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The Effect of Ozone on Photosynthesis, Vegetative Growth and Productivity of *Prunus salicina* in the San Joaquin Valley of California

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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 Lindel., cv. Casselman) were planted 1 April 1988 in an experimental orchard at the University of California Kearney Agricultural Center near Fresno, California. The trees were enclosed in open-top fumigation chambers on 1 May 1989, and were exposed to three atmospheric ozone concentrations (charcoal filtered air, ambient air, and ambient air + ozone) from 8 May to 15 November 1989, from 9 April to 9 November 1990, and from 1 April to 31 October 1991. This report will detail the results of the 1991 growing season. A no-chamber treatment plot was utilized to assess chamber effects on tree performance. The mean 12-h (0800-2000 h PDT) ozone concentration during the 1991 experimental period in the charcoal filtered, ambient, ambient + ozone, and no-chamber treatments were 0.034, 0.050, 0.094, and 0.058 ppm, respectively. Leaf net CO_2 assimilation rate of Casselman plum decreased with increasing atmospheric ozone concentration from the charcoal filtered to ambient + ozone treatment. There was no difference in plum leaf net CO_2 assimilation rate between the ambient chamber and no-chamber plots. Trees in the ambient + ozone treatment had greater leaf-fall earlier in the growing season than those of the other treatments. Yield of plum trees in 1991 was 19.8, 15.9, 6.8, and 15.8 kg $tree^{-1}$ in the charcoal filtered, ambient, ambient + ozone, and no-chamber treatments, respectively. Average fruit weight (g $fruit^{-1}$) was not affected by atmospheric ozone concentration. Fruit number per tree decreased as atmospheric ozone concentration increased from the charcoal filtered to ambient + ozone treatment. Decreases in leaf gas exchange and loss of leaf surface area were probable contributors to decreases in yield of Casselman plum trees in a commercial bearing orchard.

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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 in 1991 and previously in 1989 and 1990 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 0.09 ppm caused premature leaf-fall of Casselman plum trees in 1989, 1990, and 1991.

3. Increased ozone concentrations (ambient and 1.9 times ambient) significantly reduced yield compared to the trees grown in the charcoal filtered chamber in a commercial bearing orchard in 1991. This was despite the fact that the Casselman plum trees in this study were only exposed to ozone treatments for just three years following an initial year of orchard establishment. Additionally, yield of plum trees exposed to mean daily ozone concentrations greater than 0.09 ppm was reduced by 35% in 1990 (compared to trees in charcoal filtered air) and by 65% in 1991 indicating that the ozone induced yield response of plum trees might be cumulative.

4. The atmospheric ozone concentration was reduced approximately 14% in the ambient chambers compared to the no-chamber plots in the present study, but there were no leaf photosynthesis or yield differences between the two plots. It appears that the open-top chambers are having little effect on the overall physiology, growth, and yield of Casselman plum trees and that results from this study could be extrapolated to trees of similar age growing under true orchard conditions.

RECOMMENDATIONS

1. Further examination of the ozone induced reductions in photosynthesis, growth, and yield are necessary to more fully understand the potential impact of worsening air quality on San Joaquin Valley fruit and nut tree crop production.

2. It is not clear whether there is a direct affect of ozone fumigation on the flower buds of fruit trees once they are formed on the tree or an indirect one due to lack of carbohydrates. Counts of flower buds and fruit set are needed in order to quantify this reduced fruit number response.

3. Research should continue for an additional two years to establish the effects of ozone air pollution on mature orchard growth and yields and to determine which components of yield are affected by ozone stress and whether the yield reductions are cumulative.

4. A study should be commissioned to determine the feasibility of using branch chamber fumigation systems. This would allow further study on various other fruit and nut tree species that are too large to be grown in open-top fumigation chambers.

5. Air quality in the San Joaquin Valley of California should be improved to allow for maximum photosynthesis, growth, and yield of deciduous fruit and nut tree crops.

INTRODUCTION

The planting of an orchard is a long-term investment, usually taking three or more years to bear a commercial crop with continued economic production for another 15 to 30 years (LaRue and Johnson, 1989). The establishment and first few year's growth of newly planted trees are critical in determining overall orchard productivity once the trees are mature. It is during this time that the canopy and permanent limbs are established and the root system develops. Cultural practices have been developed to optimize growth during the establishment period (LaRue and Johnson, 1989). However, stress during this time could delay or disrupt orchard development with long-term orchard productivity being less than optimum. For example, apple trees were smaller and lower yielding as a result of competition for water and mineral nutrients during the first three years of growth in an orchard plot with a continuous grass cover compared to a clean-cultivated plot (Stinchcombe and Stott, 1983).

More than two million metric tons of fruit and nut crops are produced in the San Joaquin Valley of California annually. However, this fruit production region is characterized by ambient ozone concentrations that consistently exceed U. S. Environmental Protection Agency standards of 0.12 ppm at various times during the growing season (Cabrera et al., 1988). Ozone-induced reductions in photosynthesis previously have been related to reductions in crop growth and yield (Reich and Amundson, 1985; Lehnherr et al., 1987; Takemoto et al., 1988). Yield reductions in 'Valencia' orange trees have been documented in ozone concentrations greater than 0.020 ppm (Olszyk et al., 1990). Ozone induced yield reductions in other annual and perennial crops have been reported (Brewer and Ashcroft, 1983; Adaros et al., 1990; Mebrahtu et al., 1991).

Two studies have demonstrated that net photosynthesis and trunk circumference of various fruit and nut tree species and cultivars of the same species decreased with increasing atmospheric ozone concentration (Retzlaff et al., 1991; Retzlaff et al., 1992a). However, these studies were conducted on nursery stock trees (bud grafted the previous year) which had been transplanted directly into open-top chambers. Retzlaff et al. (1992b) reported that increased atmospheric ozone concentration decreased yield of Casselman plum trees during the orchard establishment period. The effects of ozone air pollution on deciduous fruit tree crops in a production orchard following the orchard establishment period are unknown. A long-term study examining the effects of ozone on growth and productivity of plum trees grown in the San Joaquin Valley of California was established in 1988. This report describes the effects of different atmospheric ozone concentrations during the fourth year of tree growth, the first commercial bearing year in this orchard.

MATERIALS AND METHODS

Plant Materials and Ozone Treatments

Nursery stock of plum (*Prunus salicina* Lindel., cv. Casselman) on Citation (*Prunus*) hybrid rootstock were planted 1 April 1988 in an experimental orchard at the University of California Kearney Agricultural Center near Fresno, California (36° 36′ N 119° 30′ W). 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 175 liter $tree^{-1}$ wk^{-1} via low-volume fan jet sprinklers throughout the 1989, 1990, and 1991 growing seasons.

Open-top chamber frames utilized in this study were constructed from extruded aluminum tube-lock welded to 4 cm thinwall tubing. The chamber dimensions were 3x7x3 (WxLxH) m on a 3x7 m rectangular base of 5x30 cm redwood boards. Chamber frames were initially put around the trees on 4 November 1988. Each chamber contained four plum trees. The chamber air delivery system consisted of a blower located at one end of each chamber with four 23 cm diameter plastic tube (Arizona Bag and Plastic Co., Phoenix, AZ) air ducts running from one end of the chamber to the other along the seven meter chamber length. Two of the air ducts ran along the sides of the chamber at a height of 1.5 meters above the chamber floor. Air from these two ducts was directed towards the middle and top of the tree canopy's within the chamber. An additional pair of air ducts was located directly beneath the trees and this air was directed upwards into the lower canopy. Air from all the ducts passed into the chamber atmosphere through 8.5 cm diamond shaped holes cut every 30 cm in the delivery tubes. This air delivery system provided approximately 133 m^3 min^{-1} air to each chamber, enough to change the air volume in the chambers approximately two times per minute. Clear 12 mil PVC (Goss Products Inc., Corona, CA) walls were first put on the chambers 1-8 May 1989 and chamber blowers were turned on at that time. Chamber blowers were operated 24 hours per day during the growing season.

Ozone treatments imposed in this study were charcoal filtered air, ambient air, and ambient air + ozone. Treatments were randomly assigned to a chamber and there were five replications containing one chamber of each treatment as well as an additional no-chamber treatment plot. Ozone concentrations in the treatment plots were monitored using a computer controlled monitoring system described previously (Retzlaff et al., 1991). Ozone treatments were initiated on 1 April and continued until 31 October 1991.

Air for the ambient treatment was blown directly into the chamber. Air for the charcoal filtered chambers was first drawn through activated charcoal filters before delivery into the chambers. Ozone for the ambient + ozone treatment chambers was generated from ambient air with an Griffin (Lodi, NJ) 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 Pacific Daylight Time (PDT) depending on the ambient atmospheric ozone concentration. This system resulted in ozone concentrations approximately 1.9 times ambient in the ambient + ozone treatment chambers during the 1991 ozone exposure period.

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) were calculated for each treatment. These ozone concentrations were used to assess the effects of ozone air pollution on tree growth, development, and yield.

Gas Exchange

Three weeks after treatment initiation, leaf net CO_2 assimilation was measured on all trees in the study plots. This process was repeated at three-week intervals and each tree was measured ten times in 1991. On each measurement day, leaf net CO_2 assimilation was measured on one leaf from each tree in every treatment (20 leaves/treatment, 80 total leaves per sample day). Fully expanded leaves that had been in direct sunlight prior to data collection were selected for measurement. Measurements were made between 1000 and 1200 h and leaf temperatures and Photon Fluence Rate (PFR) averaged 28 °C and 1100 $\mu mol\ m^{-2}\ s^{-1}$, respectively, across all dates. Following measurement, the leaves were harvested from the tree and their actual leaf surface area determined with a Li-Cor (Lincoln, NE) Model LC3100 Leaf Area Meter.

All photosynthesis measurements were made utilizing an Analytical Development Corporation (Hoddesdon, England) Portable Infrared Gas Analyzer (IRGA) (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.

Growth Measurements

Circumference of each tree trunk was measured at monthly intervals from 1 April through 1 November in 1991. Painted bands on the trees eighteen centimeters above the soil-line were used as reference points in order to minimize measurement errors. The increase in trunk cross-sectional area from 1 April to 1 November was calculated from the circumference measurements. Trees were visually inspected for foliar symptoms of chronic ozone injury when measurements were taken.

Leaf-fall was measured by collecting the leaves from the ground below the trees in the chamber treatments (charcoal filtered, ambient, and ambient + ozone) at various times throughout the growing season. On 26 November 1991, 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.

Trees in the present study were dormant pruned on 14 January 1992. Fresh prunings were weighed and then placed in a forced air oven at 70 °C until there was no further weight change and final dry weight determined.

Fruit Yield

Differences in fruiting potential among trees in the four treatments was determined by counting all flowers on one tree in each plot just prior to full bloom (16 February 1991). After fruit set, any fruit that fell from the trees were picked up, counted, and added to total fruit number after harvest. At fruit maturity, fruit from individual trees in each treatment was picked on 21 August 1991. Individual tree fruit samples were passed through an Autoline, Inc. (Reedley, CA) camera sizer/sorter and separated into six size classes. Number of fruit, fruit weight, and percent distribution in each size class were determined.

Statistical Analysis

The main experimental design was a randomized complete block with 3 ozone (charcoal filtered, ambient, and ambient + ozone) 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). Data collected on individual dates and/or only once during the study were analyzed by two-way ANOVA. In all analyses, linear contrasts with the 12-hour mean ozone levels were used for *a priori* comparisons among treatment means ($\alpha<0.05$). In addition, two-way ANOVA was used to compare the responses of trees in the ambient chambers with those of the no-chamber plots.

RESULTS

Ozone Treatments

Hourly ozone concentrations were averaged from 1 April to 31 October 1991 (Figure 1). In 1991, seasonal 12-hour mean ozone concentrations in the charcoal filtered treatment were 68% of the ambient treatment, whereas the ambient + ozone treatment was 1.9 times that of ambient (Figure 2). Ozone concentrations in the ambient treatment/chambers averaged 86% of the no-chamber ozone concentrations.

Gas Exchange

Within one month after treatments were initiated in 1991 leaf net CO_2 assimilation rate of Casselman plum was reduced in the ambient and ambient + ozone treatments when compared to the charcoal filtered treatment (Figure 3). Further reductions in Casselman plum leaf net CO_2 assimilation in the ambient and ambient + ozone treatment chambers occurred on the remaining measurement dates. There was no difference in Casselman plum leaf net CO_2 assimilation between the ambient and no-chamber plots. Stomatal conductances of Casselman plum leaves responded similarly to changing atmospheric ozone partial pressure as the leaf assimilation response (data not shown).

Tree Growth

Cross-sectional area growth of Casselman plum was the same in all the chamber treatments in 1991 (Figure 4, Table 2). Cross-sectional area growth of trees in the no-chamber treatment was less than that in the ambient treatment/chamber in 1991.

Dormant pruning weights on 14 January 1992 were similar in all the chamber treatments (Figure 5, Table 2). However, pruning weight on the aforementioned date of the no-chamber trees was less than that of trees in the ambient treatment/chambers.

Foliar Injury

Visual injury, in the form of chlorotic spots and yellow flecking on the leaf surface of older foliage, was observed on Casselman plum trees in the ambient + ozone treatment approximately two months following treatment initiation in 1991. As the season progressed, foliar ozone injury increased and some leaf abscission of injured foliage occurred. By November in 1991, more than 85% of the total foliage (calculated on 26 November 1991) remained on the charcoal filtered and ambient trees while less than 73% of the total foliage remained on the ambient + ozone trees (Figure 6, Table 2). Following an application of 36% Zinc Sulfate (16.8 kg ha^{-1}) on 7 November 1991, most of the remaining foliage on trees in all the treatments abscised. Final cumulative foliage dry weight was similar in all the chamber treatments (Figure 7, Table 2).

Fruit Yield

The total number of flowers per individual plum tree was the same on 16 February 1991, regardless of ozone or chamber treatment (Table 3). The number of flowers that set fruit was reduced in the ambient and ambient + ozone treatments compared to the charcoal filtered treatment, but was the same in the no-chamber and ambient ozone chamber treatments. The percent of fruit dropped (abscised) after fruit set was not different among the ozone treatments, although the actual number of fruit that dropped per tree was greater in the charcoal filtered and ambient treatments compared to the ambient + ozone treatment. The percent of fruit drop inside the ambient chamber was greater than that of trees in the no-chamber plots.

Fruit number per tree at harvest in 1991 was reduced in the ambient and ambient + ozone treatments compared to the charcoal filtered treatment (Figure 8, Table 2). Fruit number per tree in the no-chamber treatment was not different than that in the ambient treatment chamber. Percent size distribution in each size class was unaffected by chamber treatments (data not shown). There was a greater percentage of fruit in the smaller size classes outside the chambers than inside and a greater percentage of fruit in the larger size classes inside the chambers than outside (data not shown). Average fruit weight was the same in all chamber treatments, but was reduced in the no-chamber treatment compared to the ambient chamber treatment (Figure 8, Table 2). Fruit yield per tree was reduced in the ambient and ambient + ozone treatments compared to the charcoal filtered treatment and there was no significant difference in fruit yield per tree between the no-chamber and ambient chamber treatment plots.

DISCUSSION

Leaf net CO_2 assimilation rate of Casselman plum was reduced in atmospheres containing ambient and twice ambient ozone concentrations compared to charcoal filtered air in 1991 (Figure 3). Similar results for Casselman plum were reported previously (Retzlaff et al., 1991; Retzlaff et al., 1992b). In all three studies, decreases in leaf CO_2 assimilation were not immediately apparent and only developed after an extended exposure period. In the absence of ozone, leaf photosynthetic capacity peaks early in the season and then declines gradually thereafter until leaf abscission (Pye, 1988). This pattern was exhibited by Casselman plum growing in charcoal filtered atmospheres and to a certain extent in the ambient ozone atmosphere. Increasing the atmospheric ozone concentration up to two-times the ambient level resulted in a more rapid decline in leaf CO_2 assimilation. Ozone has previously been found to accelerate the seasonal decline in photosynthetic capacity (Reich, 1983).

Trunk cross-sectional area growth of Casselman plum was not reduced by atmospheric ozone concentrations that were near two-times the ambient ozone concentrations (Figure 4). Previously, trunk cross-sectional area growth of plum was found to decrease linearly with increasing atmospheric ozone concentration (Retzlaff et al., 1991; Retzlaff et al., 1992b). Decreases in plum trunk growth in the previous studies was apparently related to the decreases in photosynthesis and loss of photosynthetic leaf area of these trees. One hypothesis for the lack of difference in plum trunk cross-sectional area growth between ozone treatments in 1991 could be attributed to additional reserves available to the ambient + ozone trees for trunk growth that were not partitioned to fruit because of the low fruit load on these trees.

Other measures of growth on young Casselman plum trees are less impacted by increased atmospheric ozone concentrations. Dormant pruning weights were unaffected by ozone treatment after the 1991 growing season, illustrating the lack of a shoot response by Casselman plum to changes in atmospheric ozone concentration (Figure 5). Retzlaff et al. (1991) reported that shoot length, leaf number, and numbers of lateral branches of Casselman plum trees were unaffected by increased atmospheric ozone concentration. Ozone apparently alters height growth differently than diameter for plum, as has been reported previously for other trees (Pye, 1988). This could be because in fruit trees the majority of height growth occurs early in the growing season before the treatments affect photosynthesis, whereas, diameter growth continues throughout the entire growing season (DeJong et al., 1987).

Foliar injury on Casselman plum that occurred in the ambient + ozone treatment was similar to that reported previously for other tree species (Scherzer and McClenahen, 1989; Keane and Manning, 1988; Chappelka et al., 1988; Retzlaff et al., 1991; Retzlaff et al., 1992a; Retzlaff et al., 1992b). 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 ambient + ozone treatment in the present study. Foliar leaf symptoms are often followed by leaf abscission (Prinz, 1988; Keller, 1988; Lehnherr et al., 1987; Reich and Amundson, 1985; Retzlaff et al., 1992a; Retzlaff et al., 1992b). Early leaf fall in Casselman plum results in a loss of photosynthetic leaf surface area which could potentially impact future growth and productivity. During the 1991 growing seasons, Casselman plum trees in the ambient + ozone treatment lost more than 27% of their foliage prematurely (Figure 6).

First commercial bearing year (1991) yield data indicates that increased atmospheric ozone concentrations reduced Casselman plum yield (Figure 8). These yield data are similar to that reported for Casselman plum during the orchard establishment period (Retzlaff et al., 1992b). The only other report of reduced yield as a result of chronic ozone stress in fruit trees is with citrus (Olszyk et al., 1990). Yields of 'Valencia' orange trees were 11% lower at 0.040 ppm (ambient) and 31% lower at 0.075 ppm (1.8 times ambient) ozone compared to 0.020 ppm ozone (charcoal filtered). The number of oranges per tree and individual weight per orange was reduced in the 1.8 times ambient ozone concentrations, indicating that elevated atmospheric ozone was somehow affecting orange set as well as carbon allocated to the orange fruit. This differs somewhat from the response of Casselman plum. Yield reductions of 20% in the ambient and 66% in the 1.8 times ambient ozone treatments compared to the charcoal filtered treatment were only the result of reduced fruit number per tree and not plum size, since the average weight per plum was the same in all chamber ozone treatments.

Ozone-induced reductions in the number of plum fruit per tree could be the result of several factors. Ozone-induced reductions in photosynthesis are often related to declines in yield (Reich and Amundson, 1985). It has been shown previously that apple trees grown in plots with reduced competition stress (weed-free) had a significantly higher fruit set than those in plots with weed competition (Stinchcombe and Stott, 1983). The fruit set response was attributed to the fact that trees in the competition plots stopped growing sooner in the season while the trees in the weed free plots continued shoot growth for a longer time period during August. Since fruit bud formation is more active later in the season, this extension of the growing period would be expected to increase the formation of fruit buds and thus yields (Abbott, 1977). A similar response could be hypothesized for fruit trees under chronic ozone stress. Late season declines in photosynthesis and loss of photosynthetic leaf surface area of Casselman plum trees in increased atmospheric ozone concentrations could result in a lack of sufficient carbohydrates for fruit bud formation during the latter part of the growing season. In addition, Casselman plum trees growing in the 1.8 times ambient ozone atmospheres were observed to have several periods of light bloom during August and September of 1991. Fall bloom in stone fruits is commonly associated with premature leaf fall induced by environmental stress such as water deficits or salinity stress. In this study, late season bloom was attributed to chronic ozone stress and could be a factor in the loss of yield during following growing seasons. It is not clear whether there is a direct affect of ozone fumigation on the flower buds once they are formed on the tree branch or an indirect one due to lack of carbohydrates. Counts of flower buds and fruit set are needed in order to quantify this reduced plum fruit number response to ozone exposure.

Comparison of Casselman plum trees inside the ambient chambers versus those outside the chambers in the ambient ozone indicates little difference in leaf net CO_2 assimilation and growth response (Figure 3,4, and 5). In contrast, rates of photosynthesis in cotton (Gossypium hirsutum L.) grown in no-chamber (77 ppm ozone) plots were less than that in ambient chamber (74 ppm ozone) plots (Temple et al., 1988). The most commonly observed chamber effect is that plants grown inside chambers tend to be taller than plants grown outside in no-chamber plots (Heagle, 1989). Pruning weight data from the Casselman plum trees support this observation, with trees in the ambient chamber plots having more shoot growth than trees in the no-chamber plots. Further, cross-sectional area growth of Casselman plum trees in the ambient treatment chamber was greater than that of trees in the no-chamber plots. One explanation of this effect could be that the outside trees were smaller (11.1 cm^2 cross-sectional area in the no-chamber plots versus 12.3 cm^2 in the ambient chambers) when the study was initiated. Since cross-sectional area 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 no-chamber plots were transplanted in December 1988 to replace dead trees and have not caught up with the remainder of the orchard during establishment.

One other way to measure the effects of open-top chambers is to compare the yield of plants inside the chambers with yield of plants grown in no-chamber plots (Heagle, 1989). Yield of Casselman plum trees grown outside the chamber in ambient concentrations of ozone was the same as those of trees grown inside chambers with ambient concentrations of atmospheric ozone (Figure 8). The atmospheric ozone concentration was reduced by approximately 14% in the ambient chambers compared to the no-chamber plots in the present study, but there were no leaf photosynthesis or yield differences between the two plots. It appears that the open-top chambers are having little effect on the overall physiology, growth, and yield of Casselman plum trees and that results from this study could be extrapolated to trees of similar age growing under true orchard conditions.

In the present study, exposure of Casselman plum trees to increased atmospheric ozone concentration through the 1991 growing season reduced leaf net CO_2 assimilation and induced premature leaf-fall. Similar reductions in leaf net CO_2 assimilation and induced premature leaf-fall occurred during the orchard establishment period (the first three years) in this same study (Retzlaff et al., 1992b). More importantly, even though the trees in this study were only exposed to controlled ozone treatments for three years following the first year of initial orchard establishment, increased ozone concentration exposure significantly reduced yield the first bearing year (Retzlaff et al., 1992b) and the first commercial bearing year (1991). Additionally, yield of plum trees exposed to mean daily ozone concentrations greater than 0.09 ppm was reduced by 35% in 1990 (compared to trees in charcoal filtered air) and by 65% in 1991 indicating that the ozone induced yield response of plum trees might be cumulative. Results from a study on one-year old Casselman plum trees (Retzlaff et al., 1991) indicate that if the ozone response is cumulative then the ozone effect would have been greater in the present study had the plum trees been exposed to increased atmospheric ozone concentrations during the first year. It is now clear that chronic ozone stress has a detrimental effect on plum tree yield during the first commercial bearing year. Research is continuing to establish the effects of ozone air pollution on mature orchard growth and yields and to determine which components of yield are affected by ozone stress and whether the yield reductions are cumulative.

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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. Probabilities of statistically significant ozone treatment effects on trunk cross-sectional area growth (Figure 4), dormant pruning weight (Figure 5), leaf weight remaining on the tree (Figure 6), total leaf dry weight (Figure 7), and fruit number per tree, average fruit weight, and fruit weight per tree (Figure 8) of Casselman plum exposed to different atmospheric ozone partial pressures in 1991.

	Trunk Cross-Sectional Area Growth 1991	Dormant Pruning Weight 1/14/92	Leaf Weight Remaining on Tree 10/31/91
Linear[a]	NS	NS	*
A vs. N[b]	*	*	-[c]

	Total Leaf Dry Weight 11/26/90	Fruit Number Per Tree	Fruit Average Weight	Fruit Weight/ tree
Linear[a]	NS	*	NS	*
A vs. N[b]	-	NS	*	NS

a) A significant linear treatment effect (*) indicates that each mean from the charcoal, ambient, and ambient + ozone treatments is different at the 5% level.
b) A significant treatment effect (*) indicates that each mean from the ambient and no-chamber treatments is different at the 5% level.
c) Foliage was not collected on the ground below the no-chamber trees, so no comparison with the ambient chamber treatment could be made.

Table 3. Total flower number, total fruit set, percentage set, fruit number abscised, and percentage drop of Casselman plum trees exposed to different atmospheric ozone concentrations in 1991.

	Total # Flowers per tree	Total # Fruit[a] set/tree	% Set[b]	Fruit Abscised per tree	% Drop[c]
C	6817 (594)[d]	363 (48)	5.3 (0.3)	137 (25)	37 (2.4)
A	6913 (741)	296 (32)	4.3 (0.2)	105 (13)	35 (0.7)
T	5468 (500)	126 (20)	2.2 (0.2)	47 (7)	37 (2.4)
P>F	NS[e]	*	*	*	NS
N	6113 (388)	288 (31)	4.9 (0.7)	77 (9)	27 (0.3)
P>F	NS[f]	NS	NS	NS	*

a) Total number fruit set per tree = fruit number at harvest (Figure 9) + fruit abscised per tree.

b) Percentage set = (total number fruit set per tree/total number flowers per tree) * 100.

c) Percentage drop = (fruit abscised per tree/total number fruit set per tree) * 100.

d) Numbers in parenthesis represent ± one standard error.

e) A significant linear treatment effect (*) indicates that each mean from the charcoal, ambient, and ambient + ozone treatments is different at the 5% level.

f) A significant treatment effect (*) indicates that each mean from the ambient and no-chamber treatments is different at the 5% level.

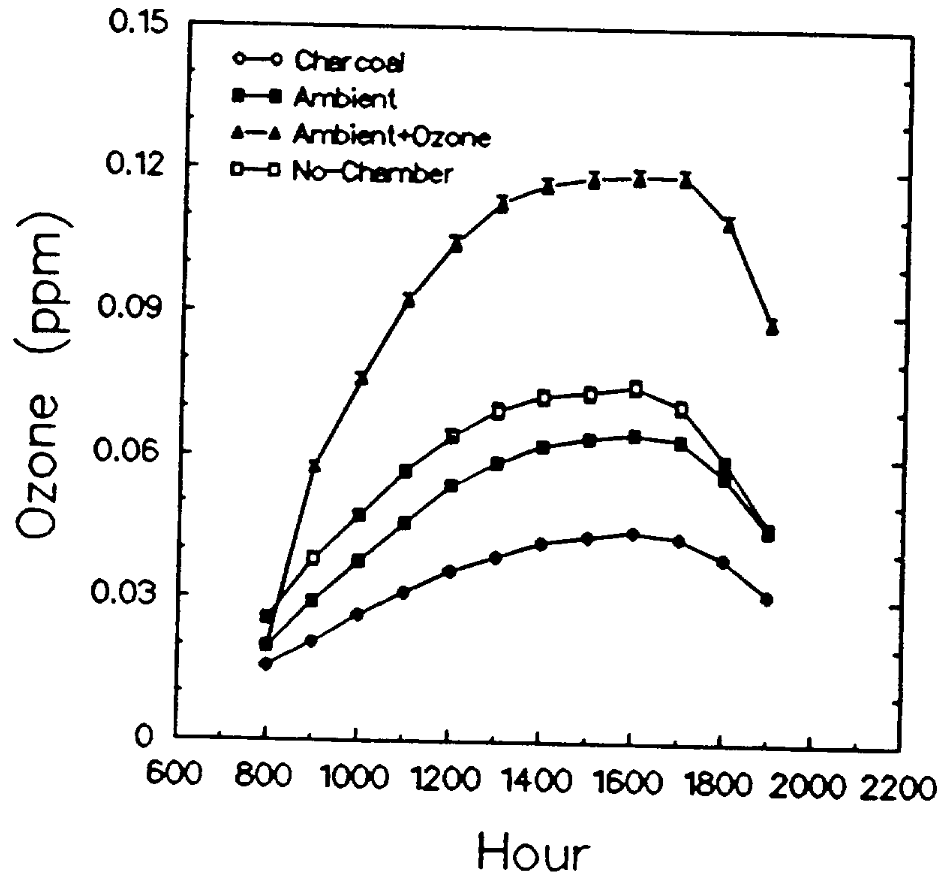

Figure 1. Average hourly ozone concentrations from 1 April to 31 October 1991. Standard error bars are included when they are larger than the individual data symbol.

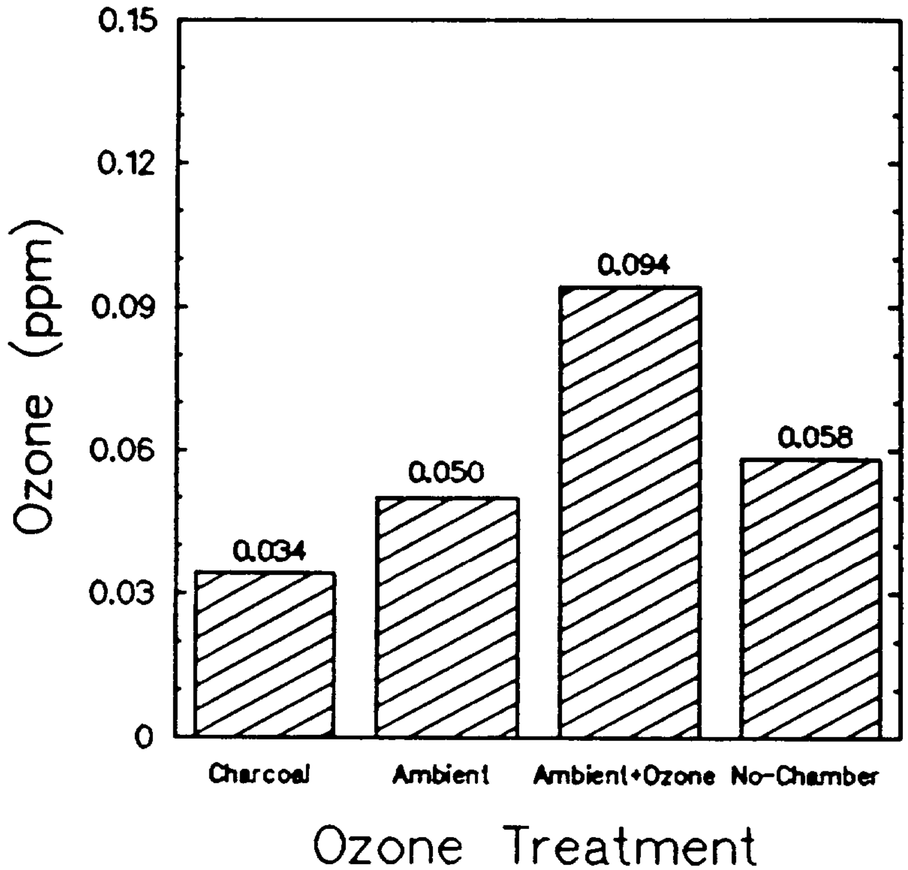

Figure 2. Treatment 12-hour (0800-2000 PDT) mean ozone concentrations for the experimental period from 1 April to 31 October 1991.

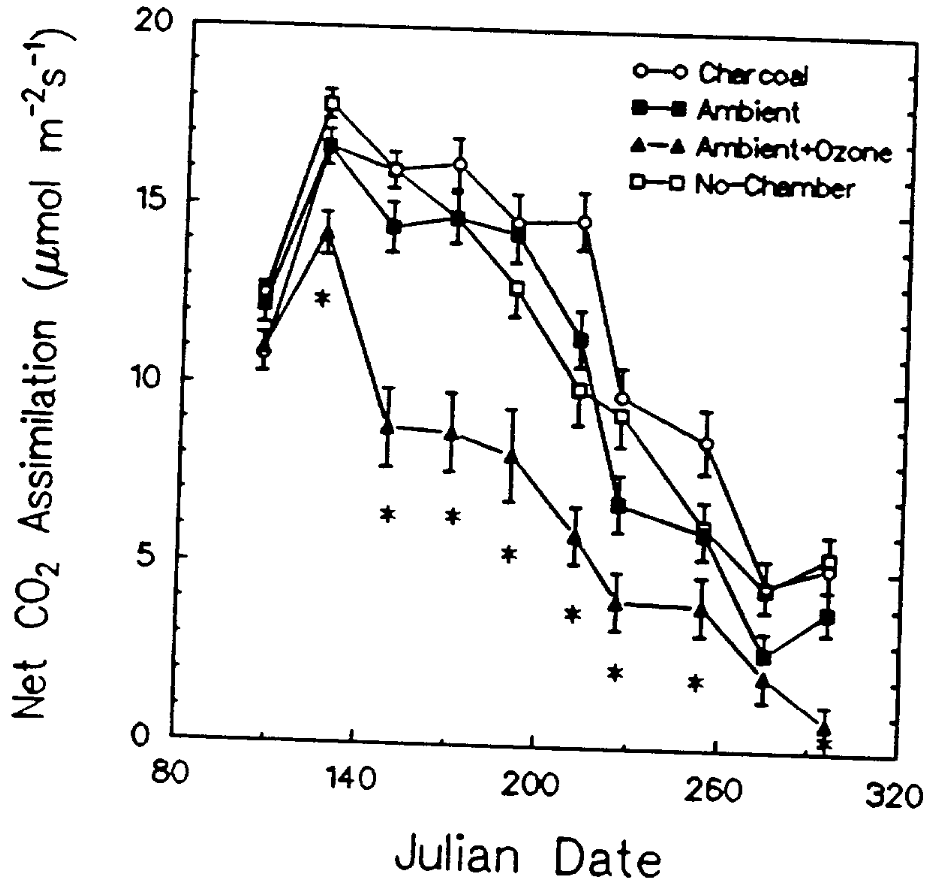

Figure 3. Leaf net CO_2 assimilation (measured at three week intervals) of Casselman plum trees exposed to different atmospheric ozone concentrations in 1991. Vertical bars represent ± one standard error. Asterisks (*) represent dates on which there was a significant linear treatment effect (α < 0.05). n=20.

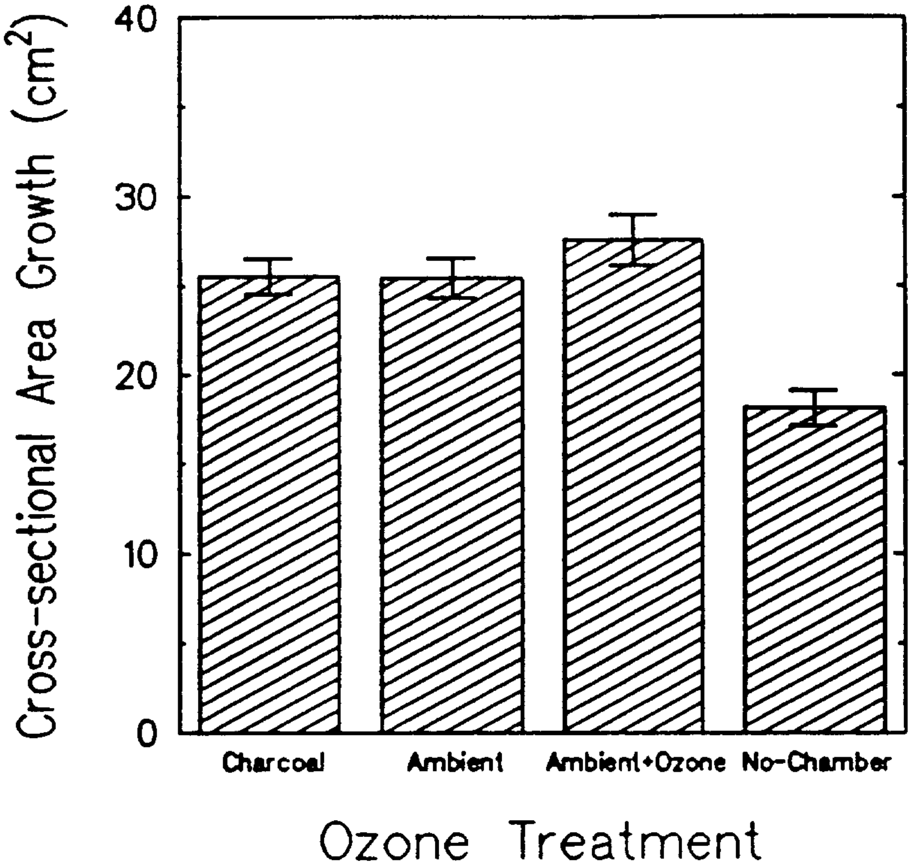

Figure 4. Trunk cross-sectional area growth from 1 April to 1 November 1991 of Casselman plum trees exposed to different atmospheric ozone concentrations in 1991. Vertical bars represent ± one standard error. Probabilities of statistically significant linear ozone treatment effects are shown in Table 2. n=20.

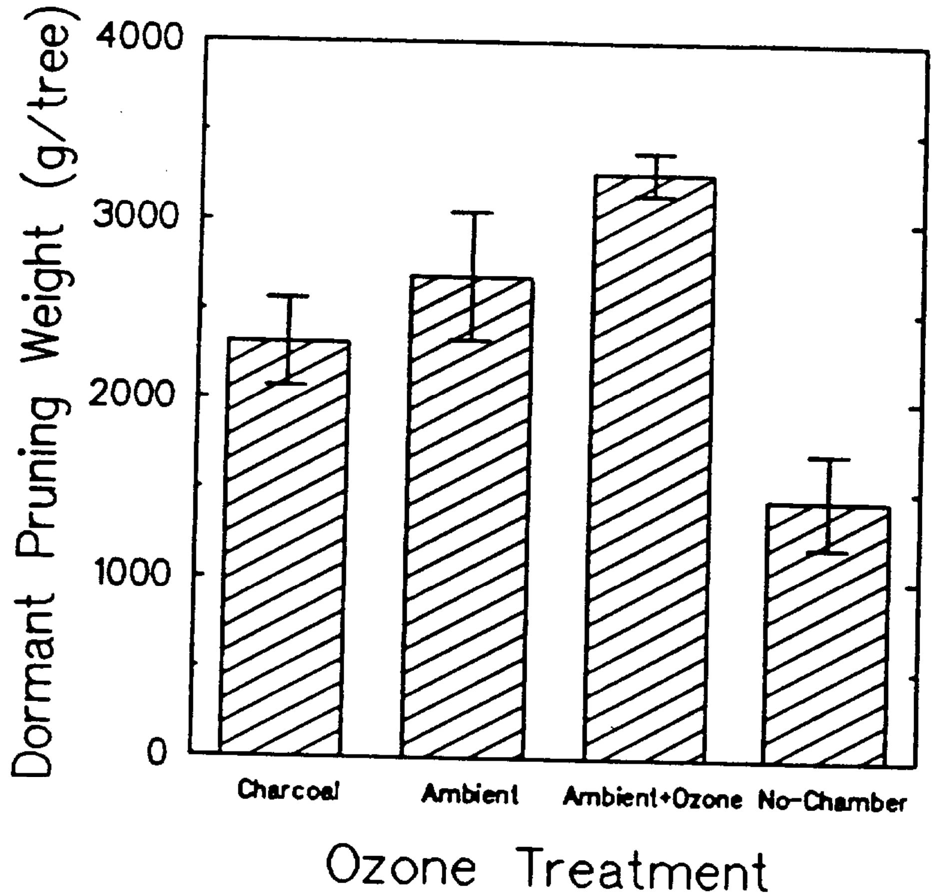

Figure 5. Dormant pruning weights on 4 January 1992 of Casselman plum trees exposed to different atmospheric ozone concentrations in 1991. Other information as found in Figure 4. n=20.

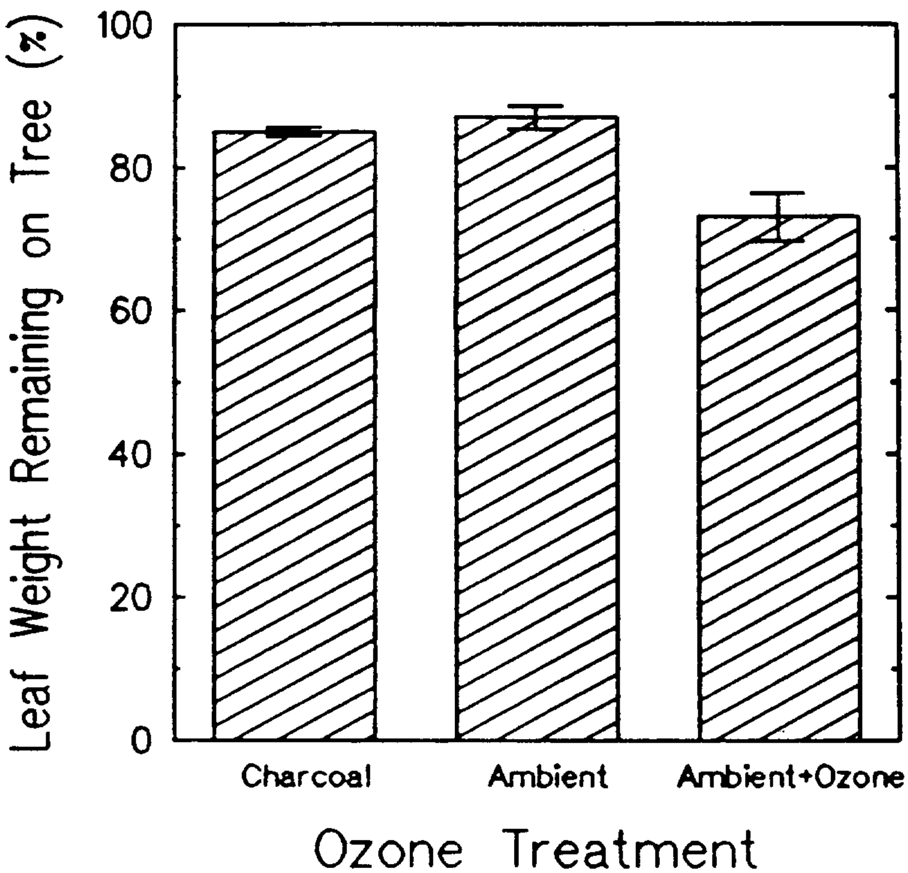

Figure 6. Percentage of leaf dry weight remaining on 31 October 1991 of Casselman plum trees exposed to different atmospheric ozone concentrations in 1991. Other information as found in Figure 4. n=5.

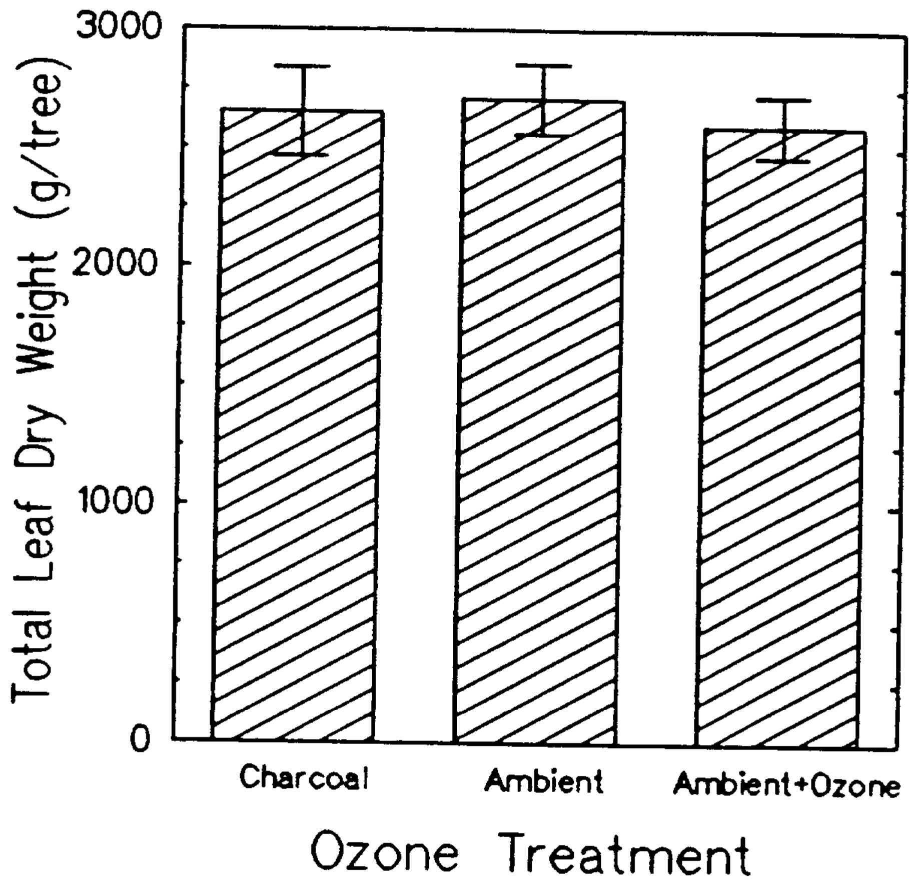

Figure 7. Total leaf dry weight on 26 November 1991 of Casselman plum trees exposed to different atmospheric ozone concentrations in 1991. Other information as found in Figure 4. n=5.

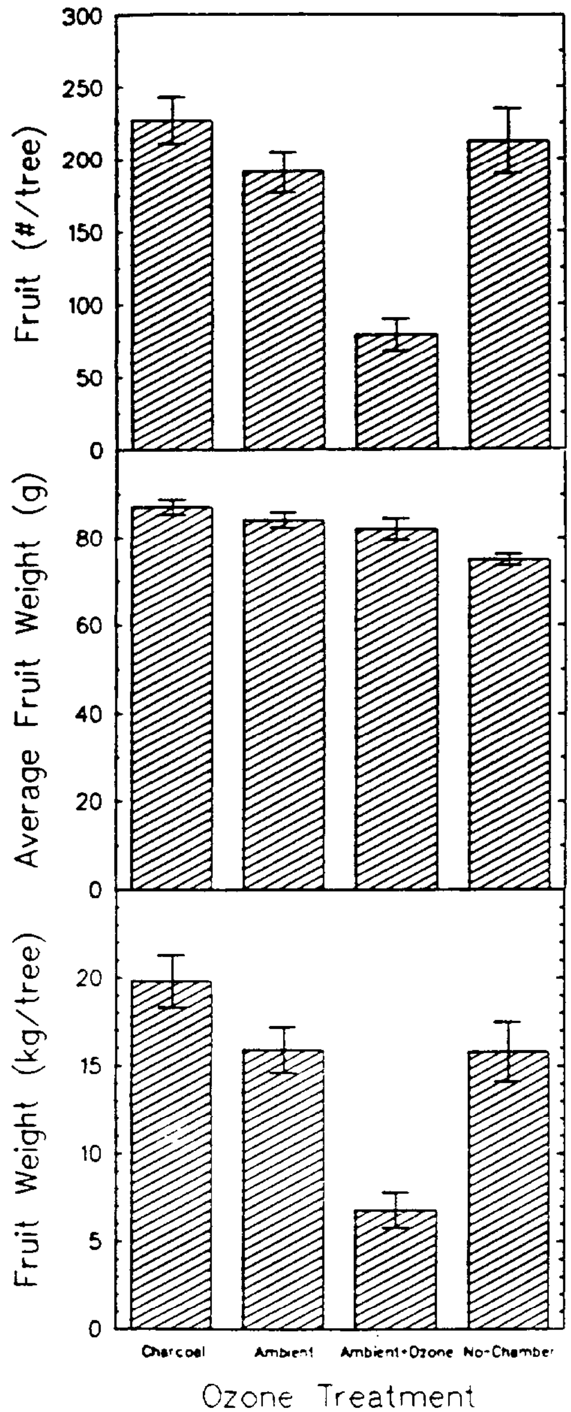

Figure 8. Number of fruit per tree, average fruit weight, and fruit weight per tree of Casselman plum trees picked on 21 August 1991 exposed to different atmospheric ozone concentrations in 1991. Other information as found in Figure 4. n = 20.

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13. ABSTRACT (Maximum 200 Words)

In 1988, an experimental orchard of Cassleman plum (Prunus salicina Lindel., cv Cassleman) was planted in open-top-fumigation chambers and exposed for 4 growing seasons to three ozone concentrations near Fresno, California. During the third year of the study, mean 12-h ozone levels (1991) were 0.034 ppm in the charcoal filtered chambers, 0.050 ppm in the ambient air chambers, 0.94 ppm in the ambient plus added ozone chambers and 0.058 ppm in the no-chamber field plots. Chronic ozone stress has a detrimental effect on photosynthesis, stomatal conductance, leaf appearance and retention, trunk growth, and yield. Yield was 19.8 kg per tree in the charcoal filtered chambers, 15.9 kg/tree in the ambient air chambers, 6.8 kg/tree in the ambient air plus ozone chambers and 15.8 kg/tree in the no-chamber plots. Premature leaf drop and a 35 percent yield loss occurred in 1990 at mean daily ozone concentrations greater than 0.09 ppm (the California Ambient Air Quality Standard). In 1991 the yield loss increased to 65%, indicating cumulative impact on long term productivity. Open top chambers had no photosynthesis or yield differences compared to the no-chamber field plots, and results can be extrapolated to trees of similar age in commercial orchards.

14. SUBJECT TERMS

air pollution, vegetation, yield loss, chronic ozone stress, San Joaquin Valley California, orchard crops

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