THE EFFECT OF OZONE ON PHOTOSYNTHESIS, VEGETATIVE GROWTH AND PRODUCTIVITY OF *Prunus salicina* IN THE SAN JOAQUIN VALLEY OF CALIFORNIA

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ABSTRACT

Nursery stock of plum (Prunus salicina cv. Casselman) were planted 1 April 1988 in an experimental orchard at the University of California Kearney Agricultural Center near Fresno, CA. The trees were covered with open-top fumigation chambers on 1 May 1989 and were exposed to three atmospheric ozone concentrations (charcoal filtered air, ambient air, or ambient air + ozone) from 8 May to 15 November 1989. A no-chamber treatment plot was utilized to assess chamber effects on tree performance. The mean 12-h (0800-2000 h PDT) ozone concentrations during the experimental period ozone in the charcoal filtered, ambient, ambient + ozone, and no-chamber treatments were 0.044, 0.059, 0.111, and 0.064 ppm, respectively. Leaf assimilation rate and stomatal conductance of Casselman plum were reduced by increased ozone concentrations. There was no difference in Casselman plum gas exchange between the ambient chamber and no-chamber plots. Trees in the high ozone treatment had greater leaf-fall earlier in the growing season than those of the other treatments. Cross-sectional area growth of Casselman plum decreased with increasing atmospheric ozone concentration. The results indicate that decreases in leaf gas exchange and loss of leaf surface area were probable contributors to decreases in growth of young Casselman plum trees.

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SUMMARY AND CONCLUSIONS

Chronic exposure to low concentrations of ozone has been shown to have a negative effect on growth and photosynthesis of deciduous tree species. However, there has been no comprehensive study assessing the effects of ozone pollution on photosynthesis, vegetative growth, and productivity of fruit tree species. The objectives of the present study were to determine the effects of ozone pollution on leaf net CO_2 assimilation, vegetative growth, and productivity of Prunus salicina during orchard development and full production in the San Joaquin Valley of California.

1. Data from this study indicate that ambient and 1.9 times ambient atmospheric ozone concentrations reduced leaf net CO_2 assimilation of Casselman plum trees compared to rates of trees grown in charcoal filtered air. Further, ambient and 1.9 times ambient atmospheric ozone concentrations also reduced stomatal conductance of these trees when compared to those in charcoal filtered air.

2. Mean daily ozone concentrations greater than 0.111 ppm caused premature leaf-fall of Casselman plum trees.

3. Ozone concentrations greater than 0.111 ppm resulted in decreased cross-sectional area growth of Casselman plum. Decreases in trunk growth in the present study were related to the reductions in leaf net CO_2 assimilation and premature loss of leaf area of these trees.

RECOMMENDATIONS

1. Research to examine the effects of air pollution in the San Joaquin Valley on the growth of fruit tree crops during orchard establishment should continue. Very little is known how air pollution stress affects the initial establishment of perennial tree crops.

2. After the orchard is established, research on the productivity of these trees as a function of air quality should proceed until the orchard has produced at least three full crops.

3. Means of predicting the potential adverse effects of ozone on economic losses of fruit trees should be developed. This would include crop growth and yield models.

4. Air quality in the San Joaquin Valley of California should be improved to allow for optimal growth of deciduous fruit and nut tree crops.

INTRODUCTION

Chronic exposure to low concentrations of ozone has a negative impact on the growth of coniferous and deciduous tree species and some of the reduction in growth of trees is apparently due to the inhibitory effect of ozone on the process of photosynthesis (Houston 1974, Reich and Amundson 1985, Steiner and Davis 1979, Townsend 1974, Pye 1988, Reich 1983). Ozone decreases the rate of leaf photosynthesis whether the plants are exposed to low pollution levels for an extended time (Reich 1983, Reich and Amundson 1985, Roper and Williams 1990, Williams et al. 1989, Retzlaff et al. 1990) or to acute levels of the pollutant for a short time (Hill and Littlefield 1969, Roper and Williams 1990). Chronic exposure to low concentrations of ozone may accelerate leaf aging and this may partially explain the decline in leaf photosynthetic capacity (Reich 1983).

The effect of ozone on the growth of woody perennials generally has been limited to studies involving small potted forest tree species and results have indicated that ambient ozone concentration can reduce dry matter production and growth (Reich and Amundson 1985, Steiner and Davis 1979, Taylor et al. 1986, Pye 1988). In a recent field study, net photosynthesis, stomatal conductance, and trunk circumference of almond, plum, apricot, and pear decreased linearly with increasing ozone concentrations (Williams et al. 1989, Retzlaff et al. 1990). However in the same study, nectarine, peach, and cherry were unaffected by the ozone treatments indicating species differences in response to atmospheric ozone pollution. Further, yields of field-grown *Vitis vinifera* have been reduced by ambient levels of ozone when compared to charcoal filtered air (Brewer and Ashcroft 1983).

The San Joaquin Valley of California produces greater than two million metric tons of pome and stone fruit and nut crops annually, with a production value in excess of one billion dollars. The response of potted trees and field-grown grapevines in open-top chambers to low concentrations of ozone indicate that the growth and productivity of fruit and nut trees may be reduced by chronic exposure to ambient ozone levels. To date there has been no comprehensive study assessing the effects of ozone pollution on photosynthesis, vegetative growth, and productivity of fruit and nut tree species. The objectives of this study were to determine the effects of ozone pollution on leaf net CO_2 assimilation, vegetative growth, and productivity of *Prunus salicina* in the San Joaquin Valley of California. This fruit production region is characterized by ambient ozone concentrations that often exceed U. S. Environmental Protection Agency standards of 0.12 ppm averaged over 1-hour (Cabrera et al. 1988).

MATERIALS AND METHODS

Plant Materials and Ozone Treatments

Nursery stock of plum (*Prunus salicina*, cv. Casselman) were planted 1 April 1988 in an experimental orchard at the University of California Kearney Agricultural Center near Fresno, CA. Tree and row spacing was 1.83 and 4.27 m, respectively. Trees were trained to an open-vase shape with other cultural practices being similar to those used for the commercial production of plums.

Trees were irrigated via low-volume fan jets approximately once a week throughout the growing season.

Open-top chamber frames used in this study were put on the trees on 4 November 1988. Each chamber contained four plum trees. A diagram of the experimental plot is found in Figure 1. The open-top chambers utilized in this study have been described previously (Brewer and Ashcroft 1983). The air delivery system was modified and consisted of a blower placed at one end of each chamber with the air ducted down both sides of the chamber (Figure 2). Air from these ducts was directed towards the middle and top of the trees' canopy within the chamber. An additional set of air ducts was added directly beneath the trees and this air was directed upwards into the lower canopy. Plastic walls were put on the chambers 1-8 May 1989 and blowers were turned on at that time. Chamber blowers were operated 24 hours per day.

Ozone treatments were initiated on 8 May and continued until 15 November 1989. After 15 November, the plastic chamber ends were removed. Trees overwintered and were then allowed to flush the following spring for the 1990 growing season treatments.

Ozone treatments imposed in this study were charcoal filtered air (C), ambient air (A), and ambient air + ozone (T). Treatments were randomly assigned to a chamber and there were 5 replications containing 1 chamber of each treatment as well as an additional no-chamber treatment (N). Ozone concentrations in the chambers were measured with a Dasibi Model 1003 AH Ozone Analyzer. Calibration occurred weekly and involved cleaning and frequency count checks. An Apple IIe microcomputer interfaced with Cyborg's Integrated System for Automated Acquisition and Control (Model 91A) permitted sequential sampling of chamber ozone concentration hourly from 0800 to 2000 h (Pacific Daylight Time, PDT) daily. Chambers were connected to the monitoring system via teflon tubing and solenoid valves. Inlets for air samples were suspended 1.5 m above the soil in the center of each chamber. Air from each chamber was passed through the monitoring system for 2 minutes prior to measuring ozone concentration to permit residue purging from common sampling lines and the ozone monitor. After each measurement, chamber number, ozone concentration, hour, and date were stored on floppy disk and printed on paper for backup.

Ozone for the ambient air + ozone (T) treatment chambers was generated from ambient air with an Griffith Model GTC-2A Ozone Generator and delivered via teflon tubing to the delivery air stream of these chambers. The ozone generator was computer automated to increase or decrease the ozone output from 0800 to 2000 h depending on the ambient atmospheric ozone concentration. This system resulted in ozone concentrations approximately 2 times ambient.

At the end of the ozone treatment period (15 November), ozone data stored on floppy disks were transmitted to a PRIME minicomputer. Final ozone concentration data analysis was conducted utilizing the means procedure (Proc Means) of the statistical analysis system (SAS Institute, 1985). Ozone 12-h means (0800-2000 h PDT) and number of hours greater than 0.10 and 0.20 ppm were calculated for each treatment. These ozone concentrations were used to assess the effects of ozone pollution on tree growth and development.

Oxides of nitrogen were measured in the treatment/chambers on a 24-h basis with a Thermo Electron Corporation Model 14B Chemiluminescent $NO-NO_2-NO_x$ Gas Analyzer to determine whether the Griffith ozone generation system was releasing additional oxides of nitrogen into the T chambers. No difference in the concentration of oxides of nitrogen was found among treatments during the 1989 season.

Gas Exchange

Three weeks after treatment initiation, measurements of leaf net CO_2 assimilation and stomatal conductance were made on each tree and this process was repeated at three-week intervals. By the end of the study each tree had been measured nine times. On each date measurements were made on one leaf from each tree in every treatment/chamber (20 leaves/treatment, 80 leaves per sample day). Fully expanded leaves that were in direct sunlight were selected for measurement. These leaves were from similar canopy levels near the point where the shoots were tagged for length measurements. Measurements were made between 1000 and 1200 h.

All measurements were made utilizing an Analytical Development Corporation (Hoddesdon, England) Portable Infrared CO_2 Analyzer (Model LCA-2), Air Supply Unit with Mass Flowmeter (Model ASUM), Data Processor for the LCA-2 (Model DL-2), and broad leaf Parkinson Leaf Chamber. The IRGA was used in the differential mode. Air for the leaf chamber was taken from the open-top chamber in which the tree was growing. Data were recorded on the data processor until all measurements on that particular date had been taken. Data was then transferred to the minicomputer for later analysis.

Growth Measurements

From 1 May 1989 (treatment initiation) and at monthly intervals through 1 December 1989 circumference of each tree trunk was measured. Painted bands on the trees just above the soil-line were used as reference points in order to minimize measurement errors. The increase in trunk cross-sectional area from 1 May to 1 December 1989 was calculated from the circumference data using the equation:

$$\text{Cross-sectional area} = (\text{circumference}^2)/4*\text{Pi}.$$

Four growing shoots per tree were selected to follow shoot growth, leaf number, and lateral branching response characteristics. Shoots were tagged on 1 May above the last fully expanded leaf, so that any increases in shoot length, leaf number, and lateral branches above this point could be determined. Trees were visually inspected for foliar symptoms of chronic ozone injury when measurements were taken.

Premature leaf-fall was measured by collecting the leaves from the ground below the trees in the chamber treatments (C, A, and T) on 5 October and 3 and 28 November 1989. On 15 December, all leaves on the ground below the trees were collected and any remaining foliage on the trees was stripped off in order to determine final foliage biomass. Total leaf nitrogen was determined from leaf samples on each collection date by the Kjeldahl procedure.

Trees in the present study were dormant pruned on 7 February 1989 and 11 January 1990. On 7 February, prunings from all four trees in each treatment were pooled and total fresh weights of the prunings were determined. On 11 January, fresh dry weights of each individual measurement tree (80 total) were determined.

Statistical Analysis

The main experimental design was a randomized complete block with 3 ozone (C, A, and T) treatments and 5 replications. The experiment was replicated/blocked five times to account for chamber location in the field and possible soil differences among chambers. Data for measurements that were repeated throughout the study were analyzed using a repeated measures analysis of variance with two grouping factors (replication and treatment) and one within factor (time) (Table 1). Data collected only once during the study were analyzed by a standard ANOVA. In all analyses, linear contrasts with the 12-hour mean ozone levels were used for post hoc comparisons among treatment means ("<0.05). In addition, a standard ANOVA was used to compare the responses of trees in the A chambers with those of the N chamber plots.

RESULTS

Ozone Treatments

Hourly ozone concentrations were averaged from 8 May to 15 November 1989 (Figure 3). Cumulative monthly 12-h mean ozone concentrations (0800-2000 h PDT) peaked by 1 September and declined thereafter (Table 2). Mean 12-hour ozone concentrations of the charcoal filtered treatment were 75% of the ambient treatment, whereas the high ozone treatment was 1.9 times that of ambient (Table 2). Ozone concentrations in the ambient treatment/chambers averaged 93% of the true ambient ozone concentrations. Monthly 12-h mean ozone concentrations generally peaked before August and thereafter declined through November (Table 2). The number of hours each treatment ozone concentration was above 0.10 and 0.20 ppm also indicated large treatment differences (Table 2).

Gas Exchange

Four months after treatments were initiated (12 September 1989) leaf assimilation rate of Casselman plum was reduced in the A and T chambers when compared with the C chambers (Table 3). The magnitude of these differences remained stable or increased slightly when measured on each subsequent date through the end of the study period. There was only one date on which there were differences between the A and N treatment trees (Table 3).

Four months after treatments were initiated (12 September 1989) stomatal conductance of Casselman plum was reduced in the A and T chambers when compared with the C chamber (Table 4). The magnitude of these differences also remained stable or increased slightly when measured on each subsequent date through the end of the study period. There were only two dates on which the stomatal conductance of the N trees was reduced when compared to the A chamber trees (Table 4).

Tree Growth

Mean cross-sectional area growth of Casselman plum was reduced in the T chambers when compared with the C chamber trees in September and October (Table 4). Mean cross-sectional area growth of trees outside the chambers (N) was also less than trees inside the chambers (A) (Table 5).

Shoot length, leaf number, and lateral branching of Casselman plum were unaffected by increasing ozone concentration in the present study. Shoot extension growth was highly variable and no response trends could be detected.

Dormant pruning weight on 7 February 1989 and 11 January 1990 were similar in all the treatment/chamber (C, A, and T) plots (Table 6). However, dormant pruning weight on 7 February 1989 and 11 January 1990 of the N treatment trees was less than that of trees in the A chambers (Table 6).

Foliar Injury

Visual injury was observed on Casselman plum trees in the high ozone chambers approximately two months following treatment initiation. At first, visible injury consisted of chlorotic spots and yellow flecking on leaf surfaces of the older foliage. As the season progressed, these chlorotic areas became larger and there was increased surface expression of the anthocyanin pigment. As the trees aged, foliar ozone injury appeared on more of the older foliage. Foliar damage in the A chambers was limited to scattered spots on the oldest foliage in October. No visual injury was observed in the C chambers.

Soon after visible injury became evident in the T chambers, lower/older leaves abscised. Foliage dry weight collected under the trees on 5 October and 3 November 1989 indicates that more foliage abscised in the high ozone chambers during this period than in the other ozone chambers (Table 7). By 3 November, less than 8% of the total foliage (measured on 15 December) on the C and A trees had abscized while 42% of the total foliage of the T trees had abscized. Following an application of 36% Zinc Sulfate (16.8 kg/ha) on 20 November 1989, most of the remaining foliage on trees in all the treatment/chambers abscized. Final cumulative foliage dry weight in the T chambers was less than that in the C chambers (Table 7).

As a result of the premature leaf abscission on 5 October and 3 November 1989, more leaf nitrogen was removed from the trees in the T chambers when compared to the C chamber trees during this period (Table 8). Total leaf nitrogen (15 December 1989) of trees in the T chambers was less compared to those trees in the C and A chambers (Table 8).

DISCUSSION

Leaf assimilation rate of Casselman plum was lower in atmospheres containing ambient and twice ambient ozone concentrations than in charcoal filtered air four months after treatments were initiated. Similar results for Casselman plum were reported in a study in 1988 (Williams et al. 1989, Retzlaff et al. 1990). In the present and previous studies, decreases in leaf assimilation were not immediately apparent and developed after an extended exposure period in the fall of the treatment year. In the absence of ozone, leaf photosynthetic capacity peaks early in the season and then declines gradually over the growing season (Pye 1988). This photosynthetic pattern was exhibited by Casselman plum in charcoal filtered atmospheres and to a certain extent in the ambient ozone atmosphere in this study. Increasing the atmospheric ozone concentration up to two-times the ambient level resulted in a more rapid decline in leaf assimilation. Ozone apparently accelerates the seasonal decline in photosynthetic capacity and increases early leaf-fall (Reich 1983).

After four months of treatment, stomatal conductance of Casselman plum was also reduced by increasing atmospheric ozone concentrations. Similar reductions in plum stomatal conductance were reported in a study in 1988 (Williams et al. 1989, Retzlaff et al. 1990). The lowered stomatal conductance in these studies indicates that inhibition of assimilation by ozone in plum is related to reductions in the intercellular CO_2 concentration. However, prune (P. domestica L.), which had decreased leaf CO_2 assimilation when grown in high ozone concentrations, showed no decrease in stomatal conductance (Williams et al. 1989, Retzlaff et al. 1990). After three growing seasons, stomatal conductance of loblolly pine (Pinus taeda L.) limited photosynthesis by approximately 29% in both charcoal filtered (0.029 ppm) and two-times ambient (0.092 ppm) ozone treated plants, suggesting that chronic ozone exposure did not affect stomatal control of loblolly pine assimilation (Sasek and Richardson 1989).

Trunk cross-sectional area growth of Casselman plum was reduced by atmospheric ozone concentrations that were near two-times the ambient ozone concentration. Previously, trunk cross-sectional area growth of plum was found to decrease linearly with increasing atmospheric ozone concentration (Williams et al. 1989, Retzlaff et al. 1990). Decreases in trunk growth in these two studies are apparently related to the decreases in photosynthesis of these trees.

Other measures of growth in these young plum trees are less impacted by increased atmospheric ozone concentrations. In the present study, as well as in a previous one (Williams et al. 1989, Retzlaff et al. 1990), shoot length, leaf number, and lateral branching were unaffected by increased atmospheric ozone concentration. Further, dormant pruning weights were unchanged following one season of ozone treatment illustrating the lack of a shoot response by Casselman plum to changes in atmospheric ozone concentration. Ozone apparently alters height growth differently than diameter as has been reported previously (Pye 1988). This could be because in fruit trees the majority of height growth occurs early in the growing season before the treatments had affected photosynthesis, whereas, diameter growth continues steadily throughout the entire growing season (DeJong et al. 1987).

Foliar injury on Casselman plum that occurred in the ozone treatment chambers in the present study was similar to that reported previously for other tree species (Scherzer and McClenahan 1989, Keane and Manning 1988, Chappelka et al. 1988, Williams et al. 1989, Retzlaff et al. 1990). Typically, this visible ozone injury is often limited to small single groups of epidermal and palisade cells resulting in flecks and stipples (Prinz 1988). Of greater concern is the premature leaf-fall observed in the high ozone treatment in the present study. Foliar leaf symptoms are often followed by leaf abscission and early or premature senescence (Prinz 1988). Early leaf-fall in Casselman plum results in a loss of photosynthetic leaf surface area which could potentially impact future growth and productivity. In addition, as a result of this early abscission, more foliar nitrogen was prematurely removed which could upset the carbon:nitrogen ratio of plum trees. Further examination of this reported premature leaf-fall is warranted and may help explain the deleterious effect of ambient ozone concentrations on crop productivity.

Comparison of net photosynthesis and stomatal conductance of Casselman plum trees in the ambient chambers versus those outside the chambers in the ambient ozone indicates little difference in response. Rates of photosynthesis in cotton (Gossypium hirsutum L.) grown in no-chamber (0.077 ppm) plots were less than that in ambient chamber (0.074 ppm) plots (Temple et al. 1988). Apparently there is no chamber effect on gas exchange of Casselman plum even though atmospheric ozone concentrations were reduced approximately 7% in the chamber over those measured outside.

Growth of Casselman plum trees outside the chambers was less than that of trees in the ambient and ambient + ozone chambers. An explanation of this effect could be that the outside trees were smaller (11.1 cm^2 cross-sectional area in the N plots versus 12.3 cm^2 in the A chambers) when the study was initiated. Since cross-sectional area growth increases geometrically, larger trees would be expected to get larger even if growing at the same rate as smaller trees. Further, some of the trees in the N plots were transplanted in December 1988 to replace dead trees and have not caught up with the remainder of the orchard in terms of establishment. Overall, it appears that the open-top chambers are having little effect on the growth of Casselman plum trees and that results from this study could be extrapolated to trees growing under true orchard conditions.

In the present study, increased atmospheric ozone concentration over an entire growing season reduced leaf net CO_2 assimilation and stomatal conductance of 2-year-old Casselman plum. Further, atmospheric ozone concentrations that were 1.9 times ambient concentrations resulted in premature leaf-fall compared to other treatment trees. The reductions in leaf photosynthesis and loss of leaf area are contributors to the loss in cross-sectional area growth of Casselman plum trees in atmospheres containing high ozone concentrations. The continuation of this study will determine whether the reduction in photosynthesis and growth as a result of atmospheric ozone pollution will result in reduced productivity of Casselman plum trees in future years.

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Table 1. Analysis of variance for a repeated measures analysis.

Source of Variation	Degrees of Freedom
Model	70
Replication	4
Treatment	2
Replication * Treatment	8
Date	8
Replication * Date	32
Treatment * Date	16
Error	64
Corrected Total	134

Appropriate F-tests:

For Replication; $F = \frac{\text{Replication}}{\text{Replication*Treatment}}$

For Treatment; $F = \frac{\text{Treatment}}{\text{Replication*Treatment}}$

Table 2. Cumulative and monthly 12-hour (0800-2000 h PDT) mean ozone concentrations and the number of hours greater than 0.1 and 0.2 ppm for the experimental period from 8 June to 14 November 1989.

From 5/8/89 through	5/31/89 May	6/30/89 June	7/31/89 July	8/31/89 August	9/30/89 September	10/31/89 October	11/14/89 November	Cumulative Month
Treatment[a]	(ppm)							
C	0.042[b]	0.042	0.043	0.044	0.045	0.044	0.044	Cumulative
	0.042	0.043	0.045	0.045	0.052	0.039	0.041	Monthly
A	0.056	0.059	0.061	0.062	0.062	0.060	0.059	Cumulative
	0.056	0.061	0.067	0.064	0.063	0.047	0.049	Monthly
T	0.107	0.111	0.117	0.118	0.117	0.112	0.111	Cumulative
	0.107	0.114	0.127	0.122	0.114	0.086	0.094	Monthly
N	0.062	0.066	0.069	0.069	0.068	0.065	0.064	Cumulative
	0.062	0.069	0.076	0.071	0.066	0.048	0.049	Monthly
	# hours treated							
C	324	674	1035	1402	1763	2120	2285	Total
	0	0	0	0	0	0	0	>0.1
	0	0	0	0	0	0	0	>0.2
A	324	674	1035	1402	1763	2120	2285	Total
	1	11	38	54	95	110	113	>0.1
	0	0	0	0	0	0	0	>0.2
T	324	674	1035	1402	1763	2120	2285	Total
	173	374	615	839	1027	1158	1236	>0.1
	11	38	84	128	160	174	180	>0.2
N	324	674	1035	1402	1763	2120	2285	Total
	8	39	101	139	190	207	209	>0.1
	0	0	0	0	0	0	0	>0.2

[a] C, A, T, and N refer to the charcoal filtered, ambient, ambient + ozone, and no-chamber treatments, respectively.

[b] Standard errors for all cumulative and monthly means were less than or equal to 0.001 ppm.

Table 3. Mean leaf net CO_2 assimilation (measured at three-week intervals) of Casselman plum trees exposed to different atmospheric ozone concentrations.

	5/30/89	6/21/89	7/10/89	8/1/89	8/18/89	9/12/89	10/3/89	10/26/89	11/14/89
	(Bmol CO_2 m^{-2} s^{-1})								
C[a]	13.3 (0.5)[b]	14.1 (0.6)	14.9 (1.0)	10.8 (0.8)	12.0 (0.7)	11.1 (0.5)	10.4 (0.7)	8.5 (0.7)	6.3 (0.6)
A	13.1 (1.0)	14.2 (0.9)	16.2 (0.6)	12.5 (0.7)	12.3 (0.8)	11.3 (0.5)	9.9 (0.8)	6.6 (0.6)	6.0 (0.4)
T	15.2 (2.1)	11.9 (0.9)	14.7 (1.1)	11.5 (0.5)	11.6 (0.5)	7.0 (0.7)	3.8 (0.4)	3.9 (0.5)	2.8 (0.4)
P>F[c]	NS	NS	NS	NS	NS	**	**	**	**
N	14.1 (1.3)	13.9 (0.8)	15.6 (0.8)	12.0 (0.8)	12.3 (0.9)	10.7 (0.8)	8.0 (0.7)	8.6 (0.6)	7.6 (0.7)
P>F[d]	NS	NS	NS	NS	NS	NS	NS	NS	**

[a] C, A, T and N refer to charcoal filtered, ambient, ambient + ozone and no-chamber treatments, respectively.

[b] Values in parenthesis represent one standard error.

[c] A significant linear treatment effect (* or **) indicates that each mean from the C, A, or T treatments within a date is different at the 10 or 5% level, respectively. n = 20.

[d] A significant treatment effect (* or **) indicates that each mean from the A or N treatments within a date is different at the 10 or 5% level, respectively. n = 20.

Table 4. Mean stomatal conductance (measured at three week intervals) of Casselman plum trees exposed to different atmospheric ozone concentrations.[a)]

	5/30/89	6/21/89	7/10/89	8/1/89	8/18/89	9/12/89	10/3/89	10/26/89	11/14/89
					($mol\ m^{-2}\ s^{-1}$)				
C	0.34 (0.02)	0.37 (0.03)	0.47 (0.04)	0.38 (0.04)	0.33 (0.03)	0.25 (0.01)	0.34 (0.03)	0.30 (0.03)	0.25 (0.01)
A	0.35 (0.03)	0.31 (0.03)	0.48 (0.03)	0.46 (0.02)	0.38 (0.03)	0.29 (0.02)	0.31 (0.03)	0.24 (0.02)	0.24 (0.01)
T	0.32 (0.03)	0.29 (0.02)	0.37 (0.03)	0.40 (0.02)	0.36 (0.03)	0.20 (0.01)	0.18 (0.01)	0.20 (0.01)	0.16 (0.01)
P>F	NS	NS	**	NS	NS	**	**	**	**
N	0.32 (0.04)	0.29 (0.03)	0.39 (0.03)	0.41 (0.03)	0.37 (0.04)	0.26 (0.03)	0.23 (0.02)	0.21 (0.01)	0.25 (0.02)
P>F	NS	NS	*	NS	NS	NS	*	NS	NS

a) Other information as found in Table 3. n = 20.

Table 5. Mean trunk cross-sectional area growth (measured at monthly intervals) of Casselman plum trees exposed to different atmospheric ozone concentrations.[a]

	6/1/89	7/1/89	8/1/89	9/1/89	10/1/89	11/1/89
	(cm^2)					
C	3.1 (0.2)	7.7 (0.4)	10.2 (0.6)	12.8 (0.9)	16.2 (1.1)	17.5 (1.2)
A	3.0 (0.3)	7.6 (0.8)	10.1 (0.9)	13.8 (1.1)	17.5 (1.4)	18.8 (1.4)
T	3.1 (0.3)	6.7 (0.5)	8.8 (0.6)	11.5 (0.8)	14.7 (0.8)	16.2 (1.0)
P>F	NS	NS	NS	*	*	NS
N	2.7 (0.6)	6.1 (0.7)	8.7 (0.9)	10.8 (1.1)	13.1 (1.2)	14.3 (1.3)
P>F	NS	*	NS	**	**	**

[a] Other information as found in Table 3. n = 20.

Table 6. Dormant pruning weights of Casselman plum trees (measured on 7 February 1989 (prunings from the 1988 growing season) and 11 January 1990) exposed to different atmospheric ozone concentrations.[a]

	-- 2/7/89 -- Fresh Weight		-- 1/11/90 -- Fresh Weight
	-------------	(g)	-------------
C	393 (84)		1712 (194)
A	456 (76)		1781 (184)
T	422 (76)		1550 (144)
		P>F	NS
N	340 (38)		881 (142)
		P>F	**

[a] Other information as found in Table 3. n = 20.

Table 7. Cumulative leaf dry weight that had fallen (5 October and 3 November) and total leaf dry weight that had fallen by 15 December 1989 from Casselman plum trees exposed to different atmospheric ozone concentrations.[a]

	10/5/89	11/3/89	Total
	------------------ (g)	---------------------	
C	42 (8)	74 (12)	949 (116)
A	42 (13)	66 (11)	966 (72)
T	140 (29)	309 (35)	741 (39)
P>F	**	**	**

[a] Other information as found in Table 3. n = 5.

Table 8. Cumulative leaf nitrogen that had fallen (5 October and 3 November) and total leaf nitrogen that had fallen by 15 December 1989 from Casselman plum trees exposed to different atmospheric ozone concentrations.[a)]

	10/5/89	11/3/89	Total
	(mg)		
C	621 (128)	1081 (182)	17031 (1977)
A	468 (109)	857 (69)	17375 (1105)
T	2135 (446)	5329 (554)	14312 (808)
P>F	**	**	*

[a)] Other information as found in Table 3. n = 5.

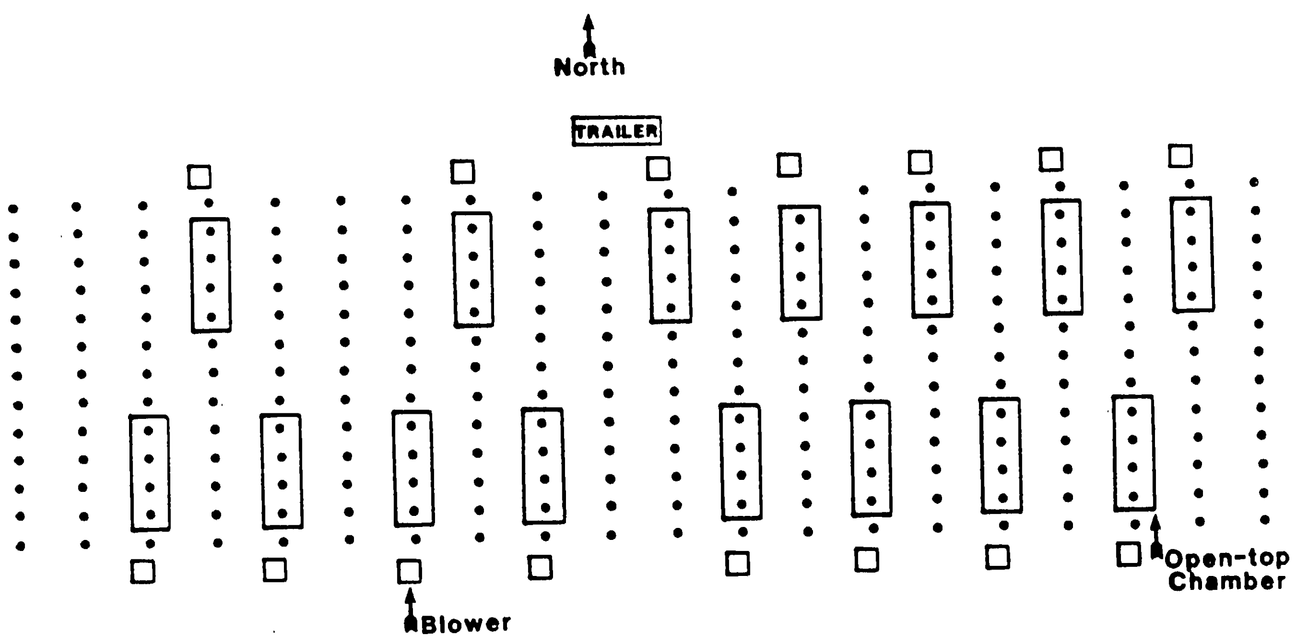

Figure 1. The field plot design of the plum orchard used in the present study. The dots represent individual trees. The tree and row spacings are 1.83 and 4.27 m, respectively.

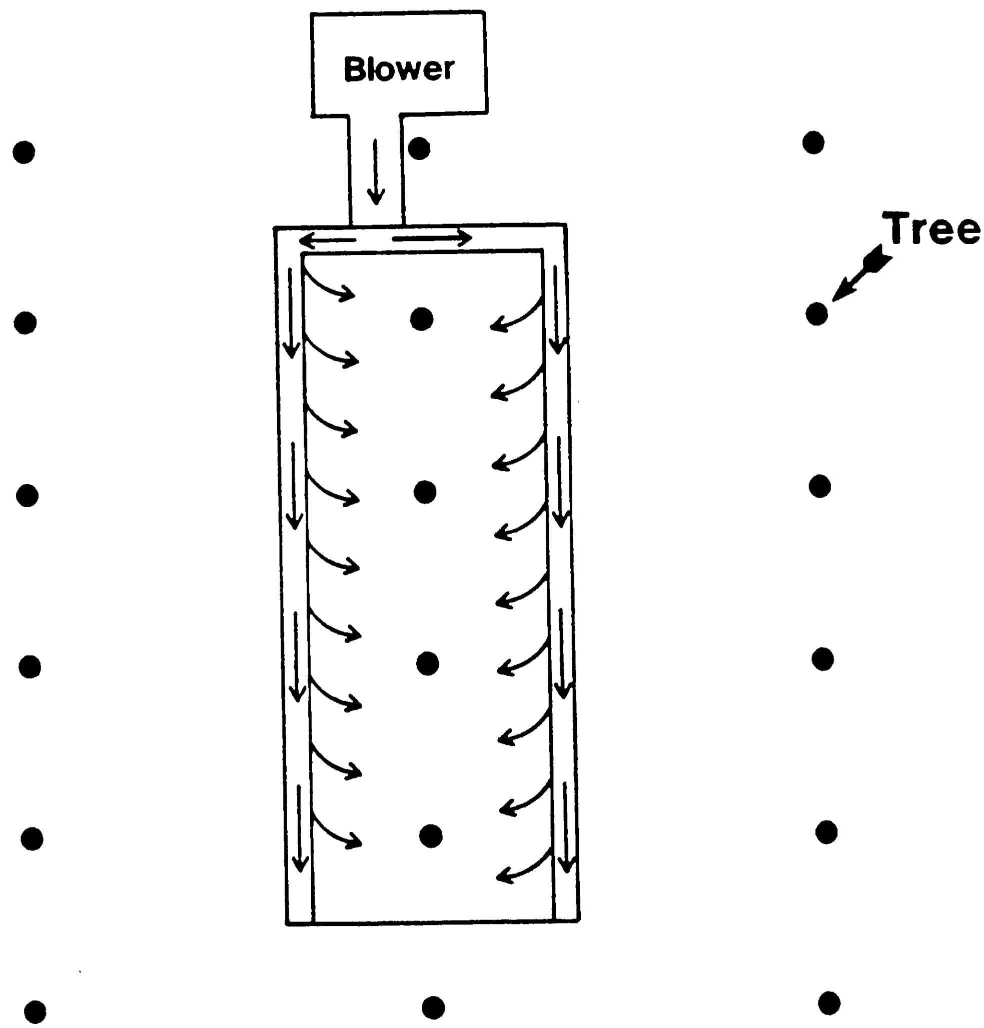

Figure 2. The open-top chamber design utilized in the present study. Air from the blower is ducted down both sides of the chamber and directed towards the trees canopies. An additional air duct (not shown) is located beneath the trees and the air is directed upwards.

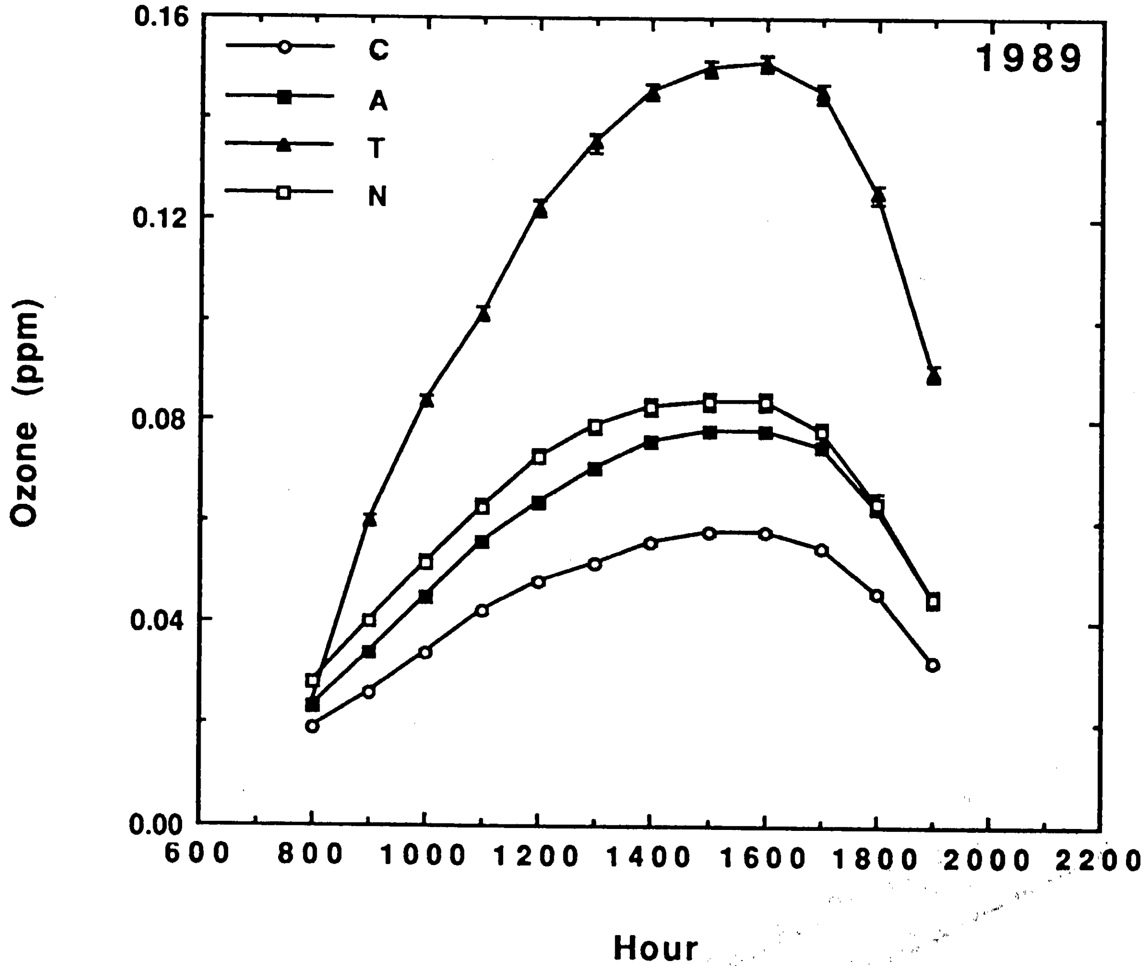

Figure 3. Average hourly ozone concentrations from 8 May to 15 November 1989. Standard error bars are included when they are larger than the individual data symbol. C, A, T, and N refer to the charcoal filtered, ambient, ambient + ozone, and no-chamber treatments, respectively.