambers for the regression design.

Significant results obtained from the study included:

1. Ozone type injury to foliage was observed only on the plants in 25% filtered to 75% nonfiltered ambient air and on plants growing outside chambers in ambient air.

2. In the factorial design experiment no oxidant (ozone) effect on tomato plants was detected.

3. Fumigation with 10 and 20 pphm SO_2 significantly reduced commercial yield but there was no statistically significant difference between the 10 and 20 pphm treatments.

4. Ambient air treatment of plants growing outside the Teflon covered chambers receiving the highest ozone exposure had a reduced commercial yield, reduced number of red and breaker tomatoes, reduced pulp color below acceptable canning standards and reduced plant dry weight. Thus, the crops would have been a total loss to a grower.

I. INTRODUCTION

This study was designed to determine yield and quality responses of a commercial variety of processing tomato to ozone and SO_2 exposure and define possible interactions between the two gases. The experiment was conducted in an ambient fumigation facility which has been documented to be comparable to the ambient environment (5). Processing tomatoes represent an economically important crop grown throughout California, having a cash value of $336,951,000 in 1978. Ozone levels were selected to represent the low to moderate ambient levels in production areas.

Ozone and SO_2 have been reported to interact to produce both antagonistic and synergistic foliar injury responses (3, 6, 7). The ozone x SO_2 interaction has also been demonstrated in terms of reduced biomass and yield on red kidney bean (4). However, the character of the interactive responses with foliar injury and yield conflicted. Red kidney bean foliar injury has been described as antagonistic with an ozone/SO_2 mixture (2) while yield responses were synergistic in a different study. The lack of correlation between foliar and yield responses therefore provided little to explain combined gas effects.

This experiment utilized a 3 x 3 factorial anova design replicated twice with three levels of ozone (100, 75 and 50% filtered to 0, 25, and 50% nonfiltered ambient air by volume) and three levels of SO_2 (0, 10 and 20 pphm). Two 25% filtered treatments and two ambient plots were also incorporated in the study so that regression analyses could be used as a second method of data analysis. In all, 20 chambers and two outside plots were used.

II. MATERIALS AND METHODS

Experimental Design

Two experimental designs were incorporated into this experiment:

1. The basic design was a 3 x 3 Factorial Analysis of Variance (Anova) using 100, 75 and 50% filtered to 0, 25 and 50% nonfiltered ambient air by volume and 0, 10 and 20 pphm SO_2 with two replications of each treatment.

2. A regression design using plant response at 100, 75, 50, and 25% filtered to 0, 25, 50 and 75% nonfiltered ambient air and at ambient air (outside plots) was also used to determine the ozone dose-response of VF 145B-7879 processing tomatoes. This design incorporated the 100, 75 and 50% filtered treatments of the preceding Anova design.

Ambient Fumigation Facility

An ambient fumigation facility constructed in 1977 under ARB contract A6-162-30 was used for the experiment.

1. General Schematic (Figure 1)

The facility consists of 20 Teflon covered exposure chambers divided into two replicate 10-chamber sets. Each set of chambers is connected to a common air handling system, consisting of ambient and filtered ducts. An instrument enclosure is centrally located between chamber sets to minimize sampling line lengths.

2. Air Handling System (Figure 2)

This system consists of two sets of two backward-curved blowers powered by 2 H.P. 220 V motors. Each set consists of a filtered (three-2′ x 2′ x 8" activated carbon filters) and an unfiltered blower, central underground plenums of 12" PVS (polyvinyl-coated steel spirallok pipe), and 6" PVS pipes with butterfly valves leading to each of 10 chambers. All PVS pipe, electrical, and water lines, and butterfly valves are underground.

Figure 1. General Schematic of Fumigation Facility

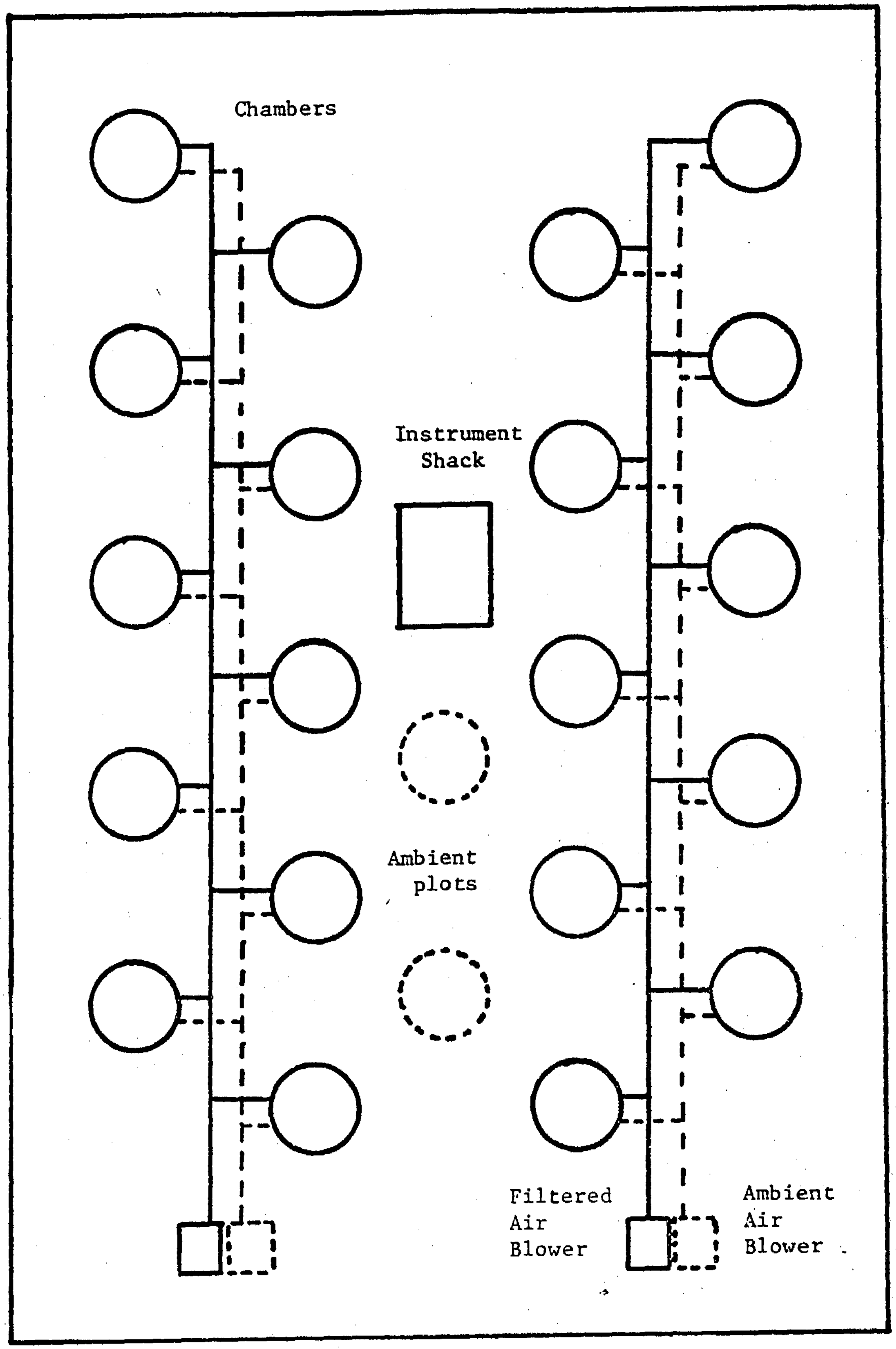
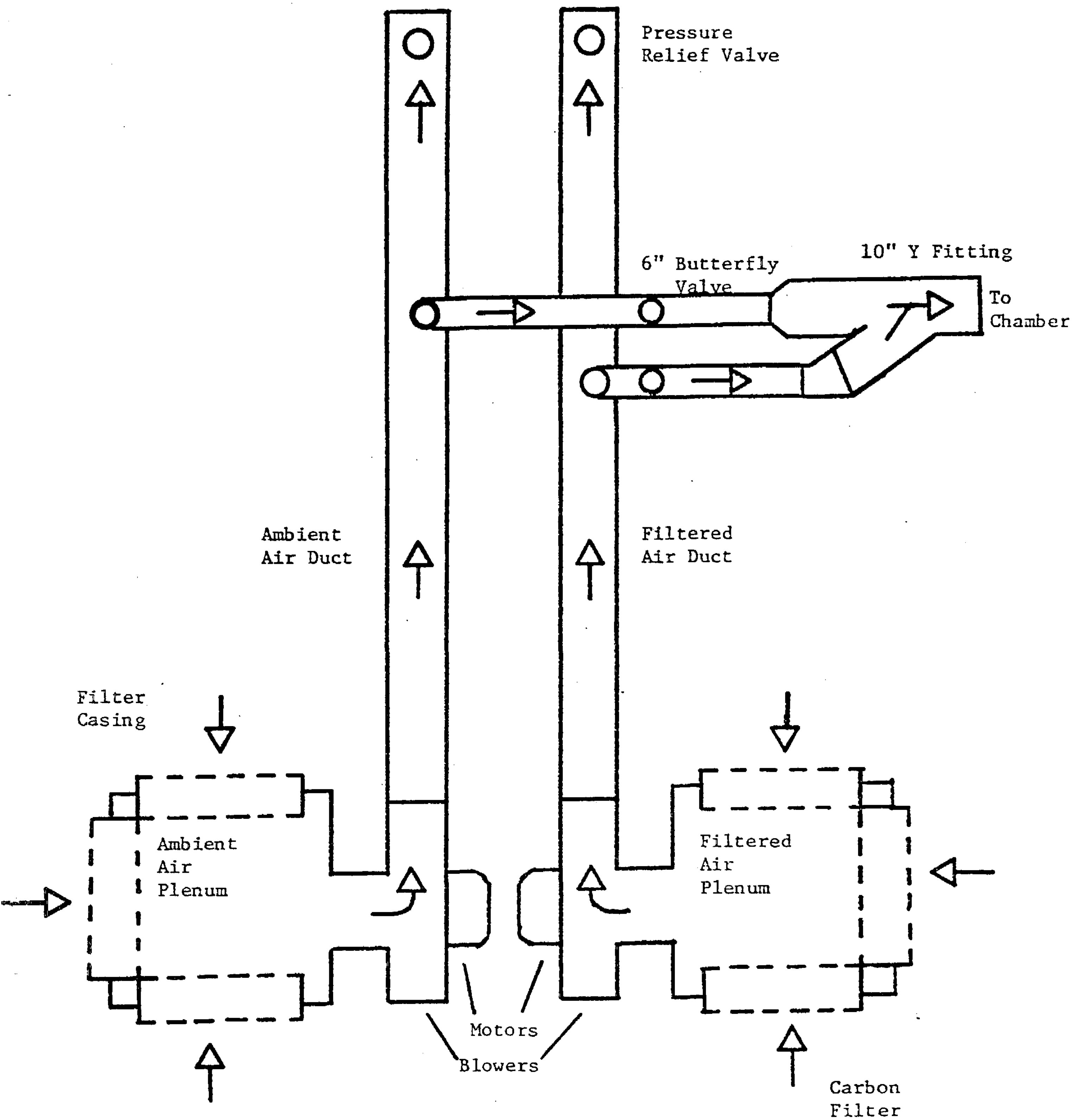


Figure 2. Detail of Air Handling System for Fumigation Chambers



The proportion of filtered to ambient air going to each chamber is controlled by the 6" butterfly valves. A comparison of replicate 0% filtered chambers with ambient ozone indicated that 17 to 21% of the ozone was lost in the air handling system.

3. Exposure Chambers (Figure 3)

The exposure chambers are a modification of the constant-stirred reactor (8) designed by Rogers, USDA, North Carolina State University, Raleigh, North Carolina. Each chamber consists of a 7′ x 7′ PVC schedule 80 frame bolted to a concrete ring. A 5 mil FEP Teflon envelope is suspended from the uppermost ring and anchored to the concrete with a 1/2" PVC ring. A small 1/120 H.P. shade pole 110 V motor is mounted at the apex of the PVC frame and anchors the uppermost portion of the Teflon envelope. An extension shaft from the motor protrudes through the Teflon envelope and supports a 6-blade impeller which rotates at 60 rpm. The mixture of filtered and nonfiltered air enters the chamber via a 10" PVS underground duct which then extends 5 ft vertically and directs the air stream directly at the impeller. Chamber exhaust is vented through a 10" PVS "U" tube directly into the atmosphere.

4. Fumigant Monitoring System (Figure 4)

Seventy-ft of 1/4" FTE Teflon lines run from each chamber. The air sample is pulled through a 3-way Teflon solenoid valve on each sample line to an exhaust minifold. An electrical control box regulates solenoid activation. Once activated, the solenoid valve diverts the flow to a sampling manifold from which the ozone and SO_2 instruments sample. This system continually pulls about 30 liters/min through each sampling line. Different chambers can therefore be monitored with a minimal lag time for

Figure 3. Diagram of Chamber Showing Structural Components
Chamber dimensions are 7' x 7'.

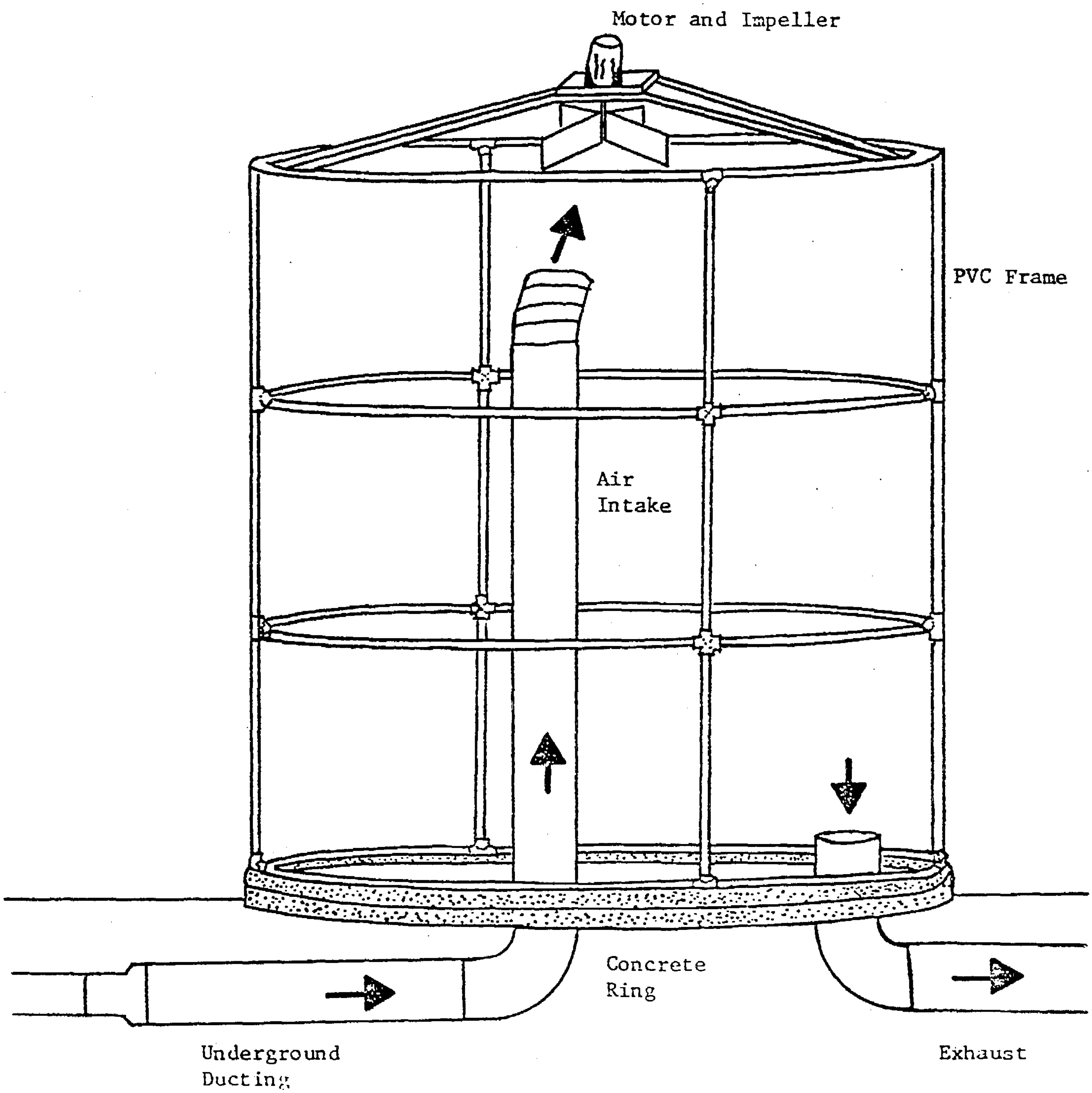
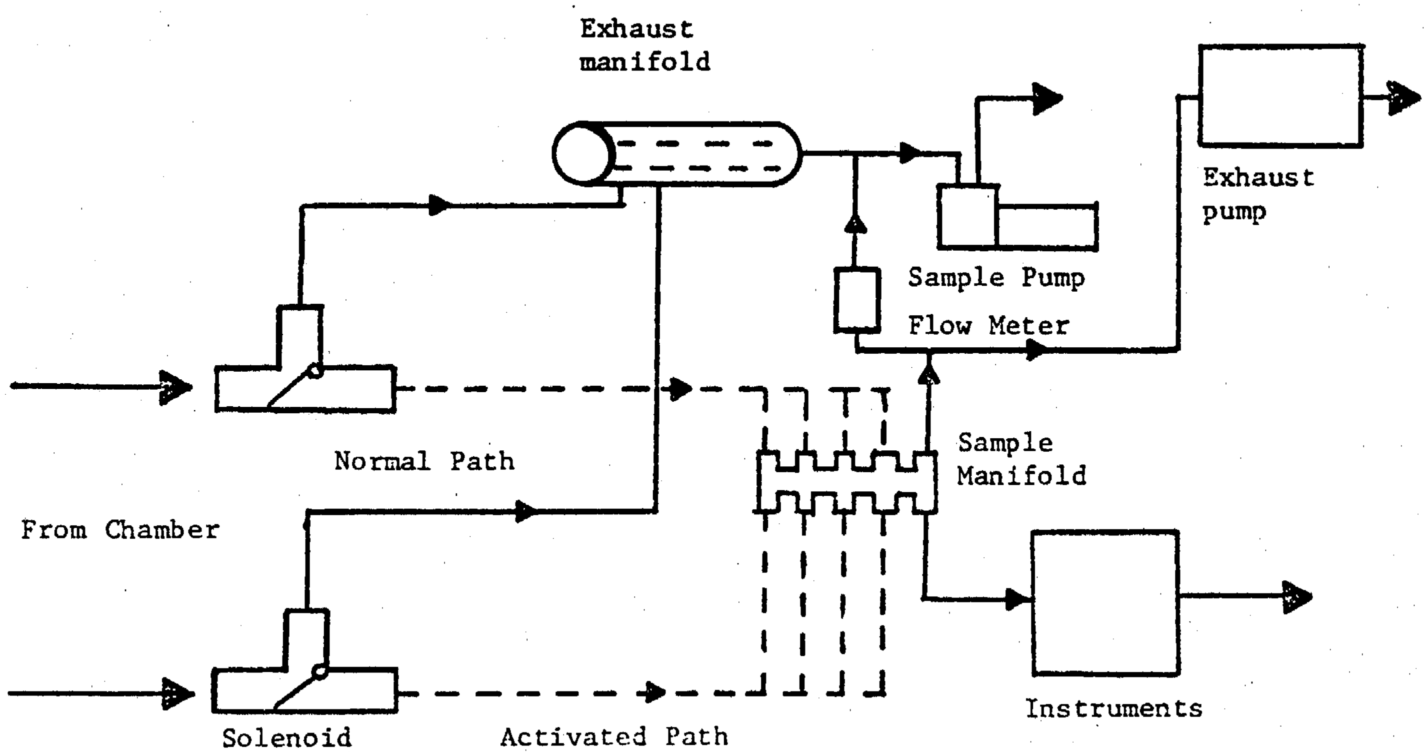


Figure 4. Flow Diagram of Gas Sampling System



purging the sampling manifold. All gas lines, solenoids and sampling manifolds are Teflon. All other valves, connectors and fittings are stainless steel. The entire sampling system, exclusive of the sampling lines, electronic control box and pumps, is contained in an insulated, thermally regulated box kept at $100^{o}F$.

Ozone was monitored by 2 Dasibi Model 1003-AH ozone monitors which use an ultraviolet absorption method for detection. Sulfur dioxide was monitored by 2 Thermoelectron Model 43 SO_2 analyzers which used a pulsed fluorescence method of detection.

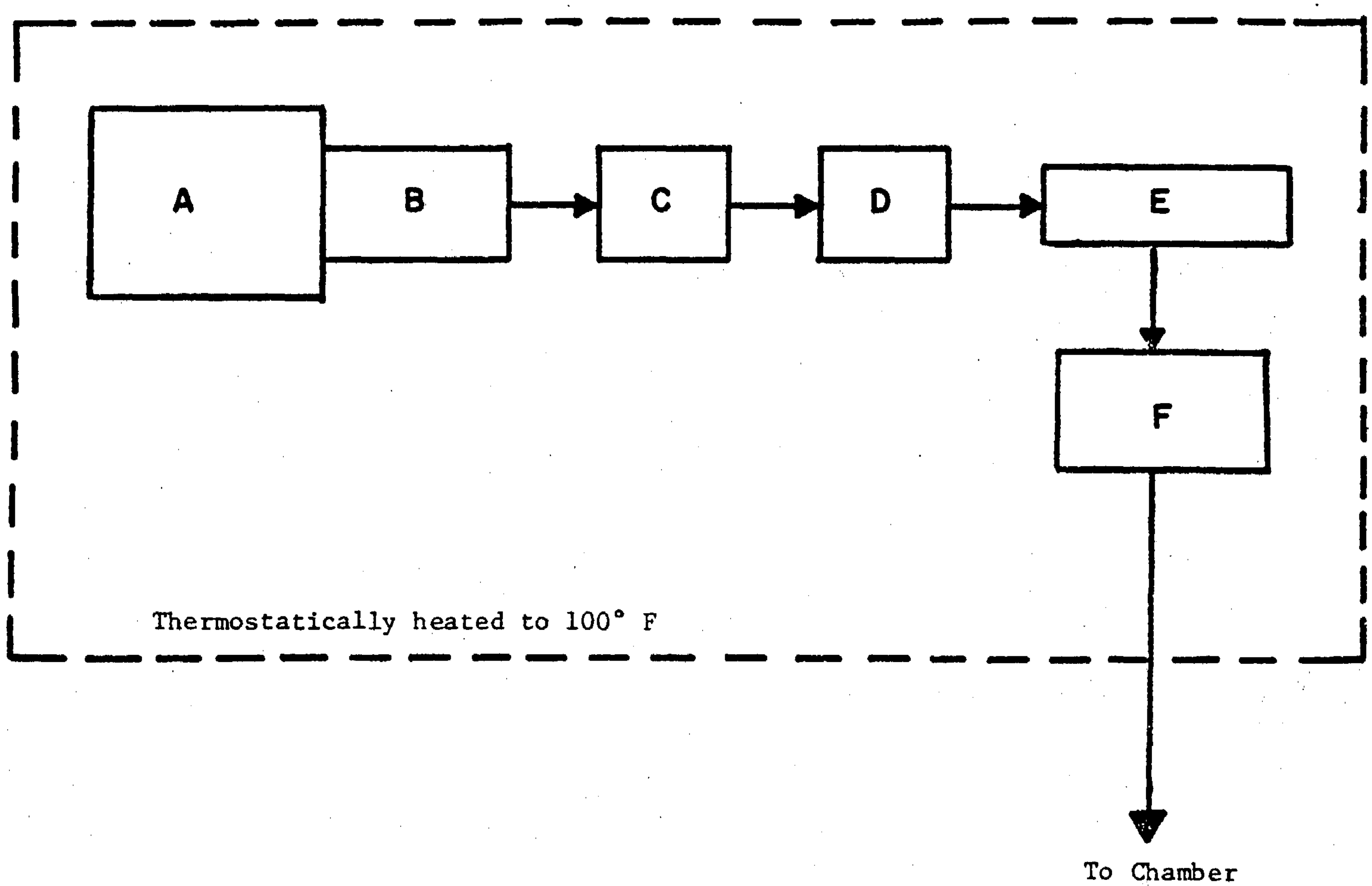
Ozone calibrations were conducted using an additional Dasibi ozone monitor as a transfer standard. This calibration instrument was verified at the ARB facility in El Monte, California by ultraviolet photometry and kept solely as a calibration standard for the Statewide Air Pollution Research Center.

The Thermoelectron Model 43 SO_2 analyzers were calibrated at the start and completion of the experiment using a Monitor Laboratories calibrator with a permeation tube. The calibrations were then verified using a known gas standard of SO_2 in nitrogen.

5. SO_2 Dispensing System (Figure 5)

The SO_2 dispensing system consists of 10 independent SO_2 generators housed in insulated, heated 40 gallon trash cans. Each generator contains a 6.7 liter tank of liquid SO_2 (99.8%), a pressure regulator, a 7 μ in-line filter, a Teflon solenoid valve, a 29 inch length of .005 inch I.D. stainless steel capillary tubing, and a manual shut-off valve. All fittings and tubing are stainless steel. The SO_2 flow is diverted into the exposure chamber inlet duct to be diluted before entering the exposure chamber.

Figure 5. Flow Diagram for Sulfur Dioxide Dispensers
The flow of SO_2 starts at the tank (A) and continues through the regulator (B), a solenoid (C), a 7 μ filter (D), a capillary tube (E), and through a shut-off valve (F) to the chamber.



Plant Selection and Cultivation

Three VF 145B-7879 tomato seeds were planted in each of 500 molded peat pots on April 27, 1978. Seedlings were thinned to a single most uniform plant per pot and grown in a carbon-filtered greenhouse until ready for transplanting. One hundred and seventy-six of the most uniform individuals were transplanted into 15-gallon containers within the 20 Teflon exposure chambers and 2 ambient plots on June 1, 1978. Each 15-gallon container was filled with a uniform soil mix (Table 1) and was buried in the ground to maintain ambient soil temperature.

Table 1. Constituents of Experimental Soil Tabulated per Cubic Yard of Mix.

Soil	14	ft^3
Canadian Peat Moss	7	ft^3
Redwood Shavings	7	ft^3
Single Super Phosphate	2.5	lbs
KNO_3	4.0	oz
K_2SO_4	4.0	oz
Dolomite Limestone	3.75	lbs
Oyster Shell Lime	1.50	lbs
Micronutrients		
Cu	30	ppm
Zn	10	ppm
Mn	15	ppm
Fe	15	ppm

All treatments received the equivalent of 200 lb N fertilizer per acre in addition to the nutrients premixed into the soil. The fertilizer was added in the form of $Ca(NO_3)_2$, and represented a commercial rate of application. Irrigation was applied uniformly throughout treatments when irrometers measured 20 to 30 millibars vacuum. All irrigations were applied with a drip system, insuring uniform application rates and excellent soil dispersion.

Malathion was applied once during the experimental period to eradicate an infestation of grasshoppers in chamber 15. The infestation stemmed from eggs laid during the winter months when the Teflon envelopes were off. Immature grasshoppers were noted in only one chamber but all chambers were treated uniformly. This problem was corrected before it was a significant factor.

Soil Samples

Core samples were taken from each 15-gallon container and mixed thoroughly to form one composite sample for each treatment. Soil samples were then sent to a private laboratory for analysis of soluble sulfate levels. These data are presented in Table 18, page 68. Core samples were taken from each container at two depths (0-8 inches and 8-16 inches) to determine the level of soluble salts. The analysis was performed using the electrical conductivity method (1).

Harvest Procedures

Tomato plants were cut at soil level and put in individual 30 gallon plastic bags for transport to the laboratory. Each plant was then subdivided into fruit and vegetative biomass. A subsample of 10 fruit per plant was collected for quality evaluation and the remainder were individually weighed, measured and evaluated for the following parameters:

1. color - red ripe, breaker and green
2. blemish - physical scars, insect predation, rot, sunburn, and overripe
3. height - measured from attachment to blossom scar
4. diameter - measured on a perpendicular axis from height
5. weight - weight of individual fruit
6. counts - the number of fruit in each color category

The following quality parameters were measured for marketable fruit:

1. soluble solids - indicative of sugar content
2. pH - indicative of acid content
3. pulp color - indicative of marketability

Analysis of the quality parameters were run on a puree of the fruit subsamples from all harvested plants in each chamber. Only red ripe and breaker fruit (commercial yield) were included since a strict limit of 2% green fruit is allowed commercially. The vegetative biomass was recorded after oven drying at 60-70°C for four days. These measurements were exclusive of fruit.

Exposure Schedule (SO_2)

The SO_2 exposure schedule for the experiment is summarized in Table 2. The original design utilized a schedule of exposures which were limited to six hours in duration. The presented schedule was agreed on after a misunderstanding caused a 24-hour exposure to be carried out.

Table 2. Sulfur Dioxide Fumigation Schedule for Treatment of VF 145B-7879 Tomato Plants.

Date	Start	End	Duration (Hours)	Date	Start	End	Duration (Hours)
6-6	1000[a]	1600	6	7-13	0900	—	-
6-7	0900	1500	6	7-14	—	0900	24
6-8	0900	1500	6	7-17	0900	1500	6
6-9	0900	1500	6	7-18	0900	—	-
6-12	1000	1600	6	7-19	—	0900	24
6-13	0900	1500	6	7-20	0900	1500	6
6-14	0900	1500	6	7-21	0900	1500	6
6-15	0900	1500	6	7-24	0900	—	-
6-16	0900	1500	6	7-25	—	0900	24
6-19	0900	1500	6	7-26	0900	1500	6
6-20	0900	—	-	7-28	0900	1500	6
6-21	—	0900	24	7-31	0900	—	-
6-22	0900	1500	6	8-1	—	0900	24
6-23	0900	1500	6	8-2	0900	1500	6
6-25	0900	—	-	8-3	0900	—	-
6-26	—	0900	24	8-4	—	0900	24
6-27	0900	1500	6	8-7	0900	1500	6
6-28	0900	1500	6	8-8	0900	—	-
6-29	0900	1500	6	8-9	—	0900	24
7-5	0900	1500	6	8-11	0900	1500	6
7-6	0900	—	-	8-14	0900	—	-
7-7	—	0900	24	8-15	—	0900	24
7-8	0900	1500	6	8-16	0900	1500	6
7-10	0900	—	-	8-17	0900	—	-
7-11	—	0900	24	8-18	—	0900	24
7-12	0900	1500	6				

[a]Time is recorded in Pacific Standard Time.

III. RESULTS

All tables and figures in this section are presented consecutively following the narrative, pages 35 to 68.

Foliar Injury

Foliar injury was only observed within chambers in the 25% filtered to 75% nonfiltered ambient treatment and in the two ambient plots. Only the most mature leaves on tomato plants in the 25% filtered treatments were affected. These displayed foliar chlorosis but no necrosis or upper surface stipple. The first observed injury on the 25% filtered plants was observed on July 26, 1978 (50 days after treatments were started). Plants in the ambient plots developed severe foliar injury. Chlorosis was observed in the ambient plots starting June 28, 1978 and rapidly progressed to necrosis and premature senescence of mature leaves. Significant defoliation and severe injury was observed on vines at harvest.

Anova Analysis

The table of means (Table 3, page 35) and table of doses (Table 4, page 37) summarize data used in the 3 x 3 factorial analysis of harvest parameters. Only doses >0 pphm were used in the actual analysis although doses with calculation thresholds are presented for comparison. Pollutant doses were calculated using the following dose expression:

$$\text{dose} = \sum_i (h_i - x) \qquad h_i = \text{hourly average for the ith hour} \geq x$$
$$x = \text{calculation threshold}$$

Ozone doses were calculated using calculation thresholds of 0, 3, 5, 8, 10, 15 and 20 pphm (Table 4). The same ozone dose calculation with a 10 pphm calculation threshold has been utilized in the past (5). Harvest variables include:

1. Total wt. red and breaker tomatoes (commercial yield)
2. Total no. red and breaker tomatoes
3. Total no. red tomatoes
4. Total wt. red tomatoes
5. Total no. breaker tomatoes
6. Total wt. breaker tomatoes
7. Total no. green tomatoes
8. Total wt. green tomatoes
9. Soluble solids
10. Pulp color
11. pH
12. Dry wt. plants

The following calculations were also included in the analysis:

1. % no. red tomatoes
2. % no. breaker tomatoes
3. % no. green tomatoes
4. % no. red & breaker tomatoes
5. % wt. red tomatoes
6. % wt. breaker tomatoes
7. % wt. green tomatoes
8. % wt. red & breaker tomatoes

An initial analysis was run to compare variability in main effects and interactions using the 7 subsamples within each chamber and to determine whether the greater degrees of freedom for subsamples could be used. The eighth plant in each chamber was not used in the analysis since it was sacrificed to determine harvest dates.

Sources of Variation	df
Blocks (B)	1
Subsamples (R)	6
SO_2 (S)	2
Ozone (O)	2
R x B	6
R x S	12
R x O	12
B x S	2
B x O	2
S x O	4
R x B x S	12
R x B x O	12
R x S x O	24
B x S x O	4
Error	24
Total	125

Mean squares were compared and tested using rules originally proposed by Bancroft and listed on page 266 of Sokal and Rohlf (9). F values calculated from the appropriate mean squares did not meet required values at $P \leq 0.75$. Variables tested using these rules did not comply with the necessary criteria and the greater degrees of freedom for the subsamples could not be used.

The following analysis was then adopted for use:

Sources of Variation		df
Blocks (B)		1
Ozone (O)		2
Linear (L)	1	
Quadratic (Q)	1	
SO_2 (S)		2
Linear (L)	1	
Quadratic (Q)	1	
S x O		4
S_L O_L	1	
S_Q O_L	1	
S_L O_Q	1	
S_Q O_Q	1	
Error		8
Total		17

The following unequal interval orthogonal polynomial coefficients were calculated and included here as an aid if others wish to repeat the analysis reported above:

Linear	-1.974399	-0.2609	2.235299
Quadratic	1.671569	-2.819006	1.147438

Harvest Variables

1. Total weight of red and breaker tomatoes (commercial yield):

Ozone effect: No ozone effect was documented on the commercial yield of VF 145B-7879 processing tomatoes in the 3 x 3 factorial experiment when a maximum of 50% ambient air was used (Table 5).

SO_2 effect: SO_2 caused a linear reduction in the commercial yield of VF 145B-7879 processing tomatoes (Table 5). The 20 pphm SO_2 treatment plants produced 20% less than the non-fumigated tomato plants but there was no difference in commercial yield between the 20 pphm and 10 pphm treatment plots.

SO_2 - O_3 interaction: A complex SO_2 quadratic-ozone quadratic interaction was significant even though the main interaction term was not (Table 5). A graphic representation of the interaction (Figure 6) indicated that high production in the 3243 pphm-hr ozone - 10 pphm SO_2 treatments produced this effect. This response was based on a single treatment effect.

2. Total number of red and breaker tomatoes:

Ozone effect: No ozone effect was detectable (Table 6).

SO_2 effect: A linear reduction in the number of red and breaker tomatoes was significant ($p<.05$) (Figure 7).

SO_2 and O_3 interaction: No interactions were significant.

3. Total number and weights of tomato fruit according to color categories (red, breaker and green):

Processing tomatoes may produce two distinct fruit sets in a season. The fruit sets are distinct and do not overlap in their maturing. The first set is normally ripe or in the final stages of ripening when the second set is hard green. The initial set would rot if the field harvest was delayed long enough to include the mature second fruit set. The first fruit set is therefore in almost all cases the commercial harvest.

The VF 145B-7879 processing tomato is normally harvested when 80% of the first fruit set is red ripe. This percentage is exclusive of the hard green fruit in the second fruit set. One plant per chamber was sacrificed on August 21, 1978 to determine the red ripe ratio. The rate of 2% ripening per day was utilized to project chamber harvests from the ratios obtained on 21 August. Chamber harvests were conducted based on these projected dates, and are listed below.

Chamber No.	Harvest Date, 1978	Chamber No.	Harvest Date, 1978
1	8-24	12	8-25
2	8-25	13	8-23
3	8-23	14	8-23
4	8-23	15	8-31
5	8-31	16	9-1
6	9-1	17	8-31
7	8-31	18	8-28
8	8-28	19	9-1
9	9-1	20	8-28
10	8-28	A1	8-23
11	8-24	A2	8-23

A mean percentage of 87% red ripe at harvest resulted within a range of 83% to 94% red ripe.

The responses of the number and weight of red ripe tomatoes produced (Tables 7, 8) were equivalent to the analysis of the commercial yield and number of red and breaker fruit except for the interaction. The graphic representations (Figures 8, 9) also indicated the same responses.

The breaker fruit represented only a small fraction (16%) of the total fruit set of the plants. The anova analyses (Tables 9, 10) indicated several significant main effects and interactions for both the number and weight of breakers produced and the graphic representations (Figures 10,

11) clearly corroborated the existence of the interactions. Although the statistical significance of differences in the breaker responses are at times quite high, the biological values of these responses is negligible. Most breaker responses are completely masked by the greater numbers of red ripe fruit and their effect on the commercial harvest was minute.

There were no green fruit main or interactive responses to ozone or SO_2.

4. Calculated percentages of red, red & breaker or green tomatoes in terms of number or weight:

None of the calculated variables were observed to be affected by SO_2, ozone or interactive effects.

5. Pulp color:

The State of California regulates the degree of pulp color acceptable for canning tomatoes. Pulp color is measured on an Agtron colorimeter with a scale from 0 to 120 arbitrary units. Color ranges in intensity from a maximum of 0 to a minimum of 120 Agtron units. The state regulation requires an Agtron reading of 40 or less before harvested fruit are acceptable for processing.

SO_2 linearly decreased the intensity of fruit color in VF 145B-7879 processing tomato fruit (Table 11). The reduction in color of fruit pulp (increased Agtron number) was well within the acceptable Agtron range and would not influence the marketability of the commercial yield. The SO_2 effect can be observed at the low ozone dose in Figure 12.

6. pH:

A pH of 4.4 or less is necessary if tomato fruit are considered to be acceptable for processing by canners. Higher pH values do not suppress bacterial spoilage and require longer processing time.

All pH values measured from fruit were below the 4.4 pH limitation. A few pH responses differed significantly (Table 12) but were based on commercially insignificant alterations in a minimal range of pH values. The range of mean values for the Anova analysis was only 4.13 to 4.26 pH units.

7. Soluble solids:

No effects of ozone, SO_2, or the combinations of both gases were detectable (Table 14).

8. Plant dry weight:

SO_2, ozone and the gas mixtures did not affect plant dry weights (Table 13). Mean weights of plants proved to be statistically different between blocks. No apparent reason for the block differences was evident.

<u>Regression Analysis</u>

Chamber replicate variables and ozone dose data are presented in the table of means (Table 14) and the table of doses (Table 15). All plant harvest variables and doses are presented but commercial yield (weight of red and breaker tomatoes) was the only biologically valid variable influenced.

The preceding Anova analysis indicated that ozone did not affect commercial yields of tomato plants exposed to ozone doses of 1530, 3243 and 5740 pphm-hrs. The 25% filtered to 75% nonfiltered ambient (average ozone dose 8268 pphm-hrs, Table 15) treatment not included in the design of the 3 x 3 factorial was included in a regression to determine the slope and compare it with the filtered treatment:

Yield = 3210.38 + .0207 (dose)   r = 8952*

The addition of this point produced a positive slope of .0207 which is not statistically significant from zero and is indicative of no yield loss. A plot of the treatment means clearly substantiated this (Figure 13).

No regressions were calculated for the SO_2 main effect since only three points were available and the responses to the 10 pphm and 20 pphm treatments were statistically equivalent. The orthogonal polynomials in the Anova analysis indicated a strong linear response but a model of the functional response should be calculated from an additional experiment designed to achieve this.

Fruit Size Distribution Analysis

A fruit size distribution analysis of red and breaker fruit was undertaken utilizing five categories based on weight. Tomato fruit were sorted into the 25-gram categories and a frequency distribution generated. Fruit size distributions are presented in Figure 14.

Only the ambient plots (ozone dose 11,671 pphm-hrs) were observed to show a shift to smaller fruit. All but a few fruit were in the three smallest size categories. In contrast, all other treatments were found to have a similar size distribution without a significant shift towards smaller fruit.

Ambient and 25% Filtered Treatments

Ambient (11,671 pphm-hrs) and 25% filtered to 75% nonfiltered ambient air treatments (8268 pphm-hrs) were incorporated into the experiment to provide data for regression analysis. Unfortunately, no significant ozone yield responses were detected in the 25% filtered to 75% nonfiltered ambient air treatment. This extended the lack of an ozone effect from the treatments used in the 3 x 3 factorial analysis to an ozone dose of 8268 pphm-hrs.

Ambient treatments provided the only discernible ozone effects in the experiment. The fruit size distribution analysis previously described was indicative of this. Also, significant reductions in weights of red and breaker tomatoes (commercial yield), number of red and breaker tomatoes, associated differences in the weights and numbers of fruit in the color categories, pulp color (not acceptable for canning by State of California standards), and plant dry weight were found using unpaired t tests with the 25% filtered to 75% nonfiltered ambient air treatments ($p < .05$). No regressions were conducted because of the lack of effect on other treatments. Regression analysis using only the 25% filtered to 75% nonfiltered ambient air and ambient treatments would be improper. The overall relationship of the ambient and 25% filtered to 75% nonfiltered ambient air treatments to the other treatments is depicted in Figure 15 for commercial yield. The functional relationship is the same for the other affected variables.

Environmental Analysis

The calibration of the environmental factors for the fumigation facility was checked before the initiation of the experiment. No significant deviations from the initial calibration carried out in 1977 (5) were observed. Environmental variables were monitored throughout the duration of the experiment.

1. Temperature: Chamber temperatures closely simulated ambient conditions. Chamber mean maximum temperatures for the experimental period were generally cooler than ambient with only a single chamber exceeding ambient by 0.5°F. Mean maximum temperatures ranged from 96.4°F to to 101.2°F compared with a mean ambient maximum of 100.7°F. Chamber mean

minimum temperature ranged from 62.6^{o}F to 63.4^{o}F in contrast to an ambient mean minimum temperature of 59.4^{o}F. Examples of chamber temperature variations are given in Appendix A.

2. Photosynthetically Active Radiation (PAR): Chamber transmission tests (Figures 16, 17, 18) were conducted on a randomly selected chamber before, during and after experimentation. The exposure chambers transmitted a mean of 86.8% of the available ambient PAR. PAR monitoring was carried out semicontinuously during the experimentation. Monitoring indicated that a mean flux of 1439 μ einsteins m^{-2} sec^{-1} was available within chambers compared to mean of 1658 μ einsteins m^{-2} sec^{-1} available in the ambient environment. Available light as measured by PAR was not considered to be a limiting factor influencing yields.

3. Relative Humidity: Mean relative humidity (RH) readings ranged between 60.9% and 54.7% in the chambers and were not significantly different at canopy heights. The RH readings were somewhat higher than the 51.3% and 44.2% ambient RH, as expected. Transpiration from the tomato plants and weekly irrigations within the chambers were probably responsible for the higher chamber RH.

All relative humidity readings were calculated from wet and dry bulb thermocouple data. Examples of chamber RH variations are presented in Appendix B.

4. Peak Chamber Ozone Concentrations: The peak ozone concentrations (highest one-hour average) for the fumigation facility and the associated ambient levels are listed in Table 16. These were taken from the highest monitored ozone days in the growing season.

5. Soil Analysis: The soil analysis before and after experimentation (Table 17) was carried out by the University of California Cooperative

Extension Laboratory at Riverside. The largest change in constituents occurred in the depletion of available nitrogen as nitrate. This was expected since the soil is rather sandy with excellent drainage and provided an excellent opportunity for leaching of the nitrates.

Sulfate analysis of soil from each chamber was quite variable (Table 18). The variability appeared to stem chiefly from sampling techniques since all samples were run without actual identification and two dummy samples of fresh soil were found to have exactly the same levels. No correlation with SO_2 treatments was observed with the SO_4 analysis. The soluble sulfate levels were all within a perfectly safe range for good tomato growth and production.

Soil salinity analysis revealed extremely low levels of soluble solids. The highest single reading was 1.50 millimhos/cm compared to a fresh soil level of 1.30 millimhos/cm. Salinity did not enter into the experiment as a significant variable.

Dose Calculations

Ozone doses were calculated using thresholds of 0, 3, 5, 8, 10, and 15 pphm. These doses are summarized in Table 15. The (SO_2) (O_3) doses were also calculated using O_3 pphm-hrs (for non-fumigated periods) + (SO_2) and (O_3) pphm-hrs (for fumigated periods). The resultant doses were as follows:

Chamber	Dose	Chamber	Dose
1	21,465	11	18,382
3	4,793	13	4,126
4	16,208	14	16,192
6	8,830	16	10,051
8	36,387	18	34,134
10	11,209	20	10,396

No regressions were conducted on the dependent variables since the only significant plant responses <u>occurred in the ambient replicates</u> or in the three point SO_2 treatment gradient.

Table 3. Mean of Data from Two Treatment Plots for All of the Tomato Plant Response Factors Measured in the 3 x 3 ANOVA Experiment (Page 1 of 2)

Filtered ambient air (%)	Level SO_2	Total # red	Total wt. red (g)	Total # breaker	Total wt. breaker (g)	Total # green	Total wt. green (g)	Total # red & breaker	Total wt. red & breaker(g)	Pulp Color[a]	Soluble Solids
100	0	61.07	3077.18	3.71	175.3	13.71	528.35	64.78	3252.48	27.28	5.98
100	10	45.21	2219.98	7.71	423.99	24.57	941.48	52.93	2643.96	31.28	5.58
100	20	49.57	2603.97	5.0	220.24	24.35	952.14	54.57	2824.21	31.64	5.98
75	0	57.07	2989.89	5.85	292.37	15.78	544.62	62.85	3282.25	28.43	5.78
75	10	56.57	3026.56	7.57	448.10	12.07	449.78	64.14	3474.67	27.78	5.76
75	20	43.28	2319.09	6.28	328.48	25.14	966.02	49.56	2647.57	29.86	5.53
50	0	58.21	2862.34	8.0	411.11	19.35	791.73	66.28	3277.16	28.14	5.47
50	10	34.42	1803.95	6.0	291.78	32.43	1133.01	40.43	2095.73	29.35	5.54
50	20	44.07	2072.67	8.14	362.71	24.79	965.92	52.21	2435.38	31.21	5.61

[a]Agtron units.

Table 3 continued (Page 2 of 2)

Filtered ambient air (%)	Level SO_2	pH	Plant dry wt. (g)	% no. red	% no. breaker	% no. green	% no. red & breaker	% wt. red	% wt. breaker	% wt. green	% wt. red & breaker
100	0	4.26	193.4	77.87	4.73	17.39	82.60	81.49	4.65	13.85	86.15
100	10	4.18	189.3	48.71	10.06	30.58	69.42	63.53	11.9	24.56	75.44
100	20	4.13	195.95	62.47	6.48	31.04	68.96	68.91	6.06	25.03	74.97
75	0	4.18	199.45	73.26	7.46	19.27	80.65	78.63	7.67	13.7	86.3
75	10	4.21	176.2	74.33	9.96	15.71	84.29	77.17	11.46	11.37	88.62
75	20	4.25	181.05	59.43	8.55	32.01	67.99	65.37	9.22	25.40	74.59
50	0	4.20	186.6	68.47	9.40	22.12	77.96	70.78	10.13	19.08	81.01
50	10	4.20	166.8	48.38	8.24	43.38	56.62	56.64	9.00	34.35	65.64
50	20	4.19	218.7	57.14	10.53	32.33	67.68	61.14	10.74	28.11	71.88

Table 4. Calculated Dose of Ozone Using the Seven Designated Threshold Levels

Filtered ambient air (%)	Level SO_2	Dose >0 pphm-hrs	Dose >3 pphm-hrs	Dose >5 pphm-hrs	Dose >8 pphm-hrs	Dose >10 pphm-hrs	Dose >15 pphm-hrs	Dose >20 pphm-hrs
100	0	1338.0	0.5	0	0	0	0	0
100	10	1403.5	1.0	0	0	0	0	0
100	20	1848.5	2.5	0	0	0	0	0
75	0	3136.0	482.0	65.0	0	0	0	0
75	10	3299.0	437.0	38.0	0	0	0	0
75	20	3295.5	492.0	63.0	0	0	0	0
50	0	5462.0	1814.5	650.0	68.5	6.5	0	0
50	10	5319.5	1915.5	742.0	94.0	11.0	0	0
50	20	6437.5	2306.5	955.0	138.0	21.0	0	0

Table 5. Analysis of Variance of Variable 1 - Wt. Red & Breaker Tomatoes

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	121914.300	121914.300	0.81	
O	2	855110.500	427555.300	2.84	
Linear	1	365877.300	365877.300	2.43	
Quadratic	1	489233.600	489233.600	3.25	
S	2	1394317.000	697158.400	4.63*	
Linear	1	1209319.000	1209319.000	8.04*	
Quadratic	1	184997.300	184997.300	1.23	
S x O	4	1225585.000	306396.300	2.04	
SL OL	1	84536.770	84536.770	0.56	
SQ OL	1	165375.100	165375.100	1.10	
SL OQ	1	956.395	956.395	0.01	
SQ OQ	1	974716.500	974716.500	6.48*	
Error	8	1203869.000	150483.700		13.5%
TOTAL	17	4800796.000			

Combination	Count per Mean	Subclass B	S	O	Means
B	9				
		1	0	0	2799.19
		2	0	0	2963.79
O	6				
1530 pphm-hr		0	0	1	2906.89
3243 pphm-hr		0	0	2	3134.83
5740 pphm-hr		0	0	3	2602.76
S	6				
0 pphm		0	1	0	3270.63
10 pphm		0	2	0	2738.12
20 pphm		0	3	0	2635.72
S x O	2				
		0	1	1	3252.48
		0	2	1	2643.96
		0	3	1	2824.21
		0	1	2	3282.25
		0	2	2	3474.67
		0	3	2	2647.57
		0	1	3	3277.16
		0	2	3	2095.73
		0	3	3	2435.38

* = significance at .05

Figure 6. Effect of Ozone and SO_2 on the Total Weight of Red & Breaker Tomatoes (grams)

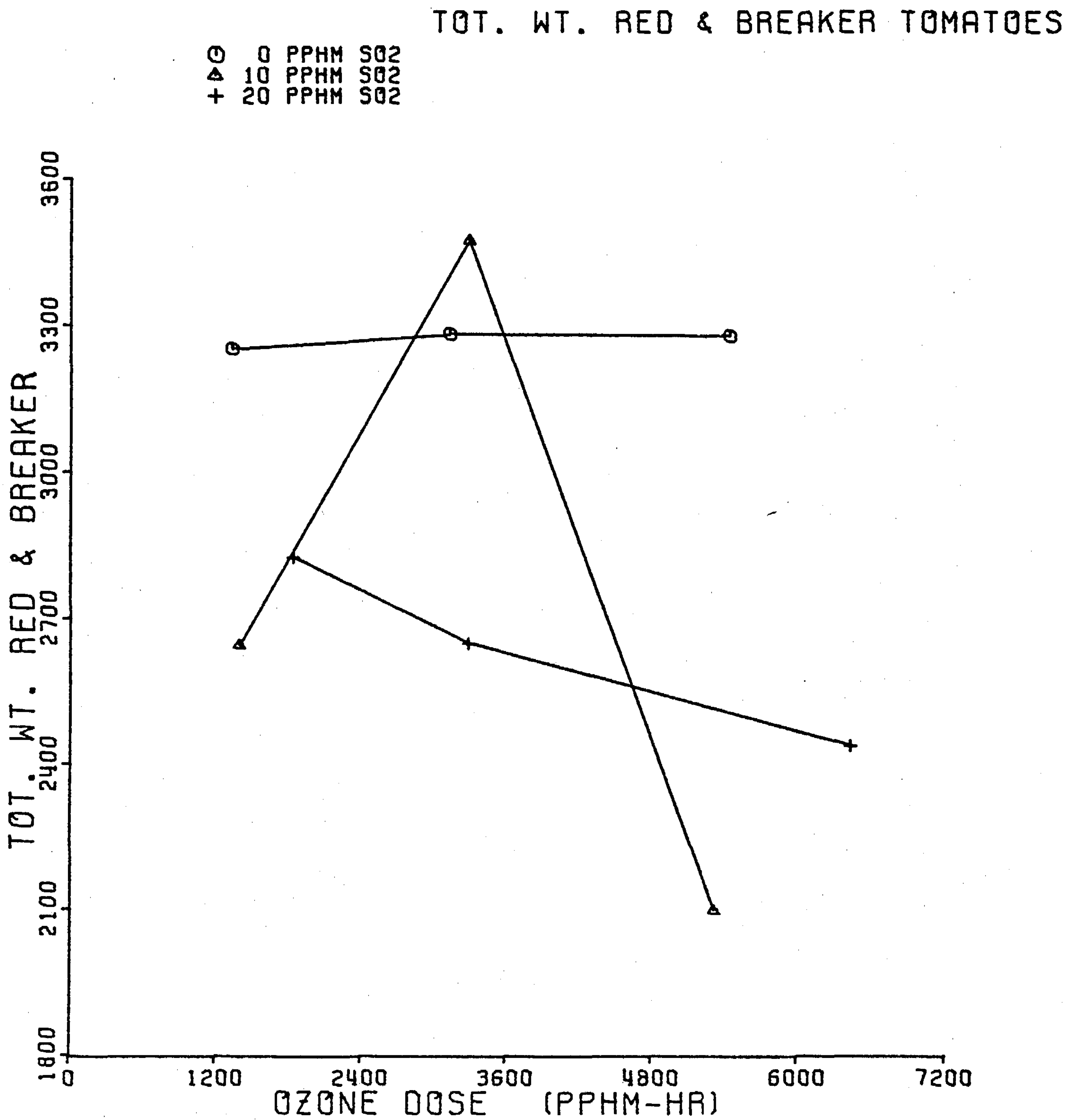


Table 6. Analysis of Variance of Variable 2 - No. Red & Breaker Tomatoes

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	1.394450	1.394450	0.02	
O	2	112.863700	56.431870	0.79	
Linear	1	71.343440	71.343440	1.00	
Quadratic	1	41.520350	41.520350	0.58	
S	2	608.720800	304.360400	4.26	
Linear	1	470.501400	470.501400	6.58*	
Quadratic	1	138.219100	138.219100	1.93	
S x O	4	486.942500	121.735600	1.70	
SL OL	1	6.816047	6.816047	0.10	
SQ OL	1	141.264700	141.264700	1.98	
SL OQ	1	1.484647	1.484647	0.02	
SQ OQ	1	337.377000	337.377000	4.72	
Error	8	571.815400	71.476910		15.0%
TOTAL	17	1781.737000			

Combination	Count per Mean	Subclass B	S	O	Means
B	9				
		1	0	0	56.70
		2	0	0	56.14
O	6				
1530 pphm-hr		0	0	1	57.43
3243 pphm-hr		0	0	2	58.86
5740 pphm-hr		0	0	3	52.98
S	6				
0 pphm		0	1	0	64.64
10 pphm		0	2	0	52.50
20 pphm		0	3	0	52.12
S x O	2				
		0	1	1	64.78
		0	2	1	52.93
		0	3	1	54.57
		0	1	2	62.86
		0	2	2	64.14
		0	3	2	49.57
		0	1	3	66.28
		0	2	3	40.43
		0	3	3	52.21

* = significance at .05

Figure 7. Effect of Ozone and SO_2 on the Total Number of Red & Breaker Tomatoes

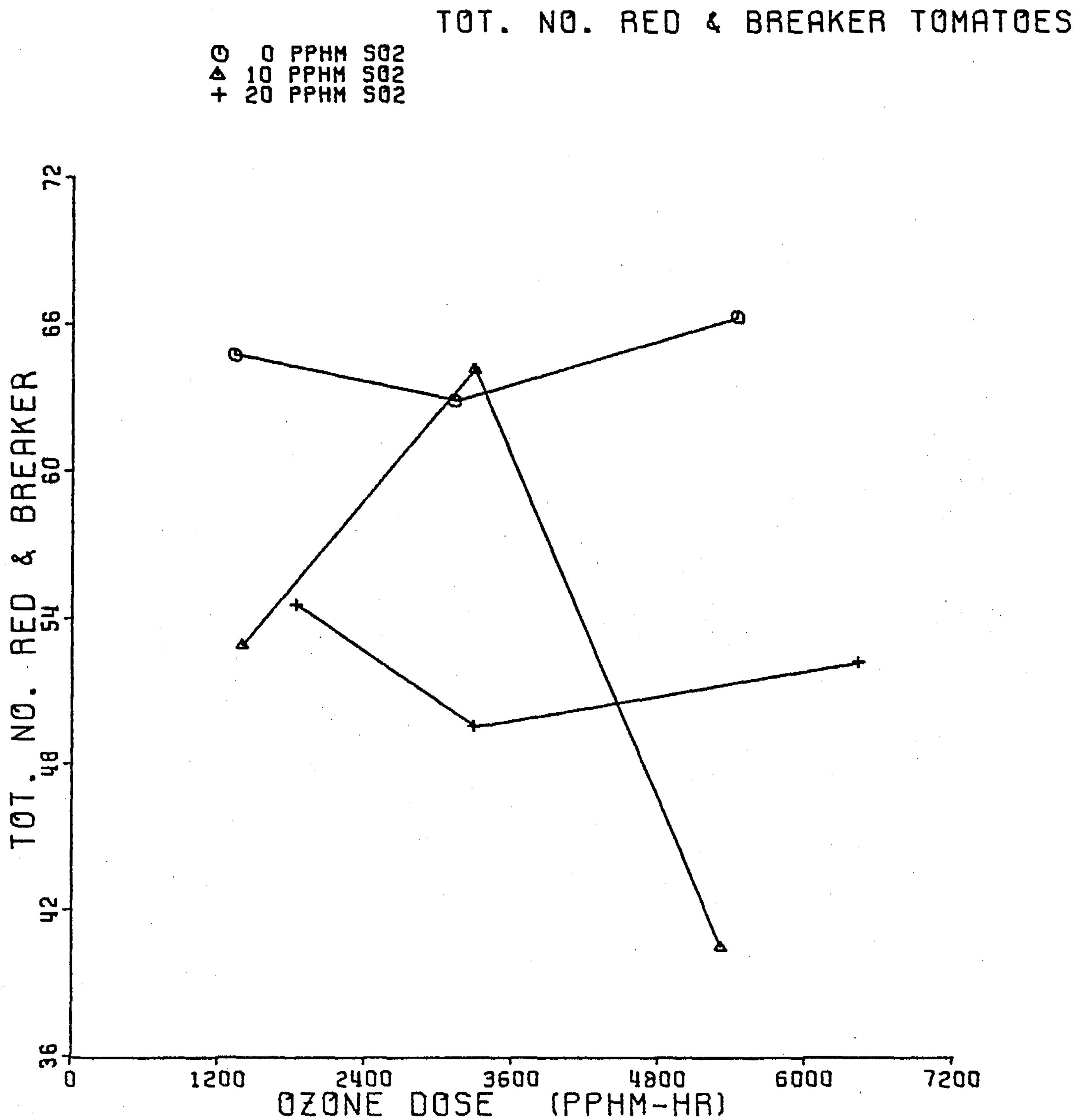


Table 7. Analysis of Variance of Variable 3 - Total No. Red Tomatoes

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	0.19427	0.19427	0.00	
O	2	172.56330	86.28166	1.40	
Linear	1	138.01210	138.01210	2.24	
Quadratic	1	34.55133	34.55133	0.56	
S	2	703.92290	351.96140	5.70*	
Linear	1	518.37290	518.37290	8.39*	
Quadratic	1	185.54970	185.54970	3.00	
S x O	4	382.10340	95.52583	1.55	
SL OL	1	3.14152	3.14152	0.05	
SQ OL	1	54.10844	54.10844	0.88	
SL OQ	1	0.95766	0.95766	0.02	
SQ OQ	1	323.89560	323.89560	5.25	
Error	8	493.98660	61.74832		15.7%
TOTAL	17	1752.77000			

Combination	Count per Mean	Subclass B	S	O	Means
B	9				
		1	0	0	49.84
		2	0	0	50.05
O	6				
1530 pphm-hr		0	0	1	51.95
3243 pphm-hr		0	0	2	52.31
5740 pphm-hr		0	0	3	45.57
S	6				
0 pphm		0	1	0	58.79
10 pphm		0	2	0	45.40
20 pphm		0	3	0	45.64
S x O	2				
		0	1	1	61.07
		0	2	1	45.21
		0	3	1	49.57
		0	1	2	57.07
		0	2	2	56.57
		0	3	2	43.28
		0	1	3	58.21
		0	2	3	34.42
		0	3	3	44.07

* = significance at .05

Table 8. Analysis of Variance of Variable 4 - Total Wt. Red Tomatoes

Source of Variation	df		SS	MS	F	Coefficient of variation
B	1		144313.400	144313.400	1.04	
O	2		908524.000	454261.900	3.26	
Linear		1	546716.400	546716.400	3.92	
Quadratic		1	361807.900	361807.900	2.60	
S	2		1616063.000	808031.600	5.80*	
Linear		1	1246340.000	1246340.000	8.94*	
Quadratic		1	369722.400	369722.400	2.65	
S x O	4		966576.600	241644.100	1.73	
SL OL		1	47988.700	47988.700	0.34	
SQ OL		1	18749.580	18749.580	0.13	
SL OQ		1	3116.907	3116.907	0.02	
SQ OQ		1	896721.300	896721.300	6.43	
Error	8		1115027.000	139378.400		14.6%
TOTAL	17		4750505.000			

Combination	Count per Mean	Subclass B	S	O	Means
B	9				
		1	0	0	2463.31
		2	0	0	2642.39
O	6				
1530 pphm-hr		0	0	1	2633.71
3243 pphm-hr		0	0	2	2778.51
5740 pphm-hr		0	0	3	2246.32
S	6				
0 pphm		0	1	0	2976.46
10 pphm		0	2	0	2350.16
20 pphm		0	3	0	2331.91
S x O	2				
		0	1	1	3077.18
		0	2	1	2219.98
		0	3	1	2603.97
		0	1	2	2989.87
		0	2	2	3026.56
		0	3	2	2319.09
		0	1	3	2862.34
		0	2	3	1803.95
		0	3	3	2072.67

* = significance at .05

Figure 8. Effect of Ozone and SO_2 on the Total Number of Red Tomatoes

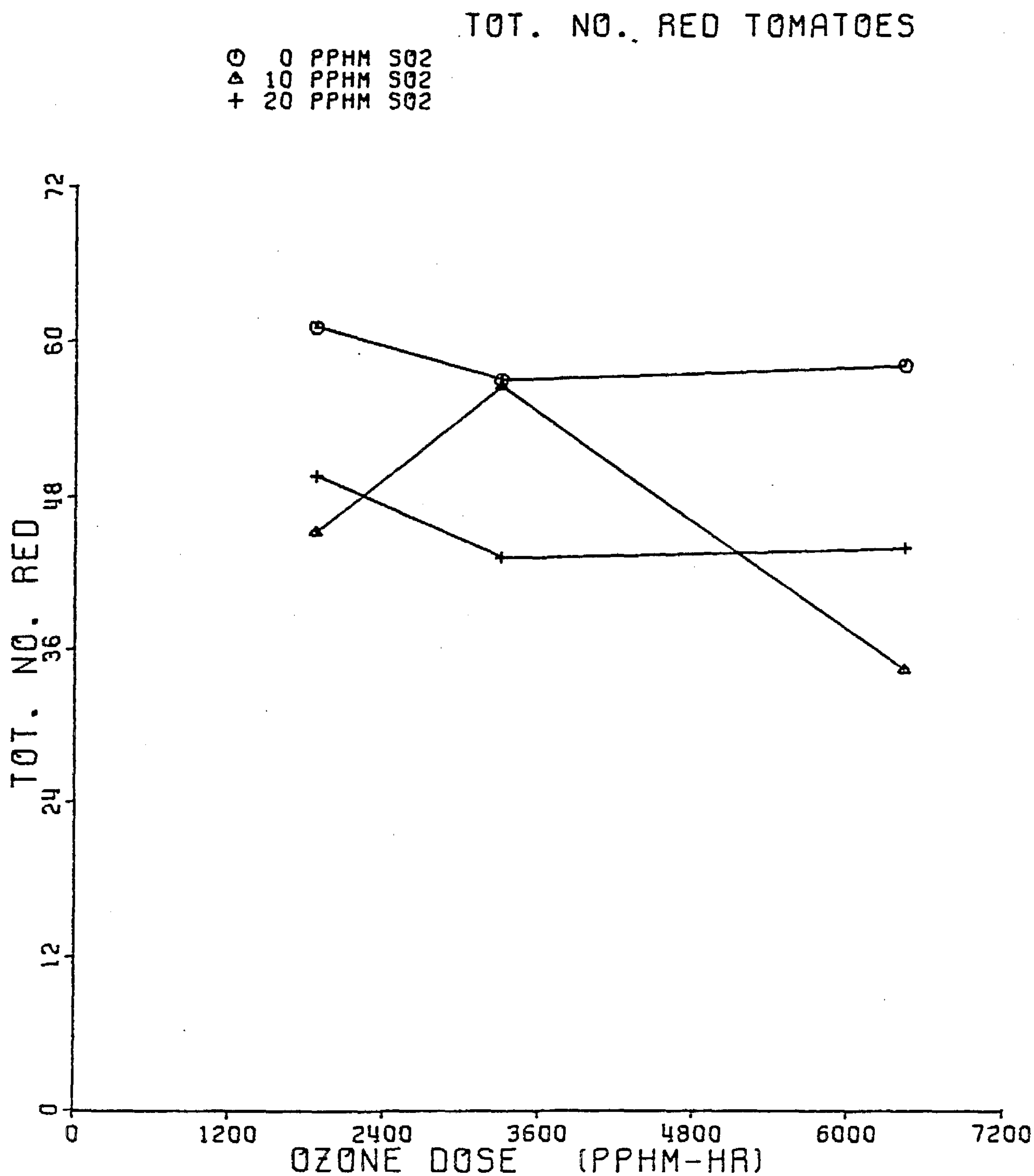


Figure 9. Effect of Ozone and SO_2 on the Total Weight of Red Tomatoes

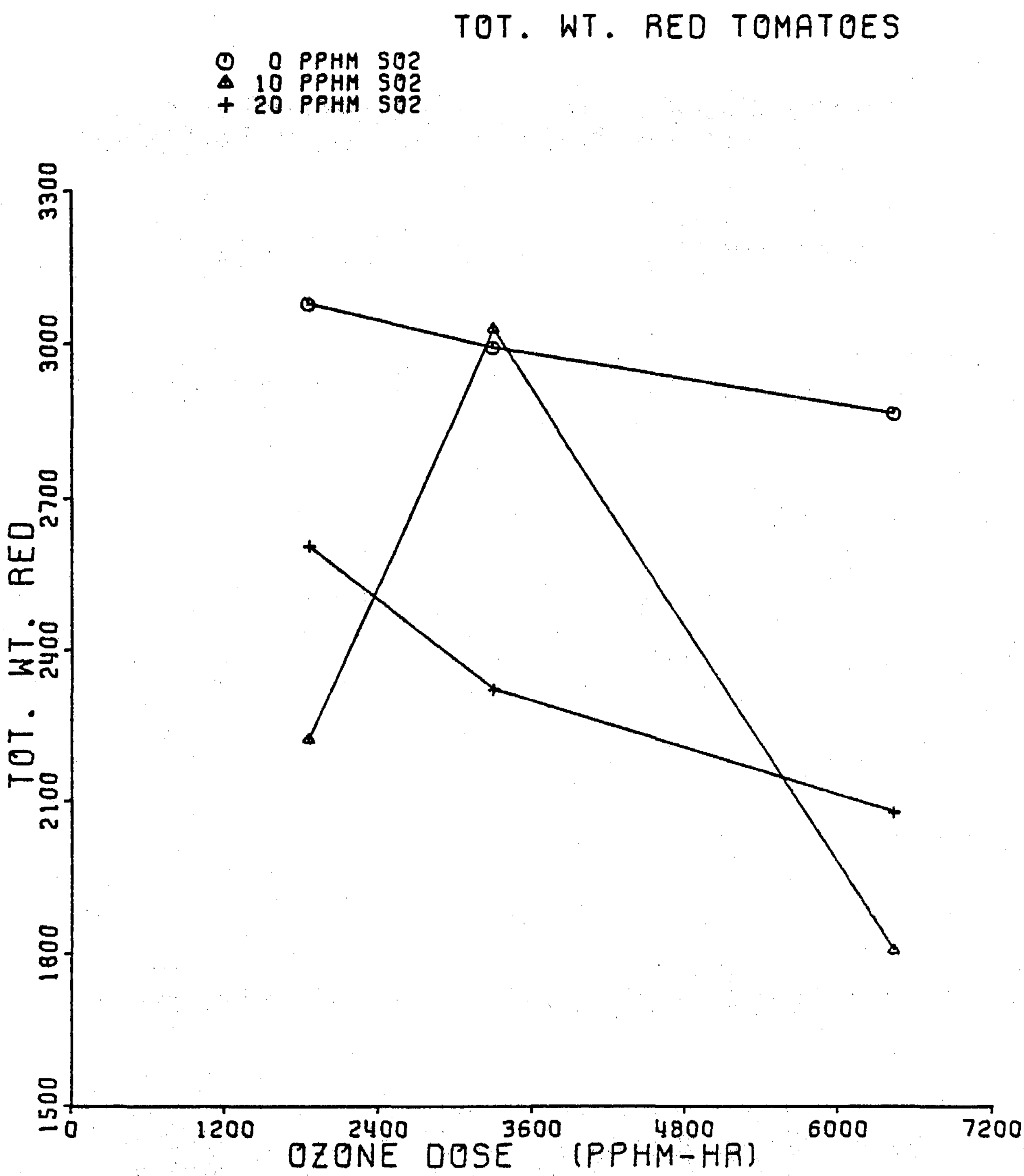


Table 9. Analysis of Variance of Variable 5 - Total No. Breaker Tomatoes

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	2.39805	2.39805	1.97	
O	2	10.96830	5.48415	4.51*	
Linear	1	10.56438	10.56438	8.69*	
Quadratic	1	0.40391	0.40391	0.33	
S	2	4.61280	2.30640	1.90	
Linear	1	1.15320	1.15320	0.95	
Quadratic	1	3.45960	3.45960	2.85	
S x O	4	21.02180	5.25544	4.32*	
SL OL	1	0.61417	0.61417	0.51	
SQ OL	1	20.19861	20.19861	16.62**	
SL OQ	1	0.10122	0.10122	0.08	
SQ OQ	1	0.10777	0.10777	0.09	
Error	8	9.72530	1.21566		17.0%
TOTAL	17	48.72625			

Combination	Count per Mean	Subclass B	S	O	Means
B	9				
		1	0	0	6.84
		2	0	0	6.11
O	6				
1530 pphm-hr		0	0	1	5.47
3243 pphm-hr		0	0	2	6.57
5740 pphm-hr		0	0	3	7.38
S	6				
0 pphm		0	1	0	5.85
10 pphm		0	2	0	7.09
20 pphm		0	3	0	6.47
S x O	2				
		0	1	1	3.71
		0	2	1	7.71
		0	3	1	5.00
		0	1	2	5.85
		0	2	2	7.57
		0	3	2	6.28
		0	1	3	8.00
		0	2	3	6.00
		0	3	3	8.14

* = significance at .05

** = significance at .01

Table 10. Analysis of Variance of Variable 6 - Total Wt. Breaker Tomatoes

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	839.9534	839.9534	0.34	
O	2	27282.6900	13641.3400	5.54*	
Linear	1	17492.9000	17492.9000	7.10*	
Quadratic	1	9789.7930	9789.7930	3.97	
S	2	32457.7200	16228.8600	6.59*	
Linear	1	355.2322	355.2322	0.14	
Quadratic	1	32102.5000	32102.5000	13.03**	
S x O	4	78779.2900	19694.8200	7.99**	
SL OL	1	4750.7480	4750.7480	1.93	
SQ OL	1	71898.4700	71898.4700	29.18***	
SL OQ	1	560.5964	560.5964	0.23	
SQ OQ	1	1569.3900	1569.3900	0.64	
Error	8	19710.2000	2463.7750		15.1%
TOTAL	17	159069.9000			

Combination	Count per Mean	Subclass B	S	O	Means
B	9				
		1	0	0	335.07
		2	0	0	321.40
O	6				
1530 pphm-hr		0	0	1	273.18
3243 pphm-hr		0	0	2	356.32
5740 pphm-hr		0	0	3	355.20
S	6				
0 pphm		0	1	0	292.93
10 pphm		0	2	0	387.96
20 pphm		0	3	0	303.81
S x O	2				
		0	1	1	175.30
		0	2	1	423.99
		0	3	1	220.24
		0	1	2	292.37
		0	2	2	448.10
		0	3	2	328.48
		0	1	3	411.11
		0	2	3	291.78
		0	3	3	362.71

* = significance at .05
** = significance at .01
*** = significance at .001

Figure 10. Effect of Ozone and SO_2 on the Total Number of Breaker Tomatoes

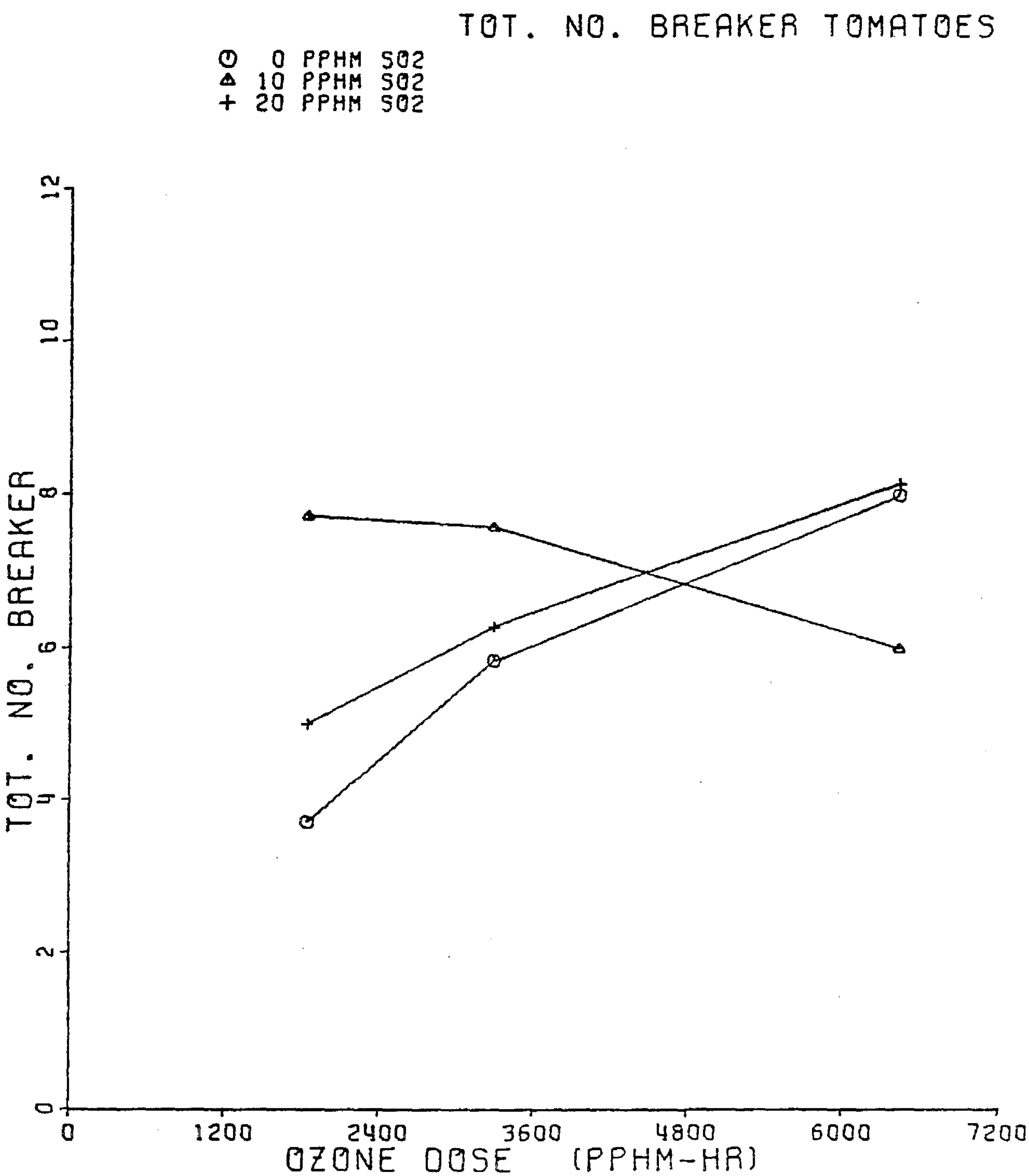


Figure 11. Effect of Ozone and SO_2 on the Total Weight of Breaker Tomatoes (grams)

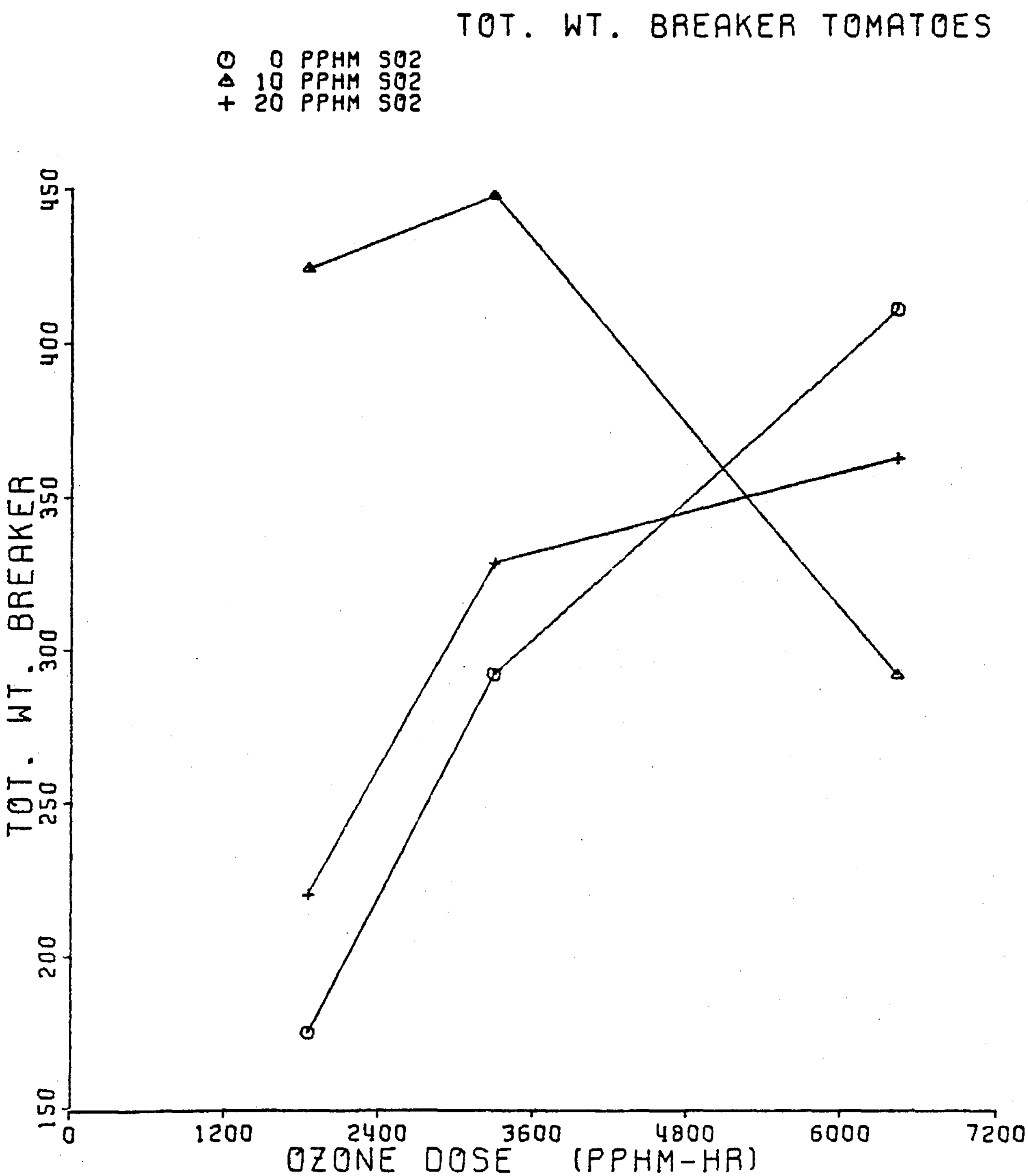


Table 11. Analysis of Variance of Variable 7 - Pulp Color

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	0.286272	0.286272	0.09	
O	2	5.852578	2.926289	0.96	
Linear	1	0.391826	0.391826	0.13	
Quadratic	1	5.460751	5.460751	1.79	
S	2	26.175240	13.087620	4.30	
Linear	1	26.166550	26.166550	8.60*	
Quadratic	1	0.008711	0.008711	0.00	
S x O	4	11.323360	2.830839	0.93	
SL OL	1	0.501018	0.501018	0.16	
SQ OL	1	2.325612	2.325612	0.76	
SL OQ	1	3.811851	3.811851	1.25	
SQ OQ	1	4.684881	4.684881	1.54	
Error	8	24.347980	3.043497		5.9%
TOTAL	17	67.985430			

Combination	Count per Mean	Subclass B	S	O	Means
B	9				
		1	0	0	29.32
		2	0	0	29.57
O	6				
1530 pphm-hr		0	0	1	30.07
3243 pphm-hr		0	0	2	28.69
5740 pphm-hr		0	0	3	29.57
S	6				
0 pphm		0	1	0	27.95
10 pphm		0	2	0	29.47
20 pphm		0	3	0	30.90
S x O	2				
		0	1	1	27.28
		0	2	1	31.28
		0	3	1	31.64
		0	1	2	28.43
		0	2	2	27.78
		0	3	2	29.86
		0	1	3	28.14
		0	2	3	29.35
		0	3	3	31.21

* = significance at .05

Figure 12. Effect of Ozone and SO_2 on the Pulp Color of Tomato. (Low Agtron No. = High Color Intensity)

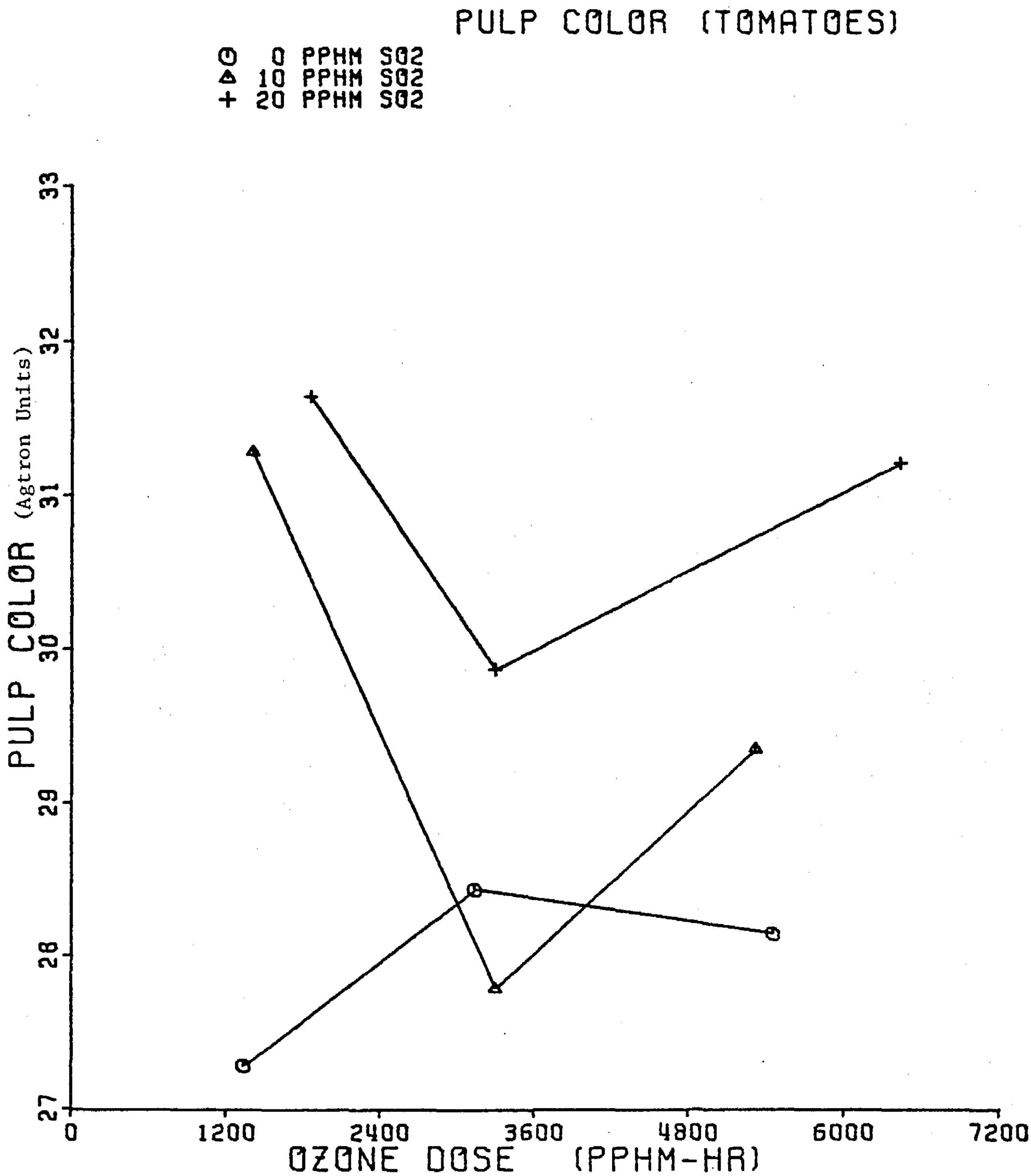


Table 12. Analysis of Variance of Variable 8 - pH.

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	0.0098000	0.0097999	10.59*	
O	2	0.0016777	0.0008388	0.91	
Linear	1	0.0001052	0.0001052	0.11	
Quadratic	1	0.0015725	0.0015725	1.70	
S	2	0.0024111	0.0012055	1.30	
Linear	1	0.0021333	0.0021333	2.31	
Quadratic	1	0.0002777	0.0002777	0.30	
S x O	4	0.0206222	0.0051555	5.57*	
SL OL	1	0.0057609	0.0057609	6.23*	
SQ OL	1	0.0001982	0.0001982	0.21	
SL OQ	1	0.0146557	0.0146557	15.84**	
SQ OQ	1	0.0000072	0.0000072	0.01	
Error	8	0.0074000	0.0009249		0.7%
TOTAL	17	0.0419111			

Combination	Count per Mean	Subclass B	S	O	Means
B	9				
		1	0	0	4.18
		2	0	0	4.23
O	6				
1530 pphm-hr		0	0	1	4.19
3243 pphm-hr		0	0	2	4.21
5740 pphm-hr		0	0	3	4.20
S	6				
0 pphm		0	1	0	4.22
10 pphm		0	2	0	4.20
20 pphm		0	3	0	4.19
S x O	2				
		0	1	1	4.26
		0	2	1	4.18
		0	3	1	4.13
		0	1	2	4.18
		0	2	2	4.21
		0	3	2	4.25
		0	1	3	4.20
		0	2	3	4.20
		0	3	3	4.19

* = significance at .05
** = significance at .01

Table 13. Analysis of Variance of Variable 9 - Plant Dry Wt.

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	4579.24500	4579.24400	15.29**	
O	2	169.30330	84.65166	0.28	
Linear	1	5.91086	5.91086	0.02	
Quadratic	1	163.39250	163.39250	0.55	
S	2	1445.94300	722.97160	2.41	
Linear	1	88.02087	88.02087	0.29	
Quadratic	1	1357.92200	1357.92200	4.53	
S x O	4	1944.88300	486.22080	1.62	
SL OL	1	570.68240	570.68240	1.90	
SQ OL	1	645.20870	645.20870	2.15	
SL OQ	1	716.76990	716.76990	2.39	
SQ OQ	1	12.22238	12.22238	0.04	
Error	8	2396.67000	299.58370		9.1%
TOTAL	17	10536.04000			

Combination	Count per Mean	Subclass B	S	O	Means
B	9				
		1	0	0	173.77
		2	0	0	205.67
O	6				
1530 pphm-hr		0	0	1	192.88
3243 pphm-hr		0	0	2	185.57
5740 pphm-hr		0	0	3	190.70
S	6				
0 pphm		0	1	0	193.15
10 pphm		0	2	0	177.43
20 pphm		0	3	0	198.57
S x O	2				
		0	1	1	193.40
		0	2	1	189.30
		0	3	1	195.95
		0	1	2	199.45
		0	2	2	176.20
		0	3	2	181.05
		0	1	3	186.60
		0	2	3	166.80
		0	3	3	218.70

** = significance at .01

Table 14. Mean Data for Each Treatment Plot of the Response Factors Measured in the Regression Analysis Experiment for VF145B-7879 Tomato Exposed to Various Concentrations of SO_2 and Polluted Ambient Air (Page 1 of 2)

Chamber #	Block	Level SO_2 pphm	Filtered ambient air (%)	Total no. red tomatoes	Total wt. red tomatoes (g)	Total no. breaker tomatoes	Total wt. breaker tomatoes (g)	Total no. green tomatoes	Total wt. green tomatoes (g)	Total no. red + breaker tomatoes	Total wt. red + breaker tomatoes (g)
7	1	0	100	60.29	2983.36	3.71	180.04	11.57	413.97	64.00	3163.40
3	1	10	100	52.71	2425.49	8.29	394.89	10.86	331.56	61.00	2820.37
10	1	20	100	41.57	2079.69	5.43	219.36	22.71	729.56	47.00	2299.04
2	1	0	75	51.14	2660.59	5.00	255.61	9.57	331.23	56.14	2916.17
6	1	10	75	57.86	2957.14	8.14	467.87	8.14	343.51	66.00	3425.01
1	1	20	75	49.00	2568.39	6.57	348.87	11.14	362.30	55.57	2917.26
5	1	0	50	56.57	2785.99	7.71	386.23	13.14	539.93	64.43	3179.63
4	1	10	50	29.71	1487.31	6.57	326.26	43.86	1604.26	36.29	1813.57
8	1	20	50	49.71	2221.84	10.14	436.46	18.29	634.24	59.86	2658.30
9	1	0	25	61.29	2736.24	10.71	505.43	10.29	332.26	72.0	3241.67
17	2	0	100	61.86	3171.00	3.71	170.57	15.86	642.73	65.57	3341.57
13	2	10	100	37.71	2014.47	7.14	453.09	38.29	1551.41	44.86	2467.56
20	2	20	100	57.57	3128.26	4.57	221.13	26.00	1174.73	62.14	3349.39
12	2	0	75	63.00	3319.19	6.71	329.14	22.00	758.01	69.57	3648.33
16	2	10	75	55.29	3095.99	7.00	428.34	16.00	556.06	62.29	3524.33
11	2	20	75	37.57	2069.79	6.00	308.10	39.14	1569.74	43.57	2377.89
15	2	0	50	59.86	2938.69	8.29	436.00	25.57	1043.54	68.14	3374.69
14	2	10	50	39.14	2120.59	5.43	257.30	21.00	661.77	44.57	2377.89
18	2	20	50	38.43	1923.51	6.14	288.96	31.29	1297.60	44.57	2212.47
19	2	0	25	66.57	3275.8	6.71	304.23	13.0	449.47	73.29	3580.03
AMB1	--	--	--	8.43	348.5	8.71	320.23	46.57	1201.03	17.14	668.7
AMB2	--	--	--	28.14	967.6	16.0	553.6	30.86	627.93	44.14	1521.2

Table 14 continued (Page 2 of 2)

Chamber #	Pulp color	Soluble solids	pH	Plant dry wt. (g)	% No. red tomatoes	% No. breaker tomatoes	% No. green tomatoes	% No. red + breaker tomatoes	% Wt. red tomatoes	% Wt. breaker tomatoes	% Wt. green tomatoes	% Wt. red + breaker tomatoes
7	26.86	5.97	4.24	182.1	79.78	4.91	15.31	84.69	83.40	5.03	11.57	88.43
3	30.00	5.77	4.17	173.9	73.35	11.54	15.11	84.89	76.95	12.53	10.52	89.48
10	32.29	6.30	4.07	169.0	59.63	7.79	32.58	67.42	68.67	7.24	24.09	75.91
2	27.43	6.06	4.14	168.4	77.83	7.61	14.56	85.44	81.93	7.87	10.20	89.80
6	27.71	5.79	4.21	170.2	78.04	10.98	10.98	89.02	78.47	12.42	9.12	90.88
1	28.86	5.78	4.24	171.8	73.45	9.85	16.70	83.30	78.32	10.64	11.05	88.95
5	27.71	5.54	4.21	181.0	73.07	9.96	16.97	83.22	75.05	10.40	14.54	85.65
4	32.14	5.19	4.17	164.5	37.07	8.20	54.73	45.28	43.52	9.55	46.94	53.06
8	30.86	5.73	4.16	183.0	63.62	12.98	23.41	76.61	67.48	13.26	19.26	80.74
9	27.14	5.64	4.20	177.8	74.48	13.02	12.5	87.5	76.56	14.14	9.30	90.70
17	27.71	6.00	4.29	204.7	75.97	4.56	19.48	80.52	79.59	4.28	16.13	83.87
13	32.57	5.40	4.19	204.7	45.36	8.59	46.05	53.96	50.12	11.27	38.60	61.40
20	31.00	5.67	4.19	222.9	65.32	5.18	29.50	70.50	69.15	4.89	25.97	74.03
12	29.43	5.51	4.23	230.5	68.69	7.32	23.99	75.86	75.33	7.47	17.20	82.80
16	27.86	5.73	4.21	182.2	70.62	8.94	20.44	79.56	75.87	10.50	13.63	86.37
11	30.86	5.29	4.26	190.3	45.42	7.25	47.32	52.68	52.43	7.80	39.76	60.24
15	28.57	5.40	4.20	192.2	63.87	8.85	27.28	72.71	66.51	9.87	23.62	76.38
14	26.57	5.90	4.23	169.1	59.69	8.28	32.03	67.97	69.76	8.46	21.77	78.23
18	31.56	5.50	4.23	254.4	50.66	8.09	41.25	58.75	54.80	8.23	36.97	63.03
19	27.71	5.31	4.17	192.9	77.15	7.78	15.07	84.93	81.30	7.55	11.15	88.85
AMB1	43.57	5.29	4.30	165.3	13.23	13.68	73.09	26.91	18.64	17.13	64.23	35.77
AMB2	38.86	5.31	4.23	153.5	37.52	21.33	41.14	58.86	45.02	25.76	29.22	70.78

Table 15. Doses of SO_2 and Calculated Doses of Ozone Used in the Experiment Designed for Regression Analysis

Chamber #	Block	Level SO_2 pphm	Filtered ambient air (%)	Dose >0 pphm/hrs	Dose >3 pphm/hrs	Dose >5 pphm/hrs	Dose >8 pphm/hrs	Dose >10 pphm/hrs	Dose >15 pphm/hrs	Dose >20 pphm/hrs
7	1	0	100	1456	1	0	0	0	0	0
3	1	10	100	1479	2	0	0	0	0	0
10	1	20	100	2016	3	0	0	0	0	0
2	1	0	75	2938	349	30	0	0	0	0
6	1	10	75	3132	326	18	0	0	0	0
1	1	20	75	3635	619	95	0	0	0	0
5	1	0	50	5296	1700	576	54	6	0	0
4	1	10	50	5273	1872	701	85	9	0	0
8	1	20	50	6638	2435	1041	167	30	0	0
9	1	0	25	8445	3969	2283	694	228	3	0
17	2	0	100	1220	0	0	0	0	0	0
13	2	10	100	1328	0	0	0	0	0	0
20	2	20	100	1681	2	0	0	0	0	0
12	2	0	75	3334	615	100	0	0	0	0
16	2	10	75	3466	548	58	0	0	0	0
11	2	20	75	2956	365	31	0	0	0	0
15	2	0	50	5628	1929	724	83	7	0	0
14	2	10	50	5366	1959	783	103	13	0	0
18	2	20	50	6237	2178	869	109	12	0	0
19	2	0	25	8091	3611	1942	547	168	2	0
AMB1	--	--	--	11671	7827	5914	3677	2537	824	180
AMB2	--	--	--	11671	7827	5914	3677	2537	824	180

Figure 13. Total Weight (Grams) of Red and Breaker Tomato Fruit Produced by VF145B-7879 Tomato Plants Treated with Five Dose Levels of Ozone

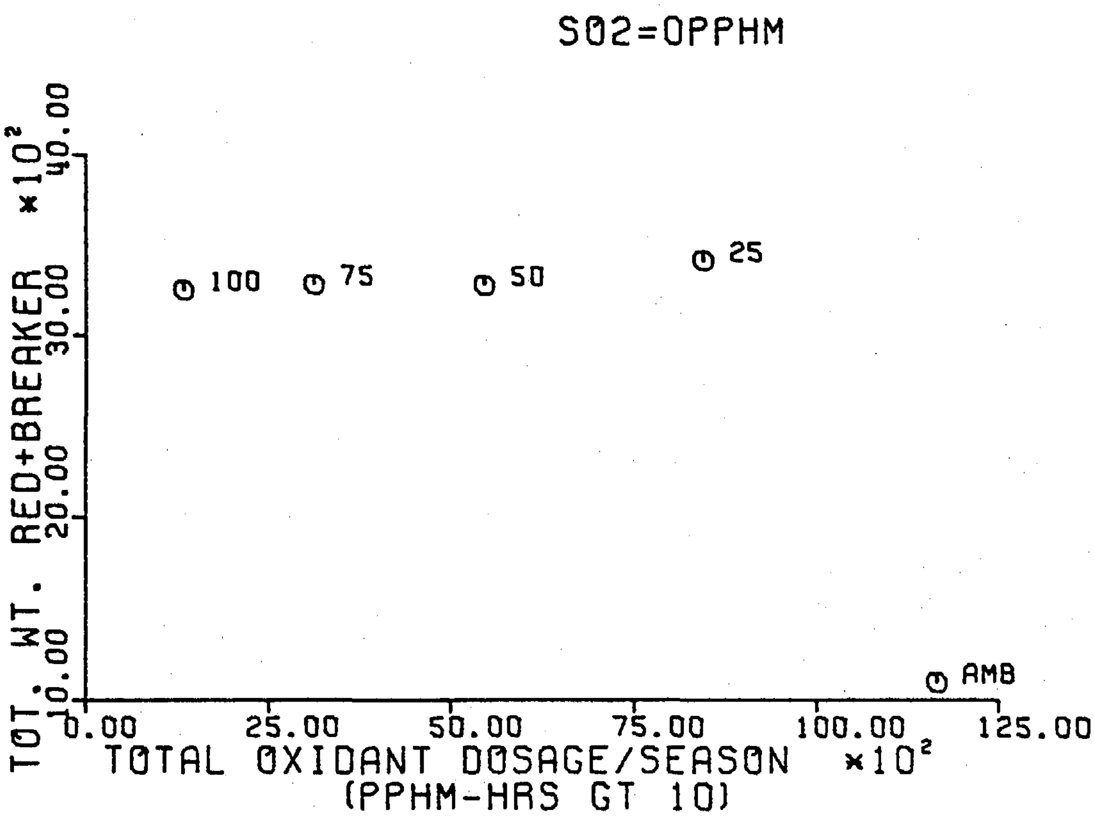


Figure 14. Fruit Size Distribution for Treatment Replicates by Number and Percent of Fruit in 25-gram Weight Categories (Page 1 of 4)

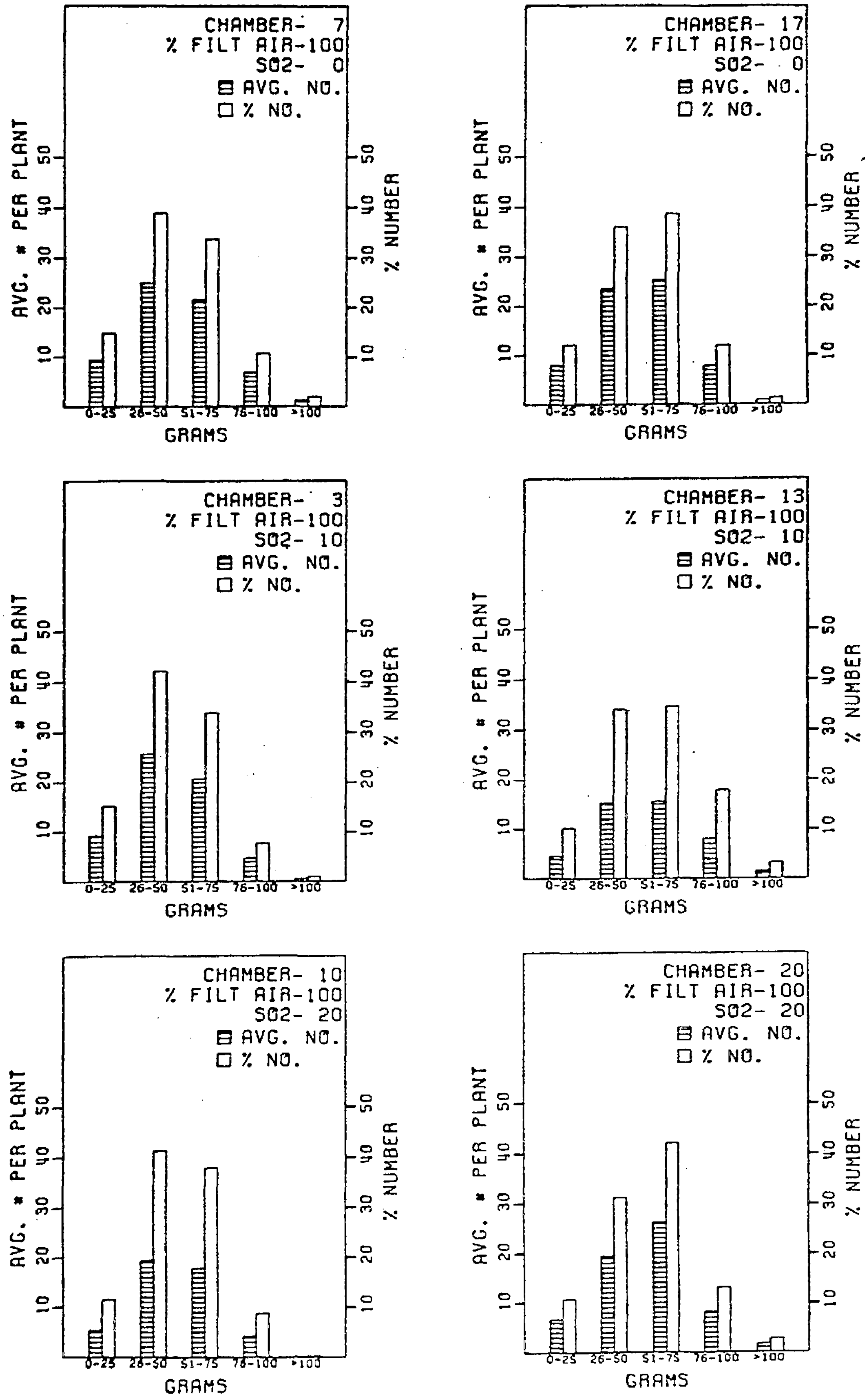
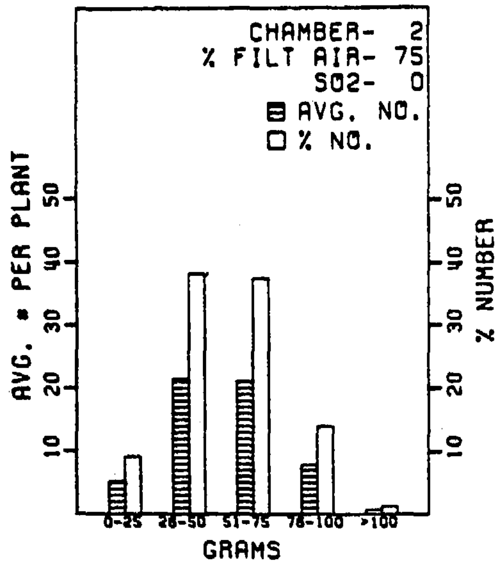
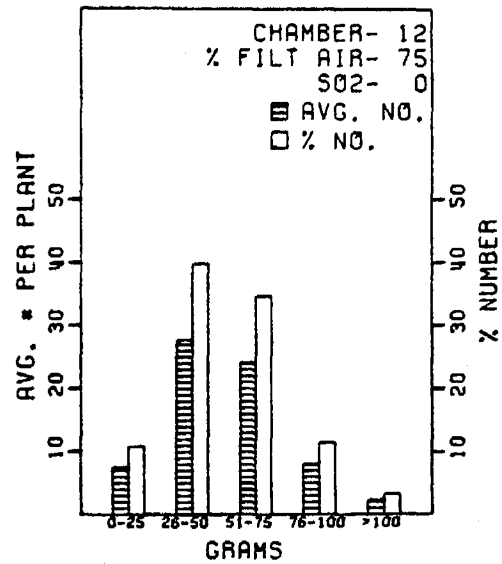
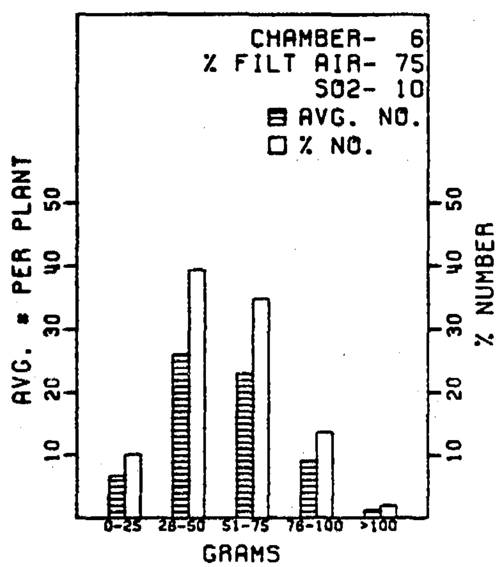
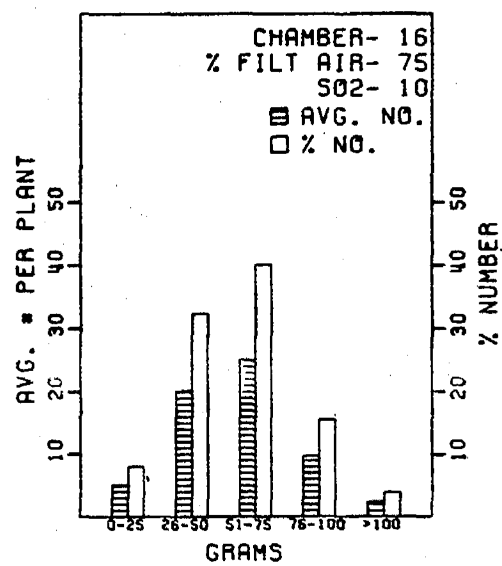


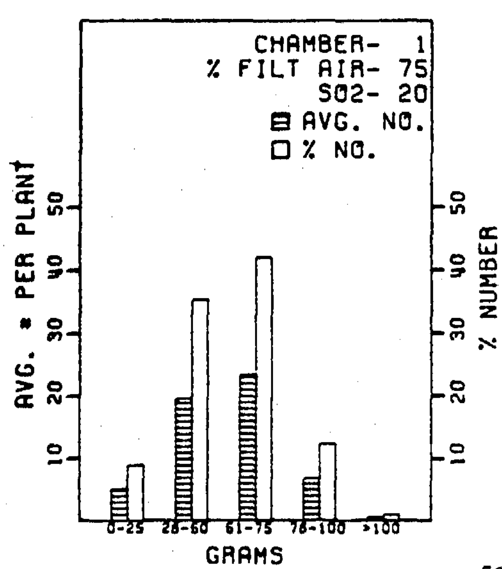
Figure 14 continued (Page 2 of 4)











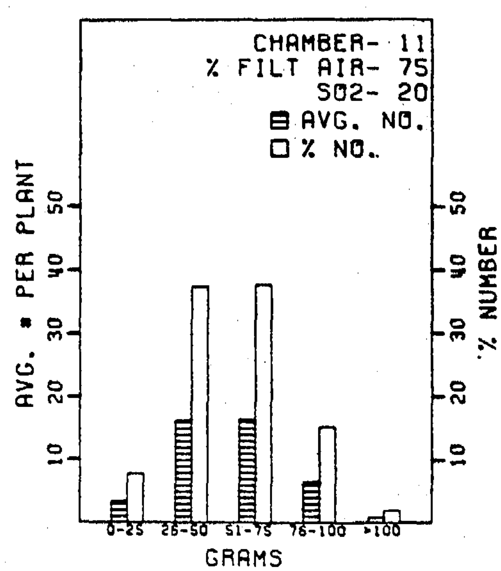


Figure 14 continued (Page 3 of 4)

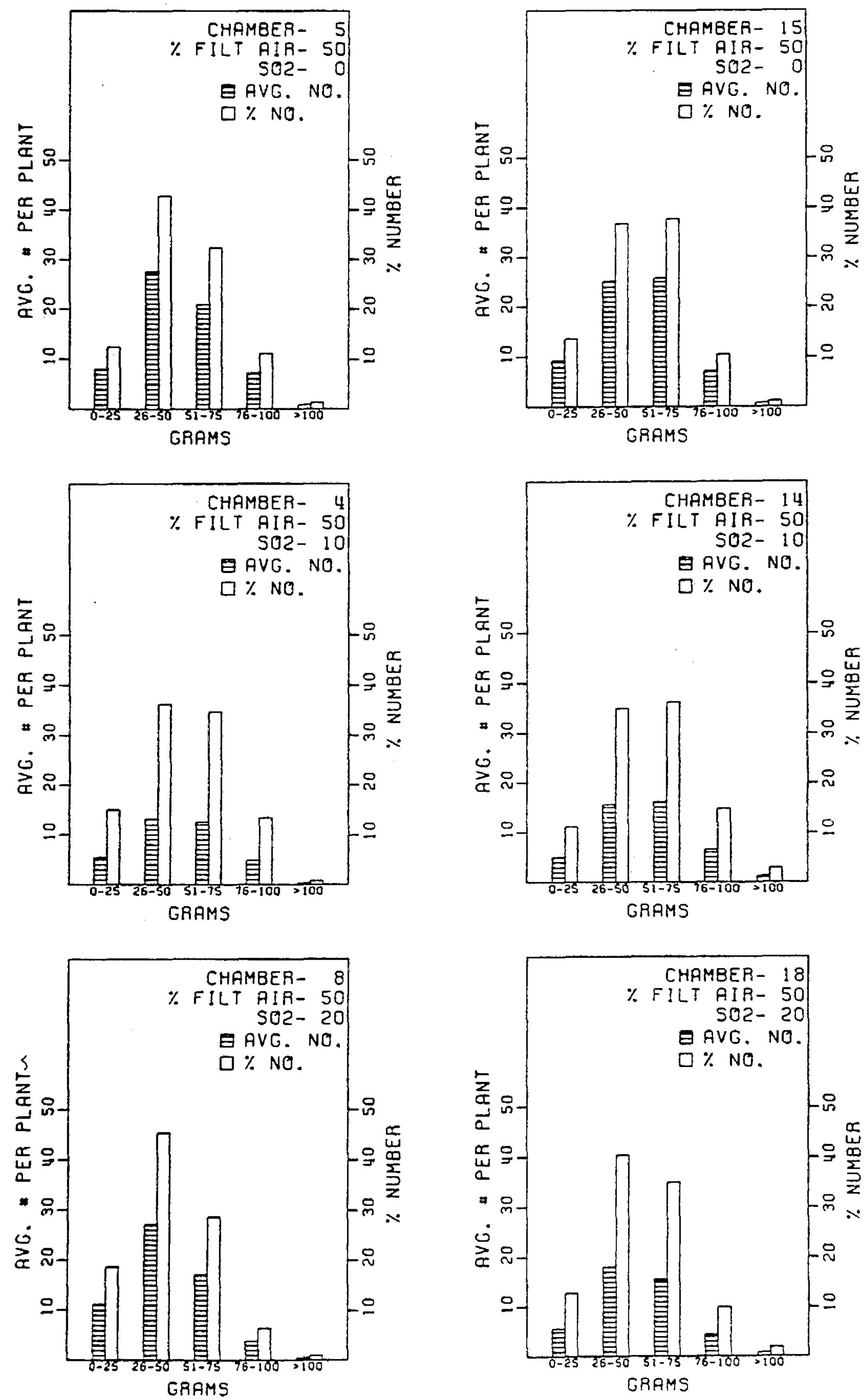


Figure 14 continued (Page 4 of 4)

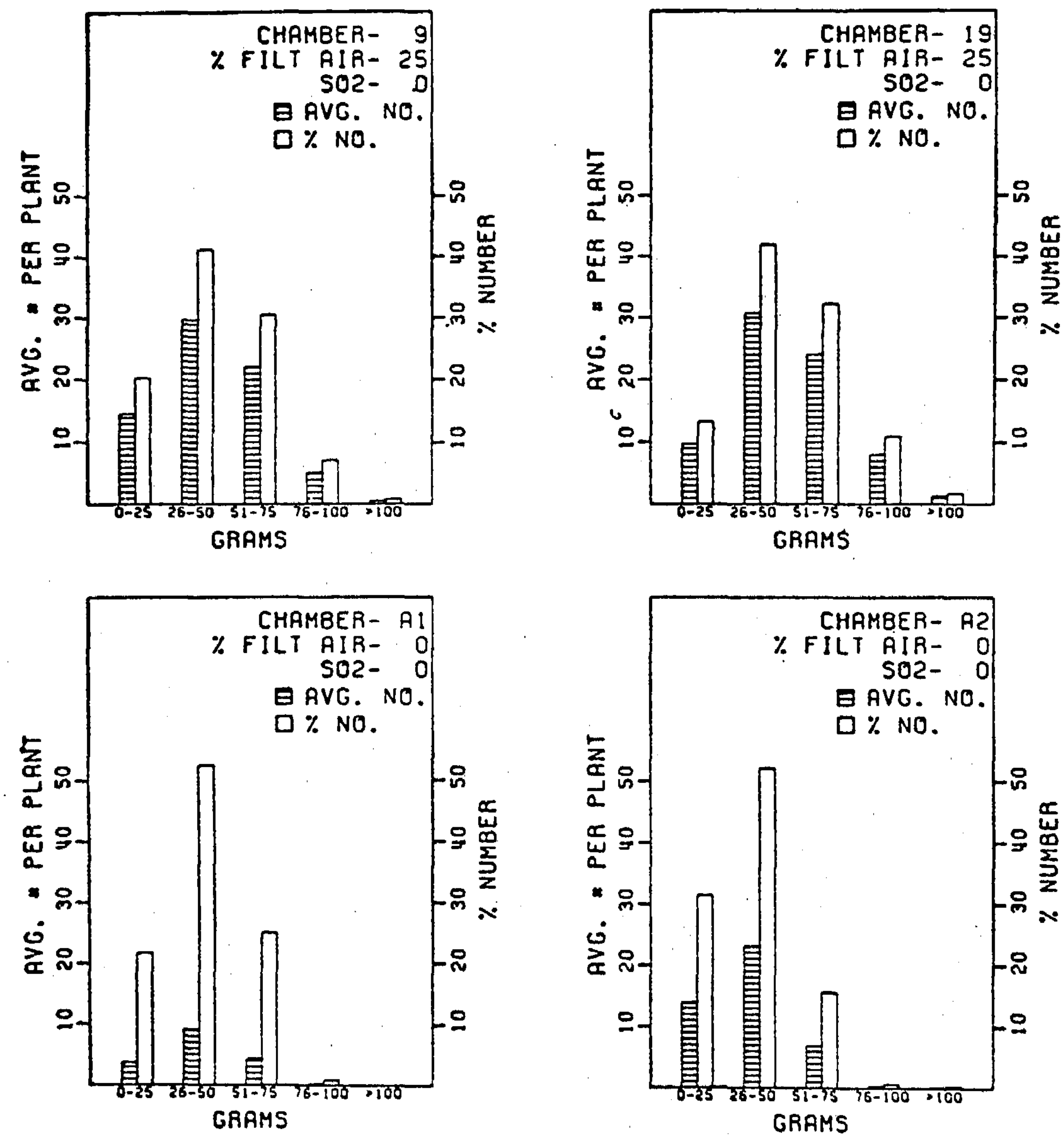


Figure 15. Relationship of Ozone Treatments by Chamber Number to the Commercial Yield of VF 145B-7879 Processing Tomato

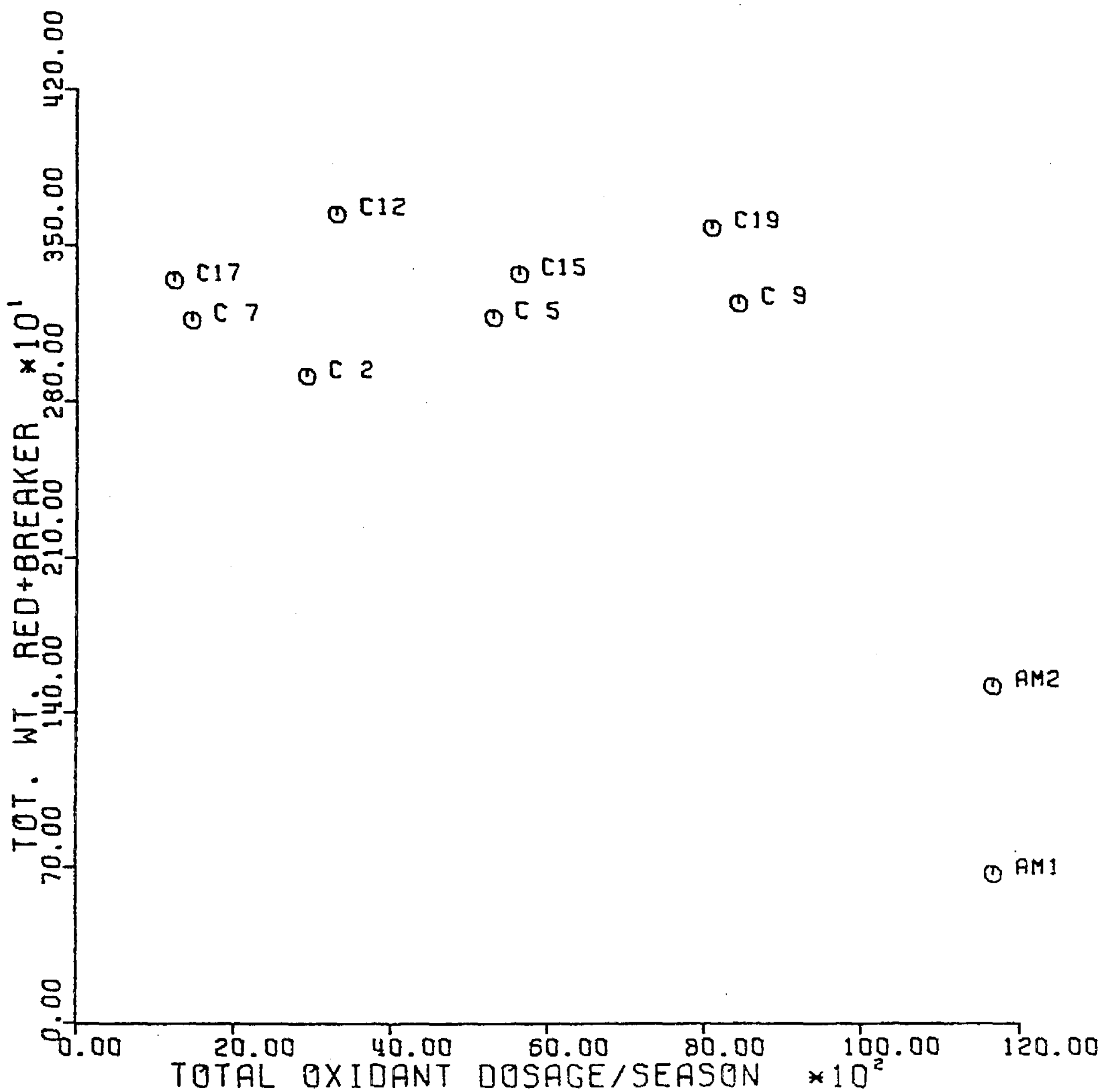


Figure 16. Comparison of Photosynthetically Active Radiation (PAR) Curve for Chamber 2 with the Ambient Curve June 19, 1978

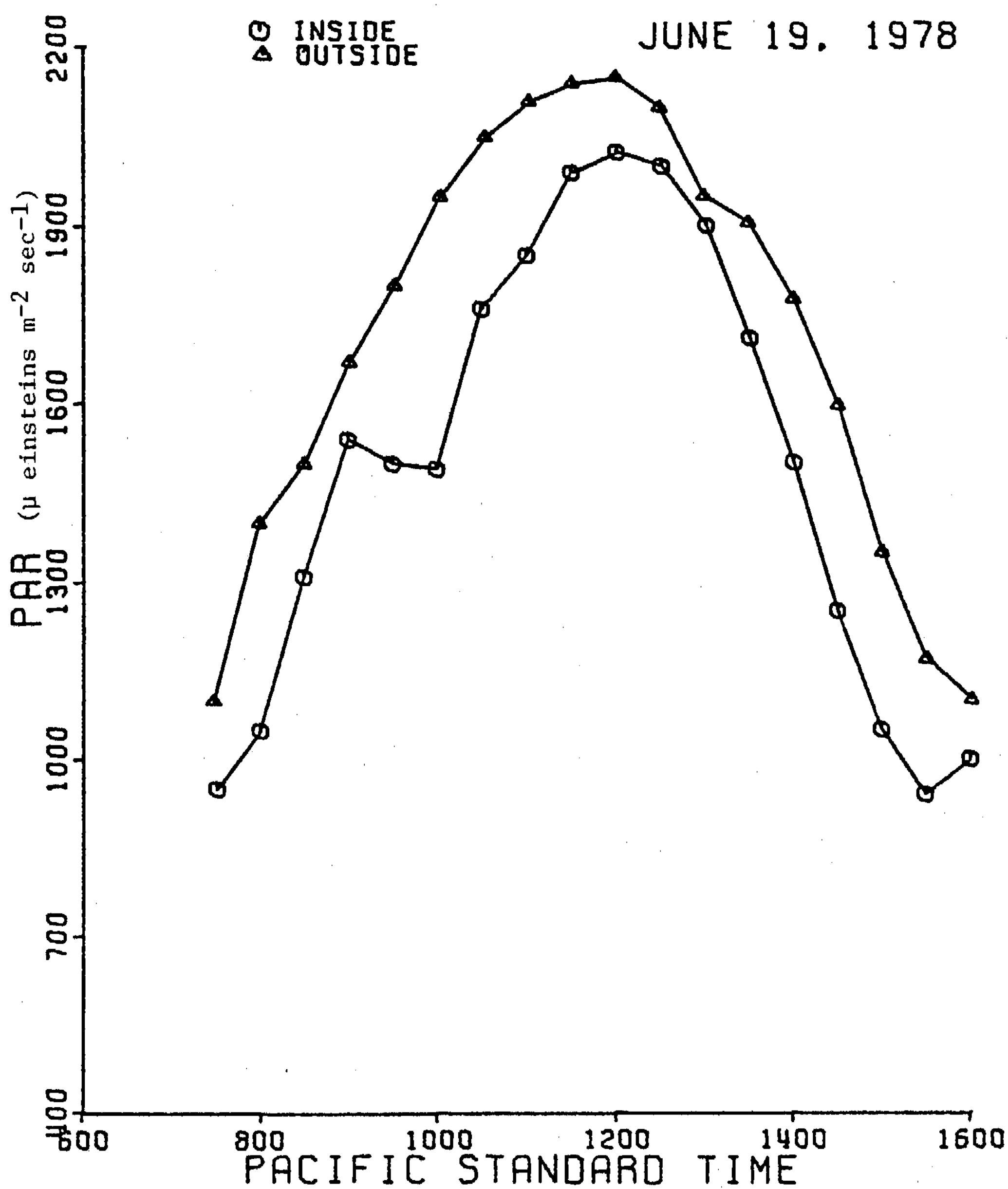


Figure 17. Comparison of Photosynthetically Active Radiation (PAR) Curve for Chamber 2 with the Ambient Curve July 28, 1978

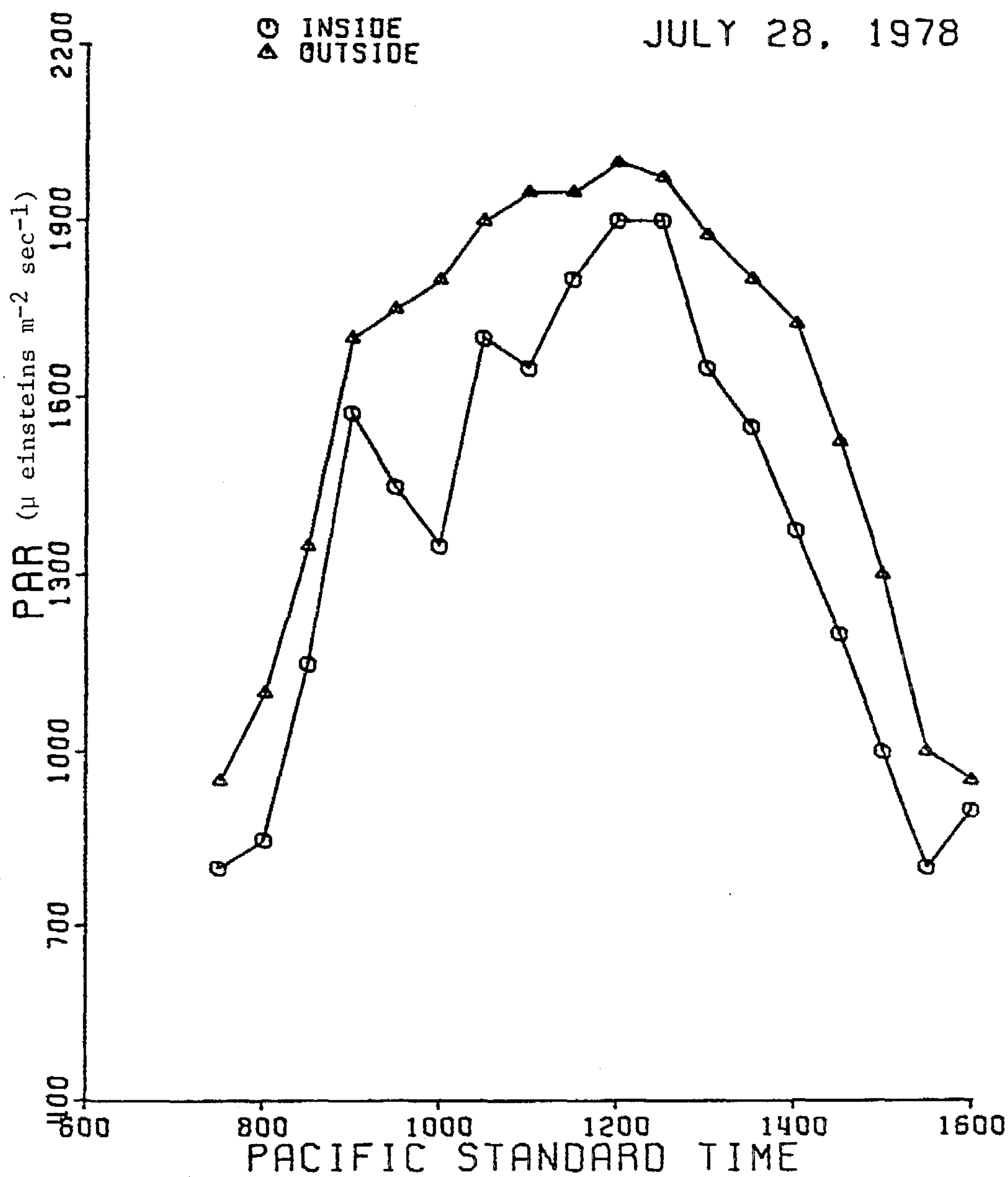


Figure 18. Comparison of Photosynthetically Active Radiation (PAR) Curve for Chamber 2 with the Ambient Curve September 8, 1978

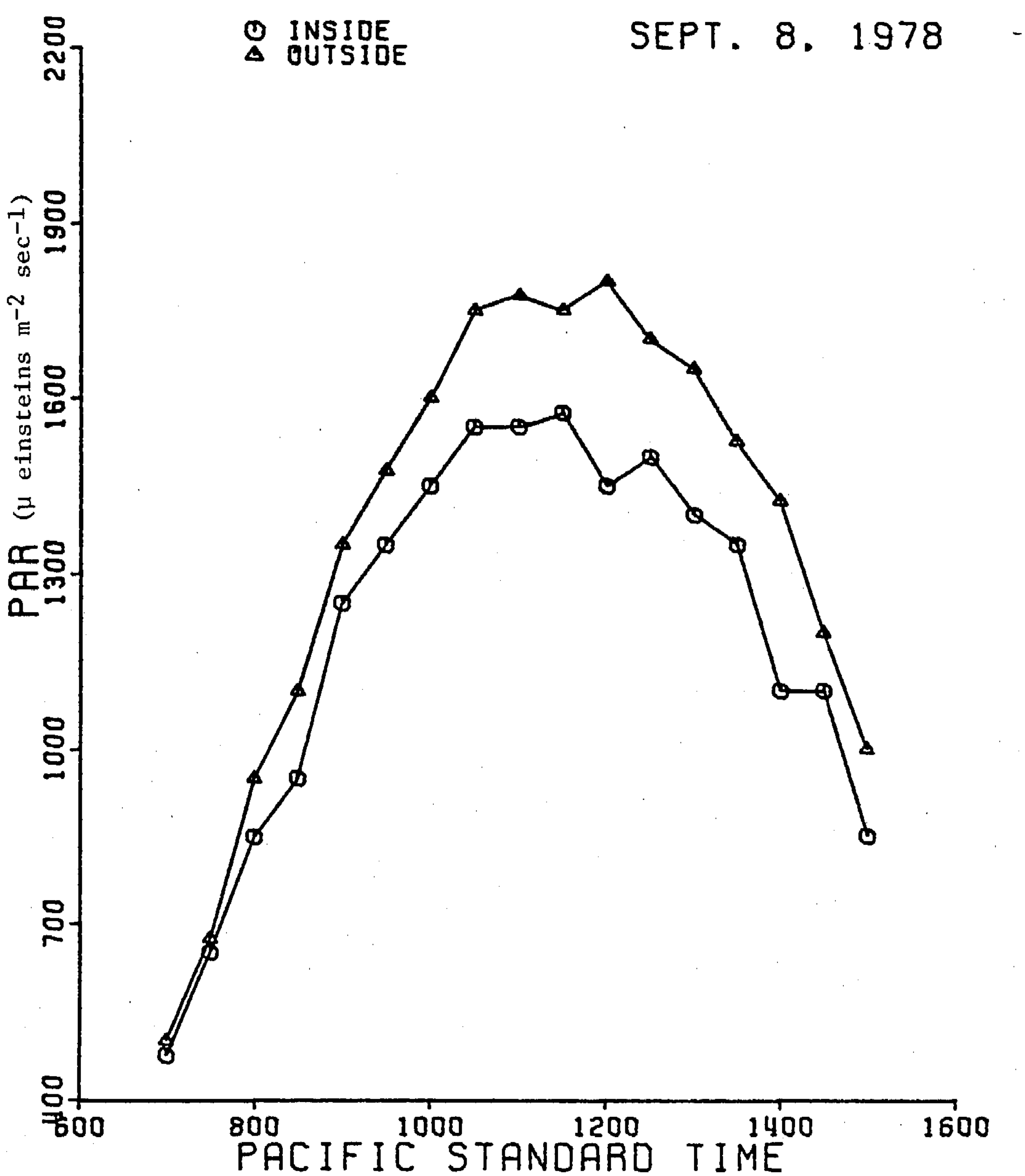


Table 16. Peak Chamber Ozone Concentrations (Highest One-Hour Average) with Corresponding Ambient Readings on Three Days During the Experiment when Ambient Oxidant (Ozone) was Highest

Chamber No.	% Carbon Filtered	6/17/78 ppm O_3	7/13/78 ppm O_3	7/14/78 ppm O_3
1	75	.07	.07	.08
11	75	.06	.06	.07
2	75	.06	.06	.06
12	75	.07	.08	.08
3	100	.03	.03	.03
13	100	.03	.02	.03
4	50	.11	.10	.11
14	50	.11	.11	.12
5	50	.10	.09	.11
15	50	.11	.10	.11
6	75	.06	.05	.06
16	75	.07	.06	.07
7	100	.03	.03	.03
17	100	.03	.03	.03
8	50	.12	.13	.12
18	50	.11	.13	.12
9	25	.15	.17	.15
19	25	.14	.17	.15
10	100	.03	.03	.04
20	100	.03	.03	.03
Ambient	0	.27	.23	.28

Table 17. Analyses of Soil Placed in the 15-Gallon Containers before Tomatoes were Transplanted to the Chambers and of the Same Soil at the Termination of the Experiment

Parameter	Preplant	Post Harvest
Mn (ppm)	6.4	4.7
Fe (ppm)	14.0	16.0
Cu (ppm)	9.1	9.1
K (ppm)	660.0	628.0
SP[a] (%)	46	53
pH	5.9	6.8
EC_e (millimhos/cm)	1.30	0.81
P (ppm)	101.0	57.0
Zn (ppm)	6.3	8.3
Ca + Mg (me/l)	10.7	4.5
Na (me/l)	1.1	3.0
Cl (me/l)	1.9	1.8
B (ppm)	0.40	0.64
NO_3-N (ppm)	23.0	1.1

[a]Saturation percentage - grams of water to saturate 100 grams of soil.

Table 18. Analysis of Water Soluble Sulfur as SO_4 in Soil Samples from Each of the Chambers and Two Ambient Air Plots. Two Samples of Soils not Used in the Experiment were Added as a Blank Test

Chamber No.	SO_4 (ppm)	Chamber No.	SO_4 (ppm)
1	100	7	20
11	65	17	55
2	130	8	10
12	35	18	45
3	225	9	20
13	25	19	20
4	165	Ambient 1	95
14	40	Ambient 2	35
5	75	Soil[a] 1	150
15	20	Soil 2	150
6	50		
16	30		

[a]Soil - refers to non-utilized soil.

IV. DISCUSSION

Commercial yield, expressed as total weight of red and breaker tomato fruits, was significantly reduced when plants were exposed to 10 and 20 pphm SO_2 for six-hour periods on 27 days and 24-hour periods on 12 days during a 10-week fumigation experiment. No visible symptoms of SO_2 injury were detected during the fumigation. Although the addition of SO_2 to the treatments significantly reduced commercial yield, there was no differential in effect produced by 10 pphm SO_2 compared to the 20 pphm treatment. Regression analysis could not be used for the SO_2 treatments since there was no difference between effects from the 10 and 20 pphm treatments. Thus, only two varying points were available and regression analysis was not appropriate.

The absence of a difference in plant response to the two levels of SO_2 used in the experiment cannot be explained. The average number of red and breaker fruits was identical for the two levels of SO_2 and the difference in average weight was about 3.5%. There was no evidence of a synergistic response between the ambient oxidant and SO_2; therefore, it must be assumed that an increase from 4,500 pphm-hr to 9000 pphm-hr of SO_2 or an increase in concentration from 10 pphm to 20 pphm had no measurable effect on the tomato plants.

The 3 x 3 factorial design used for the Anova analysis for the combined SO_2-O_3 experiment revealed a significant interaction between SO_2 and O_3. The interaction occurred at a single treatment data point (4500 pphm-hrs SO_2 + 3243 pphm-hrs O_3) which corresponds to the 10 pphm SO_2 + 75% filtered to 25% nonfiltered ambient air chamber. The reason for the increased fruit weight was not apparent and was viewed with some degree of skepticism since this data point did not appear to fit with the pattern of the other data points.

The results of the analyses of the numbers and weights of fruit in the red ripe, breaker and green categories provided no explanation for the tomato yield response to SO_2-O_3 mixture. Red ripe fruit produced essentially the identical response as the commercial yield. Breaker fruit yield tended to produce an interactive response but this was actually an insignificant harvest variable because of the small number of fruit in the category. As indicated in the Results Section (p. 22), the green fruit variable did not respond to SO_2, O_3, or the interaction of these pollutants.

Sulfur dioxide treatment resulted in a slight but statistically significant difference in color intensity but these changes were well within the acceptable pulp color range for marketability. The interaction of ozone and SO_2 produced a slight but statistically significant change in pH of the fruits. Overall, the pH ranged from a low of 4.07 to a high of 4.30 and this difference is well within the commercially desirable range.

Regression analysis was run with data from the 3 x 3 factorial design plus the added data from two chambers which received 25% filtered to 75% nonfiltered ambient air and two plots in ambient air (not enclosed in chamber). This regression analysis proved to be unproductive in showing a relationship of the pollutant treatments largely because there was no differential in response within the ozone treatments and because the response to the 10 and 20 pphm SO_2 treatments was essentially identical. Yield response of both SO_2 treatments was significantly different from the no SO_2 treatment but the SO_2 treatments were not different from each other. Regression analysis with only two significantly different points is inappropriate. A greater range in concentration of SO_2 and ozone (ambient oxidant), which would provide a range in plant yield and/or fruit quality response, should have produced data that could be used in regression analysis.

Response of plants in ambient air, measured as fruit size distribution, commercial yield, pulp color, weight and number of fruits in color categories and plant dry weight, was significantly different from that of plants in the filtered chambers. Although the reduced growth, yield and fruit quality may have been due entirely to the higher ozone level in the ambient air, it must be recognized that this treatment was not enclosed in chambers and much of the response may have been due to other unaccounted for environmental conditions or interactions. The "chamber effect" is well known in the research field and as yet attempts to entirely eliminate such effects have been unsuccessful. The ambient plots in this study produced significantly less fruit, lower fruit quality and less growth than the other ozone treatments. These data could not be used to evaluate chamber effects because of the absence of a 0% filtered to 100% nonfiltered ambient air treatment.

Environmental variables, soluble soil sulfate, and soil nutrients were monitored and these conditions were sufficiently uniform that it was concluded they should not have been a factor in altering yield responses of VF 145B-7879 processing tomatoes. Water soluble sulfate (SO_4) ranged from 10 ppm to 255 ppm in the soils from the various plots, but this variation is well within the allowable limits for good growth and production.

V. REFERENCES

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GLOSSARY

activated carbon, charcoal -- a powdered or granular carbon or charcoal prepared from wood, coconut shell, coal or petroleum and treated to increase porosity and enhance its capacity to remove oxidants, some organic vapors and other contaminants from air or liquids.

additive effects -- the combined effects of more than one pollutant acting simultaneously or in succession to give a total plant response equal to the sum of the independent effects.

air monitoring -- measurement of pollutant concentrations in the atmosphere.

ambient air -- air surrounding a given locus; the outside air.

antagonism -- when the combined effect of two or more pollutants is less than the sum of their independent effects; the antonym of synergism.

chronic injury -- injury which develops only after long-term or repeated exposure to an air pollutant, and expressed as chlorosis, bronzing, premature senescence, reduced growth etc.; can include necrosis.

damage -- a measure of the decrease in economic or aesthetic value resulting from plant injury by pollutants. (Term considered by some to be synonymous with injury.)

dose -- a measured concentration of a toxicant for a known duration of time (concentration per unit time) to which a receptor is exposed.

fumigation -- the natural or controlled exposure of plants to toxic gases or volatile substances.

injury -- any change in the appearance and/or function of a plant that is deleterious to the plant.

monitoring -- the use of gas sensing instruments or other devices to measure the concentrations of pollutants.

oxidant -- a substance capable of oxidizing a reference substance, that substance itself incapable of being oxidized by atmospheric oxygen; refers to several oxidizing gases in the atmosphere, particularly ozone, nitrogen dioxide and peroxyacetyl nitrates (PAN); those compounds capable of liberating iodine from neutral buffered potassium iodide solutions.

ozone -- the triatomic (O_3) allotrope of oxygen; a colorless to faintly bluish, unstable, pungent gas produced by electrical discharge in air, by solar ultra-violet radiation, or by other photochemical reactions of mixtures of certain hydrocarbons and NO_x; a strong oxidizing agent that is phytotoxic at low concentrations.

phytotoxicant -- any agent that becomes toxic to plants.

pollutant (air) -- any gas, liquid or solid air contaminant that causes undesirable effects on living organisms or materials.

pphm -- parts by weight or volume of pollutant per hundred million parts by volume of air. (Usually refers to volume of pollutant if not so stated.)

sensitivity -- a physiological condition of susceptible plants, or particular plant tissues, whereby they are prone to injury by pollutants.

synergism -- when the combined effect of two or more independent treatments is greater than the sum of each treatment alone. (Definition considered by some to be that of potentiation.)

APPENDIX A

Chamber Temperature Data for June 22, June 23 and June 24, 1978

Description of Data TEMPERATURE

Date JUNE 22, 1978

1978 ARB Data Summary Log

Chamber or T. C. Number (1 2)	Julian Date (3 4 5)	Year (6)	Data I. D. (7 8)	00 (9)	01 (12)	02 (15)	03 (18)	04 (21)	05 (24)	06 (27)	07 (30)	08 (33)	09 (36)	10 (39)	11 (42)	12 (45)	13 (48)	14 (51)	15 (54)	16 (57)	17 (60)	18 (63)	19 (66)	20 (69)	21 (72)	22 (75)	23 (78)	Daily Peak	Daily Total	Hourly Mean
1	173	8	TE	40	71	68	67	65	67	76	82	87	91	96	99	102	101	99	98	97	93	89	80	77	74	73	71			
2												91	94	101	104	105	101	99	99	97	93									
3												88	91	98	101	103	99	100	99	98	93									
4												90	93	94	104	105	102	101	100	97	94									
5												91	95	101	106	107	104	103	103	99	96									
6												91	96	102	106	108	105	104	104	98	95									
7												90	95	101	107	107	104	105	103	98	95									
8												91	95	103	105	106	107	106	103	97	96									
9												93	96	103	106	106	107	105	104	97	96									
10												89	94	104	107	107	107	105	103	96	96									
				00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23			
11												91	93	101	102	101	100	101	99	93	93									
12												88	91	99	98	94	95	98	97	91	91									
13												89	92	99	101	99	98	103	100	94	93									
14												89	93	100	100	101	96	101	100	93	93									
15												88	94	100	101	100	98	103	100	94	94									
16												90	97	100	102	103	101	104	102	94	94									
17												90	96	102	103	105	100	105	102	94	94									
18												90	97	103	102	106	101	105	101	93	94									
19												90	94	103	101	106	101	104	102	93	95									
20												89	93	102	102	107	103	103	101	93	94									
				00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23			
A				64	70	64	61	59	66	75	78	92	95	101	105	106	105	100	98	95	94	87	80	73	68	68	67			

Description of Data Temperature

Date June 23, 1978

1978 ARB Data Summary Log

Chamber or T. C. Number	Julian Date	Year	Data I. D.	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Daily Peak	Daily Total	Hourly Mean
1	174	8	TE	70	69	68	68	69	65	76	84	93	89	96	96	103	103	103	98	99	94	90	84	81	77	75	74			
2													92	102	102	105	104	104	101	101										
3													90	98	100	105	105	105	101	101										
4													93	101	105	106	105	104	102	101										
5													93	100	105	109	107	107	103	103										
6													93	101	105	110	108	108	105	103										
7													93	101	104	110	108	109	105	104										
8													93	100	103	111	109	104	105	104										
9													94	102	104	112	109	108	106	105										
10													93	102	105	114	104	109	107	106										
				00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23			
11													91	100	102	106	104	104	102	101										
12													90	97	99	100	99	99	98	96										
13													92	99	103	106	106	105	103	101										
14													93	100	104	109	106	106	105	102										
15													92	99	102	108	108	106	105	102										
16													93	98	103	108	106	107	105	102										
17													94	99	103	110	107	108	107	103										
18													93	101	102	109	106	107	106	102										
19													93	101	105	110	107	107	107	103										
20													94	100	107	111	106	106	106	102										
				00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23			
A				67	65	65	67	63	63	74	85	94	96	99	109	109	107	107	105	103	95	88	84	80	76	73	71			

Description of Data Temperature

Date June 24, 1978

1978 ARB Data Summary Log

Chamber or T. C. Number (1 2)	Julian Date (3 4 5)	Year (6)	Data I. D. (7 8)	00 (9)	01 (12)	02 (15)	03 (18)	04 (21)	05 (24)	06 (27)	07 (30)	08 (33)	09 (36)	10 (39)	11 (42)	12 (45)	13 (48)	14 (51)	15 (54)	16 (57)	17 (60)	18 (63)	19 (66)	20 (69)	21 (72)	22 (75)	23 (78)	Daily Peak	Daily Total	Hourly Mean
1	175	8	TE	73	72	70	70	69	68	82	89	89	94	97	100	101	101	97	97	95	93	87	79	76	73	71	70			
2												93	102	103	106	107	105	99	99	96										
3												91	96	100	103	104	103	101	100	97										
4												93	97	105	107	108	105	100	100	99										
5												92	98	102	106	108	104	102	99	98										
6												94	102	105	108	112	105	105	100	98										
7												93	100	104	108	112	104	105	100	100										
8												94	101	106	106	112	106	106	102	100										
9												95	103	105	109	110	106	105	102	101										
10												93	102	106	110	112	108	103	99	102										
11												94	98	102	105	106	102	99	95	96										
12												92	97	99	101	99	97	95	92	93										
13												91	96	101	103	103	100	97	97	96										
14												91	97	100	103	104	101	97	99	97										
15												92	99	102	105	104	100	99	99	98										
16												91	99	103	105	103	101	99	99	98										
17												94	101	104	108	104	101	101	101	99										
18												92	100	103	106	101	102	101	98	97										
19												93	100	103	107	103	103	103	100	99										
20												91	100	104	107	104	106	101	100	97										
A				71	68	67	70	66	64	81	88	95	102	103	109	103	107	101	98	96	90	82	75	72	70	67	68			

APPENDIX B

Chamber Relative Humidity Data Between
June 19, 1978 and July 31, 1978.

Locations: West Exhaust, East Exhaust,
Chamber 4 Exhaust, Chamber 13 Exhaust.

LOCATION	JULIAN DATE	HOUR 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21
WEST EXH	1708	23	24	23	35	30	22	30	25	16	12	9	4	7	11	14	21	18	20	17	25	30
WEST EXH	1718	34	34	40	39	43	40	37	30	36	29	26	17	12	10	17	25	20	23	11	31	38
WEST EXH	1728	41	40	49	49	46	49	42	38	35	19	22	18	14	12	10	6	10	15	20	22	28
WEST EXH	1738	44	41	50	53	57	58	41	37	35	26	5	10	13	9	10	14	10	13	21	27	36
WEST EXH	1748	43	50	50	51	43	48	31	27	27	20	15	10	8	10	13	12	15	18	20	22	15
WEST EXH	1758	23	23	24	21	21	30	27	25	28	17	7	6	6	12	7	9	11	14	20	26	10
WEST EXH	1768	35	31	44	43	43	43	42	38	31	31	30	26	27	20	23	25	27	30	34	36	38
WEST EXH	1778	54	62	61	61	66	66	62	55	50	41	42	40	30	35	35	35	40	45	51	52	59
WEST EXH	1788	67	62	62	62	62	62	57	49	44	48	38	36	34	35	35	39	42	44	52	51	54
WEST EXH	1798	66	66	66	66	66	0	0	0	59	52	45	43	40	42	39	34	33	41	46	56	59
WEST EXH	1808	0	0	0	0	0	0	0	0	0	50	47	42	40	44	39	35	38	40	38	41	52
WEST EXH	1818	66	66	71	71	71	71	68	61	54	52	47	44	39	43	40	43	34	39	40	47	53
WEST EXH	1828	59	62	67	71	66	71	65	61	52	50	44	45	41	38	38	34	53	33	40	47	48
WEST EXH	1838	62	66	66	65	70	70	68	60	61	52	45	41	39	38	40	39	36	38	42	47	56
WEST EXH	1848	66	61	66	65	65	70	57	60	54	55	53	47	45	46	44	41	33	35	33	39	41
WEST EXH	1858	57	57	66	57	61	60	59	57	50	56	44	45	42	40	41	41	45	48	50	51	57
WEST EXH	1868	67	67	72	72	77	76	73	69	70	63	60	53	54	49	44	50	34	38	46	51	53
WEST EXH	1878	67	68	67	77	72	77	64	65	62	57	86	56	53	52	52	52	58	39	40	44	35
WEST EXH	1888	68	68	67	72	72	77	73	69	63	60	58	56	54	0	62	60	59	62	64	70	69
WEST EXH	1898	80	75	79	79	83	83	75	77	70	63	61	62	60	1	1	1	1	1	27	40	41
WEST EXH	1908	61	65	60	64	68	73	65	55	53	36	32	24	14	22	14	14	7	14	26	34	41
WEST EXH	1918	59	64	68	67	72	77	68	61	52	43	45	39	22	16	26	24	27	27	30	35	39
WEST EXH	1928	64	78	78	77	82	82	83	69	66	56	53	48	35	30	30	21	23	24	30	39	44
WEST EXH	1938	64	64	63	63	72	54	60	47	39	38	31	18	13	16	20	15	20	25	30	35	38
WEST EXH	1948	26	39	32	35	39	42	36	27	30	23	12	11	7	7	15	17	21	24	26	29	31
WEST EXH	1958	31	35	36	33	38	41	42	34	28	26	22	21	18	18	18	22	25	28	26	31	32
WEST EXH	1968	32	35	37	39	44	47	39	29	31	30	25	24	20	22	28	27	30	29	28	37	38
WEST EXH	1978	47	53	50	52	60	63	54	49	48	39	37	39	31	31	31	33	37	38	41	49	51
WEST EXH	1988	63	67	49	75	75	75	68	58	50	46	42	38	34	37	41	46	50	49	53	62	64
WEST EXH	1998	80	75	75	79	79	84	71	65	56	50	46	45	40	41	39	41	45	41	45	52	61
WEST EXH	2008	75	79	79	79	79	79	75	68	62	0	54	42	37	43	35	41	37	42	43	46	51
WEST EXH	2018	58	100	65	74	65	69	59	53	49	53	46	43	37	38	39	38	35	35	40	52	58
WEST EXH	2028	66	70	74	74	73	73	66	61	59	51	41	35	36	44	43	43	47	52	60	66	65
WEST EXH	2038	80	79	79	84	79	84	71	61	59	57	52	48	43	46	46	45	48	47	52	55	61
WEST EXH	2048	71	71	75	70	79	74	68	65	60	55	51	49	42	43	51	55	53	54	55	57	63
WEST EXH	2058	72	76	76	76	76	75	76	76	70	58	53	51	52	55	49	50	58	57	59	64	67
WEST EXH	2068	76	81	80	80	80	80	76	73	74	64	59	54	58	55	55	53	58	60	65	71	74
WEST EXH	2078	76	76	76	76	80	76	73	66	64	62	59	57	58	53	58	58	58	60	65	68	70
WEST EXH	2088	76	76	80	76	76	76	77	73	71	72	66	64	61	62	59	62	61	61	66	68	71
WEST EXH	2098	77	76	85	85	80	80	77	74	71	66	60	64	64	59	59	62	64	70	69	75	74
WEST EXH	2108	85	81	85	85	85	84	76	81	74	68	69	60	67	58	58	61	64	63	66	79	76
WEST EXH	2118	85	85	85	89	89	89	80	77	70	71	68	63	55	56	62	71	67	70	45	82	82
WEST EXH	2128	90	95	84	89	84	89	85	73	74	75	100	67	64	70	67	67	69	69	75	78	78

LOCATION	JULIAN DATE	HOUR 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21
EAST EXH	1708	14	13	18	22	18	15	21	22	16	12	9	6	7	10	13	21	18	17	17	18	26
EAST EXH	1718	28	27	30	28	33	33	32	28	35	31	30	16	13	10	17	22	19	20	9	26	31
EAST EXH	1728	31	30	33	36	32	33	38	40	33	23	27	22	19	14	12	9	14	13	20	18	20
EAST EXH	1738	28	35	37	35	38	39	41	36	35	26	10	14	11	14	12	14	13	14	20	21	24
EAST EXH	1748	31	34	37	37	30	30	32	32	28	22	14	14	10	10	15	13	17	18	19	20	9
EAST EXH	1758	11	13	11	13	17	16	26	23	26	20	11	6	9	14	7	10	11	14	16	19	22
EAST EXH	1768	20	25	27	28	28	28	31	33	33	31	31	26	23	20	22	22	24	25	28	26	29
EAST EXH	1778	39	37	40	44	43	48	48	54	52	43	44	39	36	37	35	35	37	39	41	42	44
EAST EXH	1788	46	49	49	49	49	49	45	41	43	44	38	42	39	37	38	39	38	44	41	44	46
EAST EXH	1798	52	52	52	57	47	0	0	0	54	47	45	41	42	44	38	35	35	37	43	45	47
EAST EXH	1808	0	0	0	0	0	0	0	0	0	52	50	44	42	43	37	35	37	36	35	32	45
EAST EXH	1818	49	53	52	57	51	55	58	59	57	51	24	43	40	39	25	33	30	29	34	34	36
EAST EXH	1828	46	45	50	44	52	52	55	56	50	44	42	36	29	30	30	21	35	23	21	27	27
EAST EXH	1838	40	48	43	42	46	45	52	50	52	45	39	35	30	26	24	24	18	19	23	30	31
EAST EXH	1848	36	39	39	38	36	35	38	46	44	38	40	35	30	35	33	30	39	31	30	34	32
EAST EXH	1858	38	40	39	44	43	43	49	46	45	43	37	35	34	35	33	28	30	31	30	30	39
EAST EXH	1868	46	45	49	53	57	57	58	59	60	53	50	41	42	31	26	27	30	35	36	37	36
EAST EXH	1878	42	50	54	53	49	57	54	55	53	51	75	40	35	34	30	32	38	33	31	35	36
EAST EXH	1888	52	51	50	58	53	57	63	64	57	51	46	44	39	0	36	37	31	32	34	38	40
EAST EXH	1898	46	45	45	52	51	55	57	42	52	40	39	37	25	20	26	26	27	24	28	32	33
EAST EXH	1908	45	45	48	44	52	51	52	54	52	47	39	29	20	30	17	17	8	14	27	29	30
EAST EXH	1918	41	44	47	46	40	49	55	52	54	48	47	41	27	24	34	28	28	27	30	28	31
EAST EXH	1928	49	47	51	54	58	52	63	64	61	58	57	47	42	37	35	28	28	27	31	37	38
EAST EXH	1938	45	44	43	42	50	42	47	45	44	40	35	32	30	38	39	34	39	38	39	36	34
EAST EXH	1948	25	27	31	33	34	33	38	41	44	43	31	36	33	39	46	48	47	43	40	39	33
EAST EXH	1958	36	36	35	37	36	40	46	48	50	49	45	41	40	46	44	47	46	46	41	41	42
EAST EXH	1968	39	39	42	41	40	42	45	47	49	48	46	42	41	45	48	45	49	46	45	42	43
EAST EXH	1978	43	45	47	43	50	45	50	55	56	55	53	52	53	51	51	51	47	49	48	45	43
EAST EXH	1988	46	48	29	47	50	54	52	53	59	57	55	54	51	49	55	54	54	53	51	52	47
EAST EXH	1998	51	54	54	54	53	57	58	56	61	56	57	55	56	57	51	52	54	47	48	49	52
EAST EXH	2008	51	50	50	57	57	52	62	59	61	0	57	54	53	57	54	55	51	54	49	47	49
EAST EXH	2018	48	100	45	49	50	49	50	52	58	56	57	56	51	57	55	55	55	54	53	57	49
EAST EXH	2028	47	46	41	45	44	52	50	56	58	56	52	60	55	61	61	57	57	62	58	56	51
EAST EXH	2038	54	54	54	52	52	56	53	60	65	63	64	59	60	60	60	60	57	56	58	53	55
EAST EXH	2048	52	52	54	50	45	53	58	60	66	64	62	60	61	65	68	65	64	63	56	54	53
EAST EXH	2058	53	53	52	52	52	51	51	60	61	63	61	59	63	64	61	61	64	63	59	54	53
EAST EXH	2068	53	52	52	55	54	54	59	61	62	63	61	59	63	64	61	61	58	57	55	53	49
EAST EXH	2078	53	52	52	52	55	55	56	57	63	64	62	60	60	64	64	61	58	57	59	54	50
EAST EXH	2088	46	48	48	52	48	51	56	57	62	60	65	60	63	61	62	62	58	58	56	54	54
EAST EXH	2098	50	53	52	52	52	55	60	61	63	64	62	60	64	61	61	58	61	57	59	57	53
EAST EXH	2108	49	52	52	52	54	54	55	60	62	60	58	62	60	60	55	55	55	54	56	54	52
EAST EXH	2118	48	51	54	54	53	57	54	58	52	59	57	58	53	55	58	58	57	56	35	56	52
EAST EXH	2128	51	50	54	54	53	57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

LOCATION	JULIAN DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21
		HOUR																				
CH 4 EXH	1708	23	32	30	35	34	27	31	23	18	15	13	8	11	17	18	21	22	24	22	26	34
CH 4 EXH	1718	38	45	45	44	48	44	37	32	31	28	26	18	15	16	18	23	22	23	12	32	36
CH 4 EXH	1728	41	44	43	46	50	46	46	40	32	22	25	21	18	19	14	13	17	21	25	26	31
CH 4 EXH	1738	48	48	51	54	53	54	45	42	36	31	14	18	17	18	19	20	18	21	27	57	38
CH 4 EXH	1748	44	47	51	51	43	49	32	33	32	23	18	18	15	23	18	19	22	23	26	28	18
CH 4 EXH	1758	24	26	25	28	28	34	30	29	30	21	15	11	14	21	14	14	18	21	26	30	11
CH 4 EXH	1768	36	38	45	48	48	43	43	39	39	32	32	26	25	29	25	29	30	30	38	41	42
CH 4 EXH	1778	59	57	62	66	66	71	62	61	48	35	40	45	37	39	40	38	59	54	63	66	69
CH 4 EXH	1788	68	73	72	72	72	72	67	64	54	58	50	45	43	51	47	46	58	57	62	65	68
CH 4 EXH	1798	77	72	72	77	77	0	0	0	65	55	53	51	49	54	50	46	55	53	59	61	69
CH 4 EXH	1808	0	0	0	0	0	0	0	0	0	56	51	49	47	55	51	47	53	48	52	50	61
CH 4 EXH	1818	77	72	77	82	76	76	73	66	60	54	53	50	48	56	46	45	44	46	47	51	57
CH 4 EXH	1828	68	67	67	72	71	76	69	66	60	55	49	45	45	53	43	38	51	36	35	43	48
CH 4 EXH	1838	66	71	71	70	70	76	67	61	58	53	45	43	38	47	42	41	37	35	38	46	52
CH 4 EXH	1848	62	61	66	70	70	70	62	56	54	49	47	43	44	55	51	47	53	48	46	51	50
CH 4 EXH	1858	62	62	61	66	66	71	68	61	59	53	52	50	47	56	51	47	49	52	49	47	57
CH 4 EXH	1868	67	67	67	77	77	76	78	74	67	64	58	56	47	55	48	44	50	52	50	51	57
CH 4 EXH	1878	68	73	72	77	77	77	73	66	68	65	91	57	51	59	49	52	54	52	47	52	50
CH 4 EXH	1888	73	73	73	77	77	82	83	75	72	65	63	60	54	0	53	56	52	50	49	50	53
CH 4 EXH	1898	70	65	69	73	73	73	75	57	66	63	57	58	49	54	48	56	55	45	41	50	52
CH 4 EXH	1908	69	74	69	73	78	83	74	72	73	63	57	54	48	60	49	42	35	38	45	50	52
CH 4 EXH	1918	69	68	64	63	67	77	69	75	72	66	63	57	48	56	55	48	50	47	45	46	48
CH 4 EXH	1928	65	68	73	72	72	72	73	70	68	69	66	64	61	62	55	48	48	41	47	49	55
CH 4 EXH	1938	61	64	59	59	63	63	61	63	57	58	53	48	43	54	48	39	44	41	41	42	49
CH 4 EXH	1948	43	37	37	39	43	46	50	48	52	47	40	38	32	43	46	43	42	42	37	37	34
CH 4 EXH	1958	37	40	39	38	41	43	52	51	53	48	47	28	46	48	41	44	43	43	36	36	35
CH 4 EXH	1968	37	37	36	42	44	47	53	56	54	49	45	46	42	49	48	45	45	41	34	37	35
CH 4 EXH	1978	43	49	49	52	59	62	60	62	60	58	56	54	52	53	52	52	49	45	45	46	47
CH 4 EXH	1988	59	62	41	66	70	70	63	69	67	64	62	59	56	64	63	65	65	57	59	61	64
CH 4 EXH	1998	75	75	75	74	84	84	70	76	74	71	68	65	62	67	62	59	58	54	52	54	61
CH 4 EXH	2008	66	75	74	79	84	79	79	76	78	0	68	65	55	88	66	48	49	52	47	47	50
CH 4 EXH	2018	53	100	60	64	59	59	62	60	55	56	52	49	42	52	45	39	40	37	32	47	50
CH 4 EXH	2028	57	61	64	59	63	68	61	60	58	57	48	44	48	58	50	46	48	54	52	54	56
CH 4 EXH	2038	70	70	74	79	78	78	70	72	66	60	61	55	49	60	53	52	48	45	46	44	45
CH 4 EXH	2048	54	57	57	61	65	69	70	68	66	60	55	53	54	55	55	54	56	52	44	45	45
CH 4 EXH	2058	59	58	62	62	57	61	70	71	65	63	61	56	56	61	53	57	56	53	51	53	52
CH 4 EXH	2068	63	67	71	66	70	75	76	69	70	67	62	60	60	64	60	57	53	52	53	55	58
CH 4 EXH	2078	58	62	66	62	66	66	63	65	63	64	58	59	60	61	60	56	56	55	50	49	51
CH 4 EXH	2088	59	58	62	66	66	66	67	68	70	64	65	60	63	64	58	57	57	55	38	52	52
CH 4 EXH	2098	63	63	62	66	66	70	71	65	67	64	62	60	60	65	57	57	60	58	57	59	58
CH 4 EXH	2108	67	71	71	75	79	75	80	73	70	68	68	62	63	67	57	57	53	88	50	59	65
CH 4 EXH	2118	71	70	75	79	69	84	84	76	73	67	68	62	56	58	57	57	52	51	27	74	61
CH 4 EXH	2128	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

LOCATION	JULIAN DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21
CH13 EXH	1708	37	38	42	47	41	38	41	32	25	21	24	19	19	23	29	33	31	31	33	35	40
CH13 EXH	1718	53	52	52	57	56	57	52	45	45	41	42	31	26	24	29	33	31	32	15	40	42
CH13 EXH	1728	48	51	50	58	58	58	53	49	45	39	43	35	29	28	24	25	28	29	32	32	38
CH13 EXH	1738	52	52	55	58	62	58	57	48	45	39	25	26	26	22	27	29	25	27	32	40	45
CH13 EXH	1748	55	55	55	59	55	57	42	42	40	35	29	26	22	24	25	26	25	29	33	35	30
CH13 EXH	1758	33	33	35	38	38	45	43	40	38	32	29	26	24	28	28	24	29	29	34	39	19
CH13 EXH	1768	42	45	52	56	56	60	55	50	38	45	48	40	36	34	37	38	42	43	44	48	49
CH13 EXH	1778	67	66	76	76	76	82	72	69	59	53	56	56	27	48	54	56	55	57	59	65	73
CH13 EXH	1788	78	72	71	71	76	71	67	67	62	58	65	54	52	52	52	55	57	56	61	64	68
CH13 EXH	1798	82	77	77	77	76	0	0	0	73	59	65	61	52	52	49	52	51	53	58	61	68
CH13 EXH	1808	0	0	0	0	0	0	0	0	0	60	62	59	50	53	50	50	49	51	52	53	61
CH13 EXH	1818	77	82	82	82	81	81	78	70	68	61	60	57	51	51	48	51	47	48	50	50	57
CH13 EXH	1828	67	72	77	76	82	76	78	66	64	58	60	57	51	48	48	44	61	45	42	65	52
CH13 EXH	1838	71	71	76	75	81	81	72	69	62	57	56	56	50	45	45	47	39	38	38	50	52
CH13 EXH	1848	66	71	70	70	75	75	66	60	58	60	59	59	50	50	54	47	49	51	49	54	57
CH13 EXH	1858	67	71	71	71	71	76	73	65	63	61	63	59	53	54	54	53	56	55	56	54	61
CH13 EXH	1868	77	77	77	82	82	88	78	79	75	68	66	66	53	53	50	50	53	52	53	58	61
CH13 EXH	1878	78	78	77	82	88	88	78	70	68	69	96	63	54	55	52	55	54	55	53	55	57
CH13 EXH	1888	78	78	83	77	82	88	83	79	76	69	67	64	58	0	56	56	52	53	55	57	64
CH13 EXH	1898	74	69	73	78	78	83	79	95	66	63	65	75	53	51	54	56	49	51	46	57	56
CH13 EXH	1908	74	73	73	78	68	83	79	76	73	70	69	65	56	57	50	49	45	45	52	53	59
CH13 EXH	1918	68	78	78	82	82	83	83	80	72	73	75	71	61	57	62	58	50	56	55	56	54
CH13 EXH	1928	78	83	83	88	88	88	88	84	80	77	74	79	68	65	62	58	50	53	51	56	58
CH13 EXH	1938	78	78	78	77	77	72	73	71	69	66	60	58	52	53	59	59	55	54	56	54	56
CH13 EXH	1948	51	55	55	58	63	67	65	63	66	30	61	59	50	48	51	54	54	53	51	49	46
CH13 EXH	1958	47	50	50	49	52	56	59	62	63	61	62	60	57	55	58	58	51	54	46	44	43
CH13 EXH	1968	43	46	49	48	54	58	60	63	64	62	60	64	58	55	62	58	58	54	47	45	47
CH13 EXH	1978	53	56	56	55	63	70	68	73	71	72	69	73	64	61	61	64	60	59	54	55	57
CH13 EXH	1988	67	66	47	74	74	79	76	73	70	68	72	73	63	65	69	69	59	64	63	65	64
CH13 EXH	1998	79	84	84	84	83	89	79	77	74	71	72	69	62	60	60	63	55	57	52	54	61
CH13 EXH	2008	75	74	79	79	83	83	84	81	78	0	72	72	62	63	56	59	55	54	53	50	53
CH13 EXH	2018	57	100	68	68	64	68	70	68	70	70	64	65	59	59	51	43	43	41	39	50	56
CH13 EXH	2028	65	64	64	68	72	73	65	63	66	63	57	52	50	57	53	52	54	53	56	57	60
CH13 EXH	2038	79	79	79	78	78	83	79	72	69	67	64	65	52	55	55	55	54	47	49	47	52
CH13 EXH	2048	66	61	69	65	68	73	75	72	66	67	64	62	56	54	57	57	56	52	50	48	51
CH13 EXH	2058	67	67	66	70	66	65	75	75	69	67	68	65	60	60	61	60	56	55	54	56	55
CH13 EXH	2068	63	67	70	75	75	79	80	77	70	71	68	65	66	63	63	59	56	55	53	55	57
CH13 EXH	2078	62	66	66	66	65	70	71	68	70	71	61	62	56	60	60	62	59	58	53	52	54
CH13 EXH	2088	63	62	66	70	70	70	71	72	70	67	68	69	66	63	64	63	63	62	38	55	55
CH13 EXH	2098	67	67	70	75	75	74	75	73	74	71	72	69	70	67	60	63	66	62	60	59	62
CH13 EXH	2108	71	75	75	75	84	84	80	81	78	79	75	72	69	66	66	62	62	96	57	62	65
CH13 EXH	2118	75	79	79	84	83	83	84	80	77	74	75	72	62	59	63	66	58	57	31	78	64
CH13 EXH	2128	75	79	79	84	83	83	80	76	74	75	75	72	69	72	69	65	62	60	50	45	64