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

Final Report on ARB Contract A933-145 (Year Two)
Prepared for California Air Resources Board

University of California
Davis, CA 95616
October 31, 1991

Dr. L. E. Williams
Associate Professor
Department of Viticulture and Enology

Dr. T. M. DeJong
Professor
Department of Pomology

Dr. W. A. Retzlaff
Post-doctoral Research Associate
Department of Viticulture and Enology

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 and from 9 April to 9 November 1990. A no-chamber treatment plot was utilized to assess chamber effects on tree performance. The mean 12-h (0800-2000 h PDT) ozone partial pressures during the two-year experimental period in the charcoal filtered, ambient, ambient + ozone, and no-chamber treatments were 0.044, 0.059, 0.111, and 0.064 ppm in 1989 and 0.038, 0.050, 0.090, and 0.050 ppm in 1990, 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. Cross-sectional area growth of plum decreased with increasing atmospheric ozone concentrations from the charcoal filtered to ambient + ozone treatment. Yield of plum trees in 1990 was 8.8, 6.3, 5.5, and 5.5 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 concentrations. 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 cross-sectional area growth and yield of young Casselman plum trees during orchard establishment.

ACKNOWLEDGEMENTS

The advice and assistance of the following people are gratefully acknowledged:

1. Brian Doyle, Lab Asst. I, Kearney Agricultural Center, Parlier, CA.
2. Jim Doyle, SRA IV, Kearney Agricultural Center, Parlier, CA.
3. Pete Biscay, SRA II, Kearney Agricultural Center, Parlier, CA
4. Bill House, Fresno County Air Pollution Control District, Fresno, CA.
5. JoAnn Coviello, Senior Wordprocessing Specialist, Kearney Agricultural Center, Parlier, CA.
6. Nona Ebisuda, Lab Asst. I, Kearney Agricultural Center, Parlier, CA.
7. David Jamison, Lab Asst. I, Kearney Agricultural Center, Parlier, CA.
8. Scott Williams, Lab Asst. I, Kearney Agricultural Center, Parlier, CA.
9. Dr. Neil Willits, Statistical Laboratory, University of California, Davis, CA.
10. Mary Bianchi, SRA II, Kearney Agricultural Center, Parlier, CA.

DISCLAIMER STATEMENT

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

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 1.8 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 1.8 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.

3. Ozone concentrations greater than 0.09 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.

4. Increased ozone concentrations significantly reduced yield the first bearing year when compared to the trees grown in the charcoal filtered chamber. This was despite the fact that the Casselman plum trees in this study were only exposed to ozone treatments for just two years following an initial year of orchard establishment.

5. The atmospheric ozone concentration was reduced approximately 7% 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 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.

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 0.20 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 recent 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., 1992). However, these studies were conducted on nursery stock trees (bud grafted the previous year) which had been transplanted directly into open-top chambers. The effects of ozone air pollution on deciduous fruit tree crops in a production orchard during and/or 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 first three years of tree growth, a crucial period in which the canopy and permanent limbs are established and the root system develops.

MATERIALS AND METHODS

Plant Materials and Ozone Treatments

Nursery stock of plum (<u>Prunus</u> <u>salicina</u> Lindel., cv. Casselman) on Citation (<u>Prunus</u>) hybrid rootstock were planted 1 April 1988 in an experimental orchard at the University of California Kearney Agricultural Center near Fresno, California (30° 40′ N 119° 40′ 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 and 1990 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 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 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 8 May and continued until 15 November, 1989. After 15 November 1989 the plastic chamber ends were removed. Plastic end walls were put back on the chambers before 10 April 1990 and the ozone treatments initiated. All the plastic chamber walls were removed after 9 November 1990.

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 1.8 times ambient in the ambient + ozone treatment chambers during the two-year 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.

Oxides of nitrogen were measured in the treatment/chambers on a 24-h basis with a Thermo Electron Corporation (Hillsborough, NC) Model 14B Chemiluminescent NO-NO_2-NO_x Gas Analyzer to determine whether the Griffin ozone generation system was releasing additional oxides of nitrogen into the ambient + ozone treatment chambers. No differences in the concentration of oxides of nitrogen were found among treatments during the 1989 or 1990 growing seasons (data not shown).

Gas Exchange

Three weeks after treatment initiation in each year, 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 nine times in 1989 and ten times in 1990. 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 30 °C and 1300 μmol m^{-2} s^{-1}, respectively, across all dates each year. 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. Leaves were then dried in a forced air oven at 70 °C until there was no further weight change and Kjeldahl nitrogen was later determined for each leaf.

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 May through 1 December in 1989 and 1990. 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 May to 1 December each year 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 both growing seasons. On 15 December 1989 and 30 November 1990, 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. Collected leaves were dried and analyzed for N as stated previously.

Trees in the present study were dormant pruned on 7 February 1989, 11 January 1990, and 10 January 1991. 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

Fruit from individual trees in each treatment was picked on 28 August 1990. 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

Treatments were not imposed until the second year of growth, therefore no ozone data was collected in 1988. Hourly ozone concentrations were averaged from 8 May to 15 November 1989 and from 9 April to 9 November 1990 (Figure 1). In November 1989, seasonal 12-hour mean ozone concentrations in the charcoal filtered treatment were 75% of the ambient treatment, whereas the ambient + ozone treatment was 1.9 times that of ambient in 1989 (Figure 2). Ozone concentrations in the ambient treatment/chambers averaged 93% of the no-chamber ozone concentrations in 1989. In November 1990, seasonal 12-hour mean ozone concentrations in the charcoal filtered treatment were 78% of the ambient treatment, whereas the ambient + ozone treatment was 1.8 times that of ambient (Figure 2). Ozone concentrations in the ambient treatment/chambers were identical to those in the no-chamber treatment in 1990.

Gas Exchange

Within 3 (1990) or 4 (1989) months after treatments were initiated 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 in both years. 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 reduced in the ambient + ozone treatment compared to the charcoal filtered treatment in 1989 and 1990 (Figure 4, Table 2). Cross-sectional area growth in the ambient treatment was reduced compared to the charcoal filtered treatment in 1990. Cross-sectional area growth of trees in the no-chamber treatment was less than that in the ambient treatment/chamber in 1989 and 1990.

Dormant pruning weights on 7 February 1989, 11 January 1990, and 10 January 1991 were similar in all the chamber treatments (Figure 5, Table 2). However, pruning weights on the aforementioned dates of the no-chamber trees were less than that of trees in the ambient treatment/chambers. Nitrogen concentrations (% dry weight) of the dormant prunings were 0.4, 0.3, 0.3, and 0.3% on 11 January, 1990 in the charcoal filtered, ambient, ambient + ozone, and no-chamber treatments, respectively and 0.2% for all treatments on 10 January 1991.

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 1989 and 1990. As the season progressed, foliar ozone injury increased and some leaf abscission of injured foliage occurred. By November in 1989 and 1990, more than 90% of the total foliage (calculated on 15 December 1989 and 30 November 1990) remained on the charcoal filtered and ambient trees while less than 60% 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) on 20 November 1989 and 14 November 1990, most of the remaining foliage on trees in all the treatments abscised. Final cumulative foliage dry weight in the ambient + ozone treatment was less than that in the charcoal filtered treatment in 1989, but ozone did not affect final leaf dry weight in 1990 (Figure 7, Table 2).

Seasonal average leaf N concentration (% dry weight) of Casselman plum leaf samples removed from the tree on each photosynthetic measurement date in 1989 was less in the ambient + ozone treatment compared to the charcoal filtered treatment (Figure 8, Table 2). Seasonal average leaf N concentration of attached foliage in 1990 decreased slightly due to increasing atmospheric ozone partial pressure. There was no difference in attached Casselman plum leaf nitrogen concentration between the ambient and no-chamber plots in 1989 or 1990.

Leaf N concentrations of abscised leaves in the charcoal filtered and ambient treatments were approximately 75% of that of the attached foliage in 1989 and 1990 (Figure 8, Table 2). Leaf N concentration of abscised foliage from the ambient + ozone treatment was the same as the nitrogen concentration of the attached foliage in this treatment in 1989, but was approximately 75% of the nitrogen concentration found in the attached foliage in 1990.

Fruit Yield

Fruit number per tree at harvest in 1990 was reduced in the ambient and ambient + ozone treatments compared to the charcoal filtered treatment (Figure 9, 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 1). 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 1989 and 1990 (Figure 3). Similar results for one-year old Casselman plum were reported previously (Retzlaff et al., 1991). In both 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, especially in 1990. Ozone has previously been found to accelerate the seasonal decline in photosynthetic capacity (Reich, 1983).

Trunk cross-sectional area growth of Casselman plum was 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). Decreases in trunk growth in these two studies are apparently related to the decreases in photosynthesis and loss of photosynthetic leaf area of these trees. The additional growth of the plum trees in the "clean air" of the charcoal filtered treatment (low stress) is similar to the results found in other stress studies. Apple trees grown in a weed-free orchard plot had a larger stem diameter and produced a more extensive branching system compared to trees growing with weed competition controlled by herbicide (Stinchcombe and Stott, 1983).

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 two seasons, 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 this plum tree and 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 McClenahan, 1989; Keane and Manning, 1988; Chappelka et al., 1988; Retzlaff et al., 1991; Retzlaff et al., 1992). 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., 1992). 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 1989 and 1990 growing seasons, Casselman plum trees in the ambient + ozone treatment lost more than 40% of their foliage prematurely (Figure 6).

The processes of leaf senescence involve the recovery of mineral nutrients by the permanent structures of perennial plants (Grigal et al., 1976; Oland, 1963; Sacher, 1973). If ozone causes premature leaf senescence followed by abscission (as opposed to just premature leaf abscission), then the concentrations of mineral nutrients such as nitrogen in leaves that have abscised should be similar to leaves that have not been exposed to elevated ozone, but have aged naturally. Foliar nitrogen concentrations of fallen Casselman plum leaves were similar regardless of ozone treatment (Figure 8). Comparable results were obtained with five almond cultivars exposed to increased atmospheric ozone concentrations for one growing season (Retzlaff et al., 1992). These data support the contention that increased atmospheric ozone does cause premature leaf senescence. Further, N concentrations of the Casselman plum stem prunings were unchanged by ozone treatment indicating that chronic ozone stress did not interfere with the accumulation of N in next year's fruiting wood.

First bearing year (1990) yield data indicates that increased atmospheric ozone concentrations reduced Casselman plum yield (Figure 9). 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 28% in the ambient and 38% 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 time, 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 three periods of light bloom during August and September of 1990. 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 9). The atmospheric ozone concentration was reduced by approximately 7% 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 over two growing seasons reduced leaf net CO_2 assimilation, induced premature leaf-fall, and decreased cross-sectional area growth. More importantly, even though the trees in this study were only exposed to controlled ozone treatments for two years following the first year of initial orchard establishment, increased ozone concentration exposure significantly reduced yield the first bearing year. 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 growth and yield during the orchard establishment period. 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.

LITERATURE CITED

Abbott, D. L. 1977. Fruit bud formation in Cox's Orange Pippin. Report Long Ashton Research Station for 1976, 167-76.

Adaros, G. H., J. Weigal and H. J. Jager. 1990. Effects of incremental ozone concentrations on the yield of bush beans (Phaseolus vulgaris var. nanus [L.] Aschers.) Gartenbauwissenschaft 4:162-167.

Brewer, R. F. and R. Ashcroft. 1983. The effects of ambient air pollution on Thompson Seedless grapes. Final Report on Air Resources Board Contract A1-132-33. The effect of present and potential air pollution on important San Joaquin Valley crops: Grapes. 15 p.

Cabrera, H. S., S. V. Dawson and C. Stromberg. 1988. A California air standard to protect vegetation from ozone. Environ. Pollut. 53:397-408.

Chappelka, A. H., B. I. Chevone, and T. T. Burk. 1988. Growth response of green and white ash seedlings to ozone, sulfur dioxide, and simulated acid rain. For. Sci. 34:1016-1029.

DeJong, T. M., J. F. Doyle and K. R. Day. 1987. Seasonal patterns of reproductive and vegetative sink activity in early and late maturing peach (Prunus persica) cultivars. Physiologia Plantarum 71:63-69.

Grigal, D. F., L. F. Ohmann and R. B. Brander. 1976. Seasonal dynamics of tall shrubs in northeastern Minnesota: biomass and nutrient element changes. For. Sci. 22:195-208.

Heagle, A. S. 1989. Ozone and Crop yield. Ann. Rev. Phytopathol. 27:397-423.

Keane, K. D., and W. J. Manning. 1988. Effects of ozone and simulated acid rain on birch seedling growth and formation of ectomycorrhizae. Environ. Pollut. 52:55-65.

Keller, Th. 1988. Growth and premature leaf fall in American aspen as bioindicators for ozone. Environ. Pollut. 52:183-192.

Lehnerr, B. F. Machler, A. Granjean and J. Fuhrer. 1988. The regulation of photosynthesis in leaves of field-grown spring wheat (Triticum aestivum L. cv. Albis) at different levels of ozone in ambient air. Plant Physiol. 88:1115-1119.

LaRue, J. H. and R. S. Johnson. 1989. Peaches, plums and nectarines: growing and handling for fresh market. University of California Cooperative Extension Publication 3331. 246 pp.

Mebrahtu, T., W. Mersie and M. Rangappa. 1991. Path coefficient analysis of ozone effects on seed yield and seed yield components of bean (Phaseolus vulgaris L.) J. Hort. Sci. 66:59-66.

Oland, K. 1963. Changes in the content of dry matter and major nutrient elements of apple foliage during senescence and abscission. Physiol. Plant. 28:682-694.

Olszyk, D. M., G. Kats, C. L. Morrison, P. J. Dawson, I. Gocka, J. Wolf and C. R. Thompson. 1990. Valencia orange fruit yield with ambient oxidant or sulfur dioxide exposures. J. Amer. Soc. Hort. Sci. 115:878-883.

Prinz, B. 1988. Ozone effects on vegetation. In: Tropospheric Ozone. I.S.A. Isaksen, ed. D. Reidel Publishing Co., Germany, pp. 161-184.

Pye, J. M. 1988. Impact of ozone on the growth and yield of trees: A review. J Environ. Qual. 17:347-360.

Reich, P. B. 1983. Effects of low concentrations of ozone on net photosynthesis, dark respiration, and chlorophyll contents in aging hybrid poplar leaves. Plant Physiol. 73:291-296.

Reich, P. B. and R. G. Amundson. 1985. Ambient levels of ozone reduce net photosynthesis in tree and crop species. Science 230:566-570.

Retzlaff, W. A., L. E. Williams and T. M. DeJong. 1990. The effect of different atmospheric ozone partial pressures on photosynthesis and growth of nine fruit and nut tree species. Tree Physiol. 8:93-105.

Retzlaff, W. A., T. M. DeJong and L. E. Williams. 1992. Photosynthesis and growth response of almond (Prunus dulcis (Mill) D. A. Webb syn. P. amygdalus Batsch) to increased atmospheric ozone partial pressures. J. Environ. Qual. IN PRESS.

Sacher, J. A. 1973. Senescence and post-harvest physiology. Ann. Rev. Plant Physiol. 24:197-224.

SAS Institute, Inc. 1985. SAS User's Guide: Basics, 1985 edition. SAS Institute, Cary, NC.

Scherzer, A. M. and J. R. McClenahen. 1989. Effects of ozone or sulfur dioxide on pitch pine seedlings. J. Environ. Qual. 18:57-61.

Stinchcombe, G. R. and K. G. Stott. 1983. A comparison of herbicide-controlled orchard ground cover management systems on the vigor and yield of apples. J. Hort. Sci. 58(4):477-489.

Takemoto, B. K., A. Bytnerowicz and D. M. Olszyk. 1988. Depression of photosynthesis, growth, and yield in field-grown green pepper (Capsicum annum L.) exposed to acidic fog and ambient ozone. Plant Physiol. 88:477-482.

Temple, P. J., R. S. Kupper, R. W. Lennox and K. Rohr. 1988. Injury and yield responses of differentially irrigated cotton to ozone. Agron. J. 80:751-755.

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 cross-sectional area growth (Figure 4), dormant pruning weights (Figure 5), leaf weight remaining on the tree (Figure 6), total leaf dry weight (Figure 7), leaf nitrogen concentration (Figure 8), and fruit number per tree, average fruit weight, and fruit weight per tree (Figure 9) of Casselman plum exposed to different atmospheric ozone partial pressures in 1989 and 1990.

	Cross-Sectional Area Growth		Dormant Pruning Weights			Leaf Weight Remaining on Tree	
	1989	1990	2/7/89	1/11/90	1/10/91	11/3/89	10/31/90
Linear[a]	*	*	NS	NS	NS	*	*
A vs. N[b]	*	*	NS	*	*	-[c]	-

	Total Leaf Dry Weight		Leaf Nitrogen Concentration: Attached		Leaf Nitrogen Concentration: Abscised	
	12/15/89	11/30/90	1989	1990	1989	1990
Linear[a]	*	NS	*	NS	*	NS
A vs. N[b]	-	-	NS	NS	-	-

	Fruit: Number Per Tree	Fruit: Average Weight	Fruit: Weight/tree
Linear[a]	*	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.

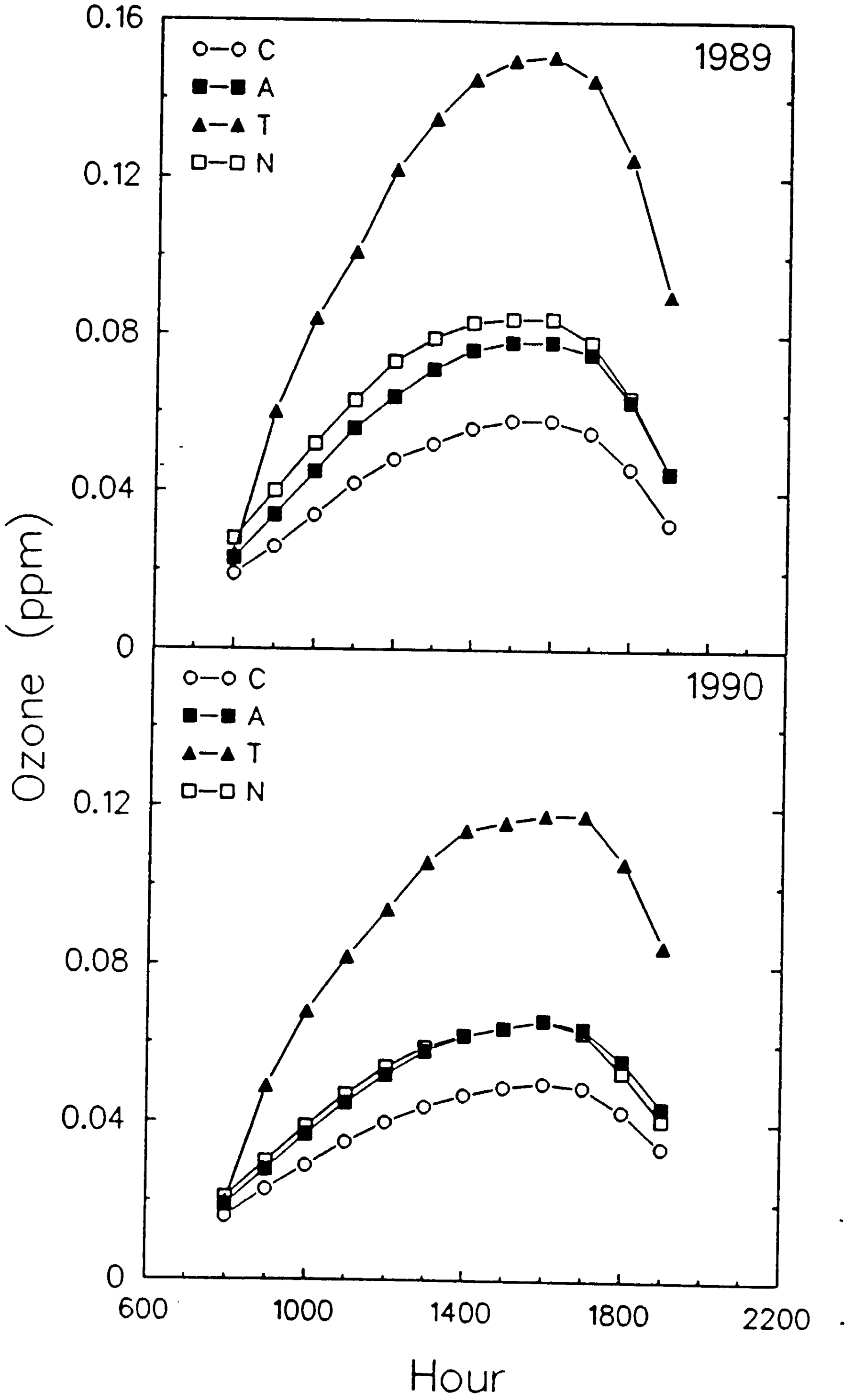

Figure 1. Average hourly ozone concentrations from 8 May to 15 November 1989 and from 9 April to 9 November 1990. Standard error bars are included when they are larger than the individual data symbol. C, A, T, and N refer to the charcoal filtered, ambient, ambient + ozone, and no-chamber treatments, respectively.

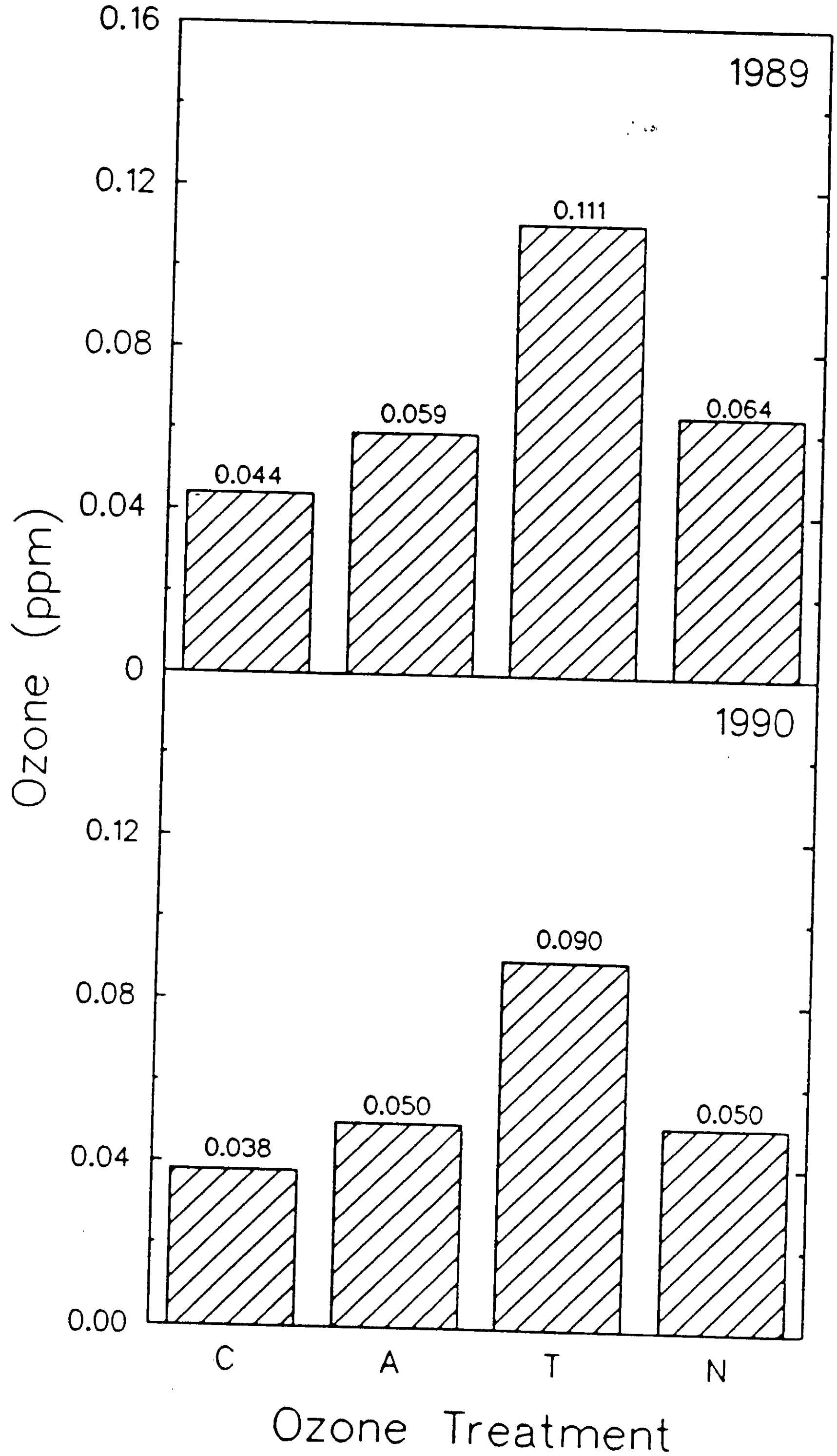

Figure 2. Treatment 12-hour (0800-2000 PDT) mean ozone concentrations for the experimental period from 8 May to 15 November 1989 and from 9 April to 9 November 1990. C, A, T, and N refer to the charcoal filtered, ambient, ambient + ozone, and no-chamber treatments, respectively.

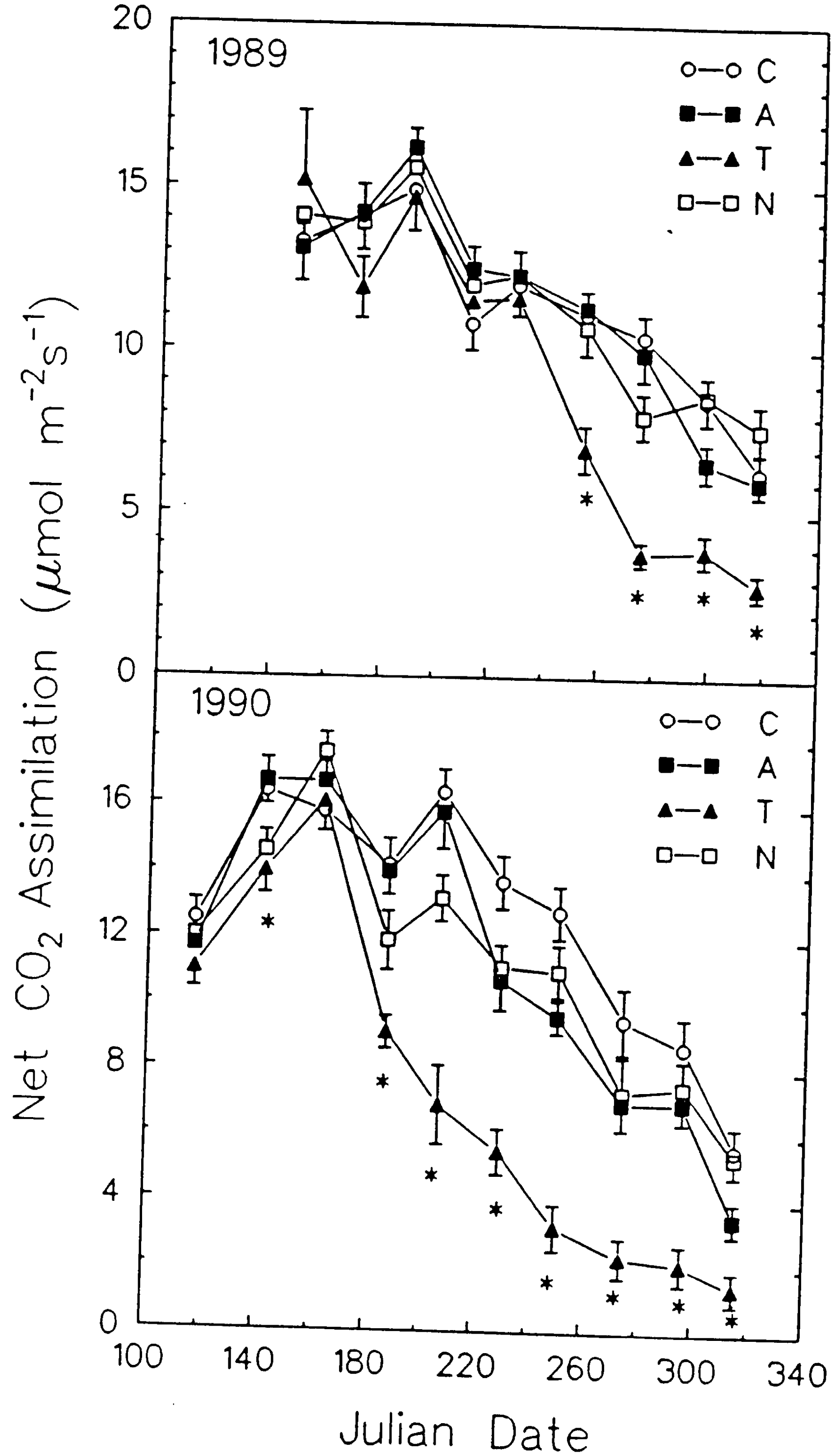

Figure 3. Leaf net CO_2 assimilation (measured at three week intervals) of Casselman plum trees exposed to different atmospheric ozone concentrations in 1989 and 1990. Vertical bars represent ± one standard error. C, A, T, and N refer to the charcoal filtered, ambient, ambient + ozone, and no-chamber treatments, respectively. Asterisks (*) represent dates on which there was a significant linear treatment effect ($\alpha < 0.05$). n=20.

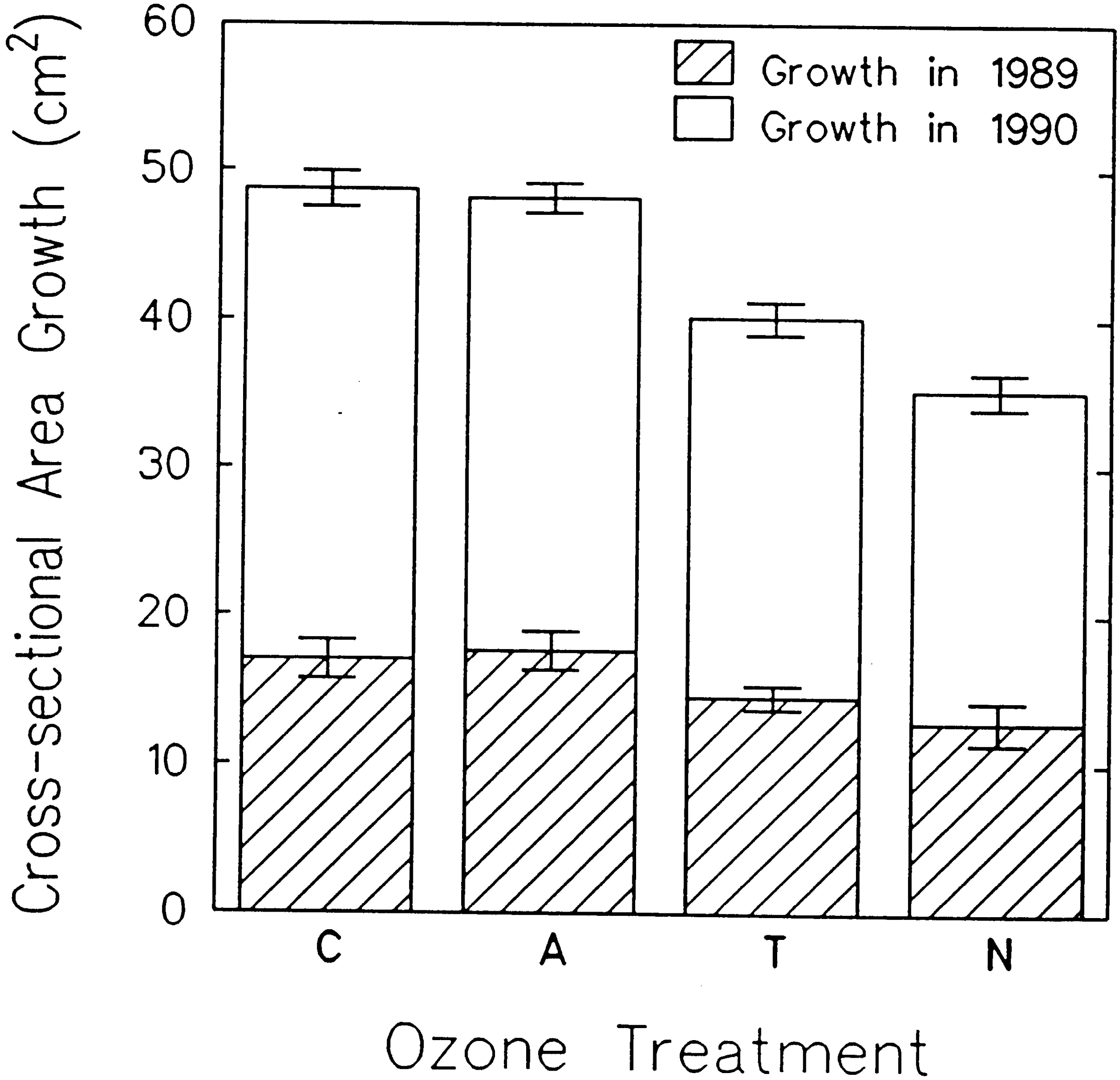

Figure 4. Trunk cross-sectional area growth from 1 May to 1 December in 1989 and 1990 of Casselman plum trees exposed to different atmospheric ozone concentrations in 1989 and 1990. Vertical bars represent ± one standard error. C, A, T, and N refer to the charcoal filtered, ambient, ambient + ozone, and no-chamber treatments, respectively. Probabilities of statistically significant linear ozone treatment effects are shown in Table 1. n=20.

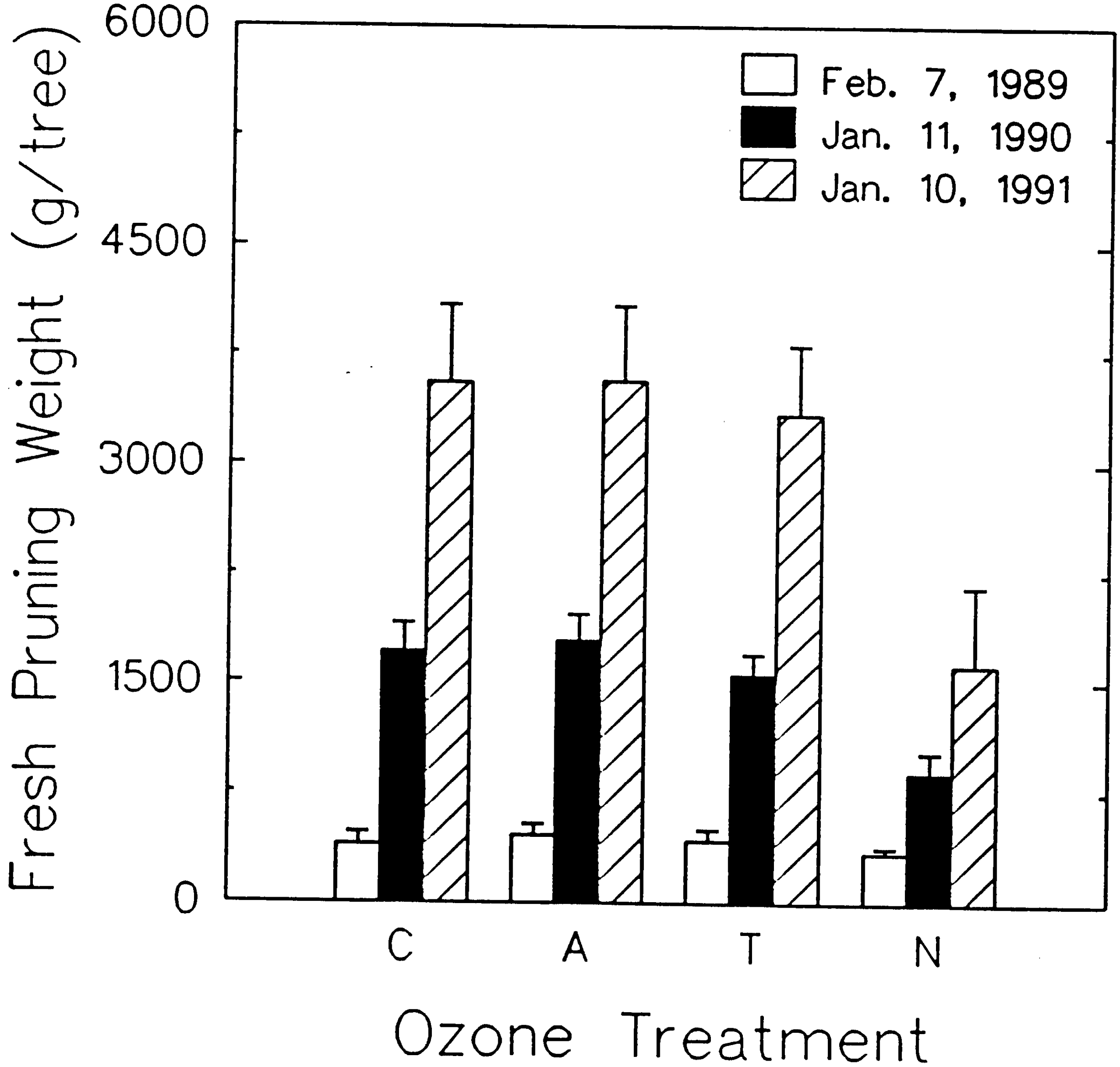

Figure 5. Dormant pruning weights on 7 February 1989, 11 January 1990, and 10 January 1991 of Casselman plum trees exposed to different atmospheric ozone concentrations in 1989 and 1990. Other information as found in Figure 4. n=20.

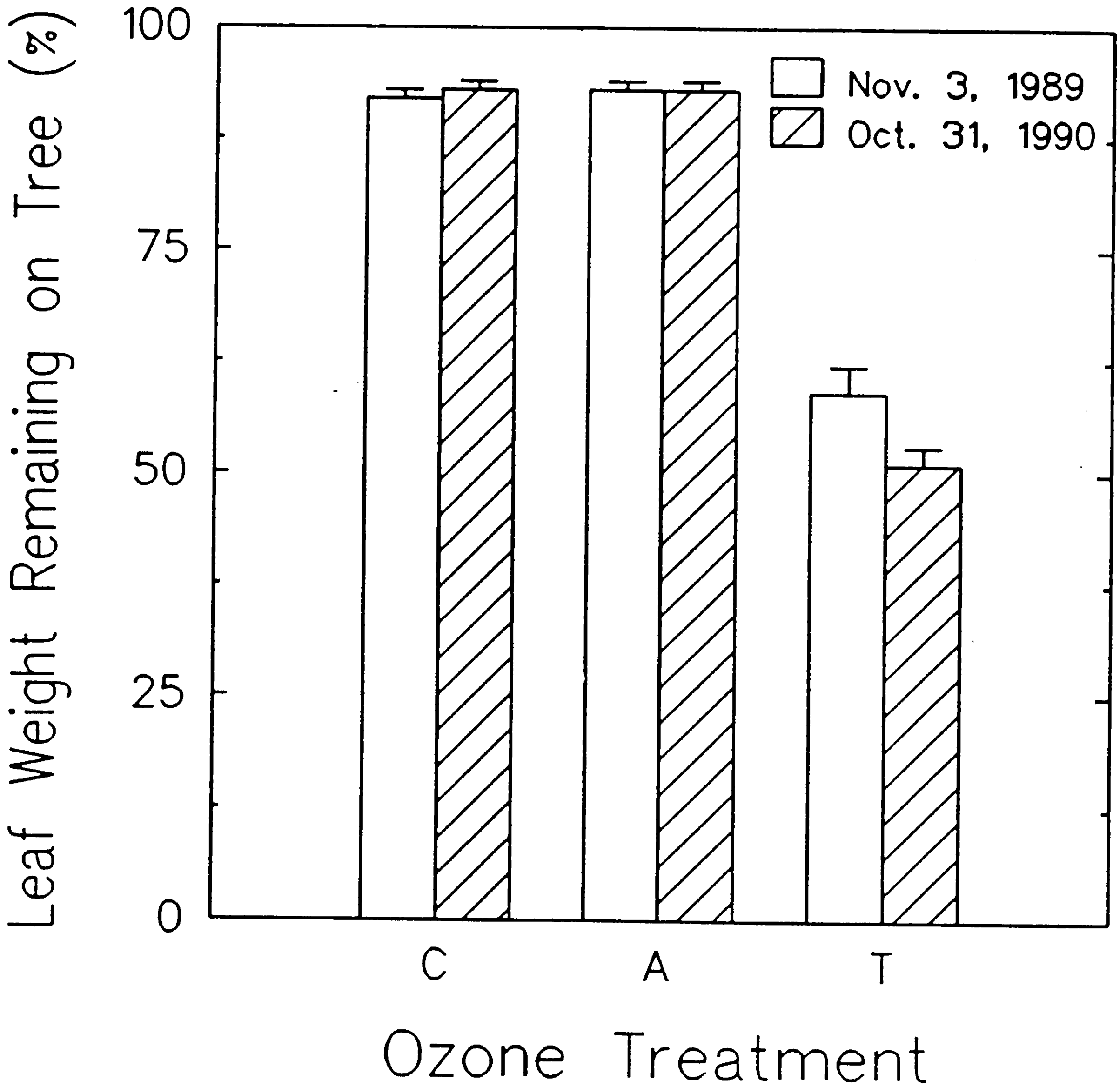

Figure 6. Percentage of leaf dry weight remaining on 3 November 1989 and 31 October 1990 of Casselman plum trees exposed to different atmospheric ozone concentrations in 1989 and 1990. Other information as found in Figure 4. n=5.

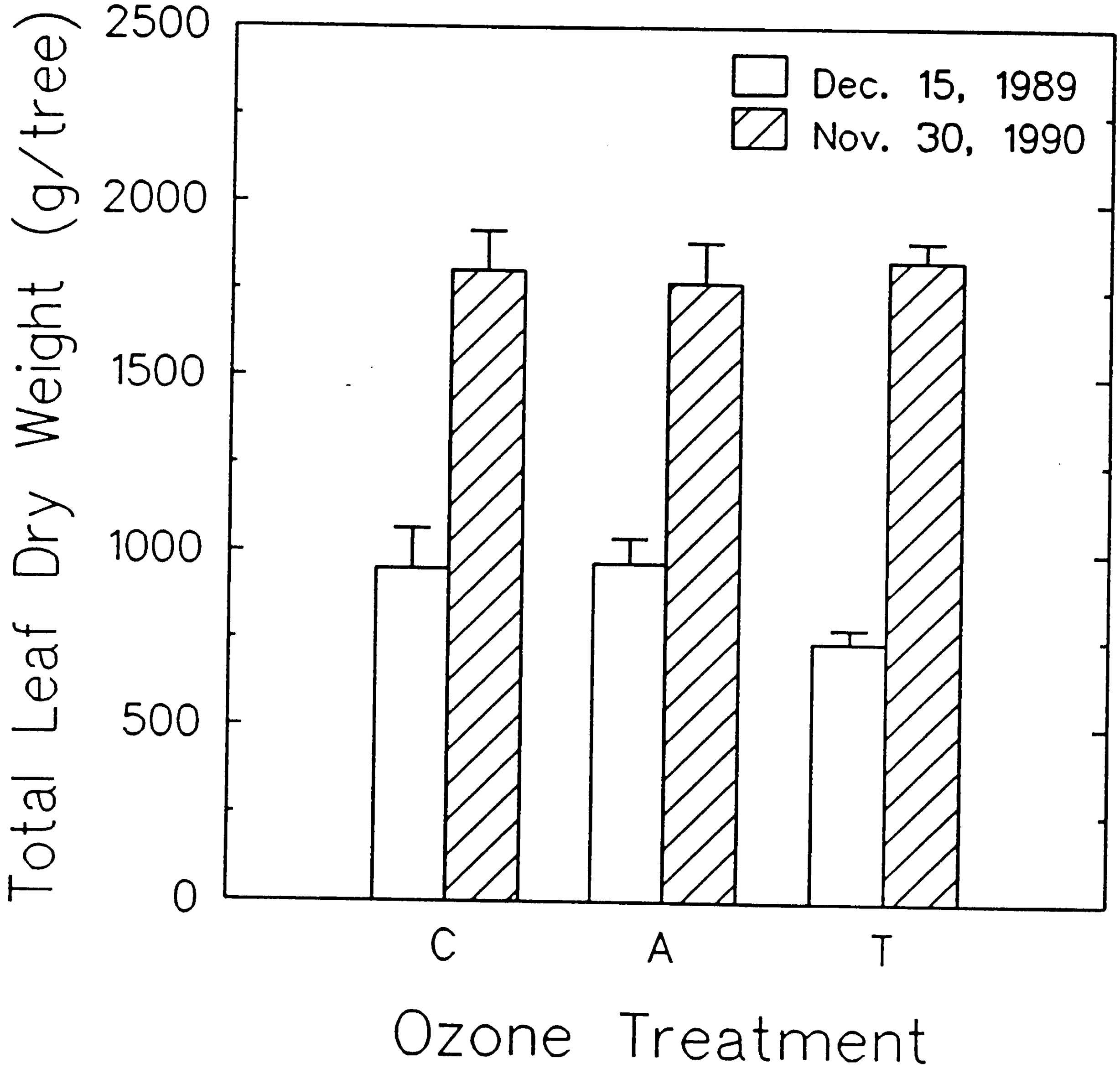

Figure 7. Total leaf dry weight on 15 December 1989 and 30 November 1990 of Casselman plum treesexposed to different atmospheric ozone concentrations in 1989 and 1990. Other information as found in Figure 4. n=5.

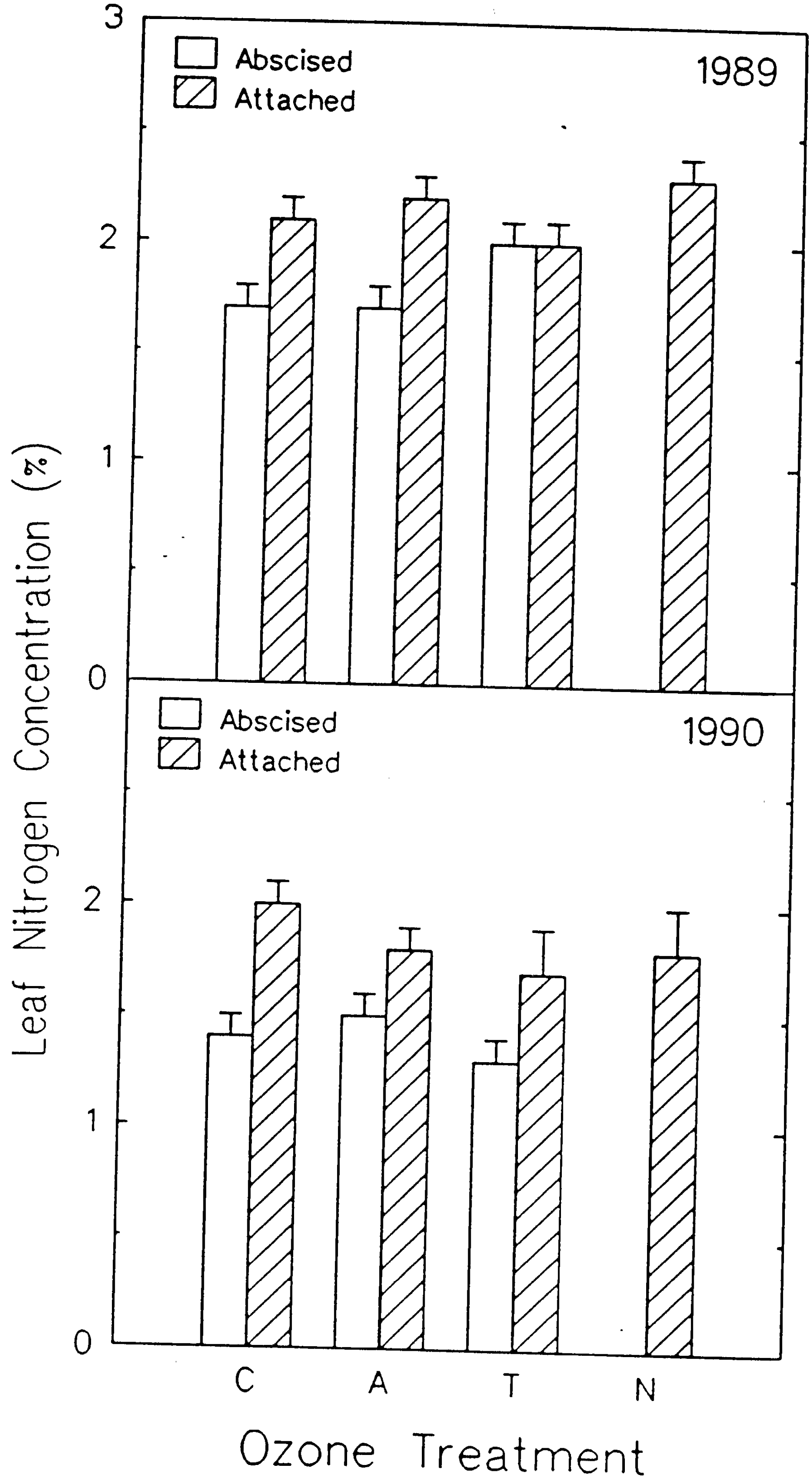

Figure 8. Leaf nitrogen concentration (% dry weight) of attached and abscised foliage from Casselman plum trees exposed to different atmospheric ozone concentrations in 1989 and 1990. Other information as found in Figure 4. n = 40 (attached 1989); n = 20 (abscised 1989); n = 15 (attached 1990); n = 20 (abscised 1990).

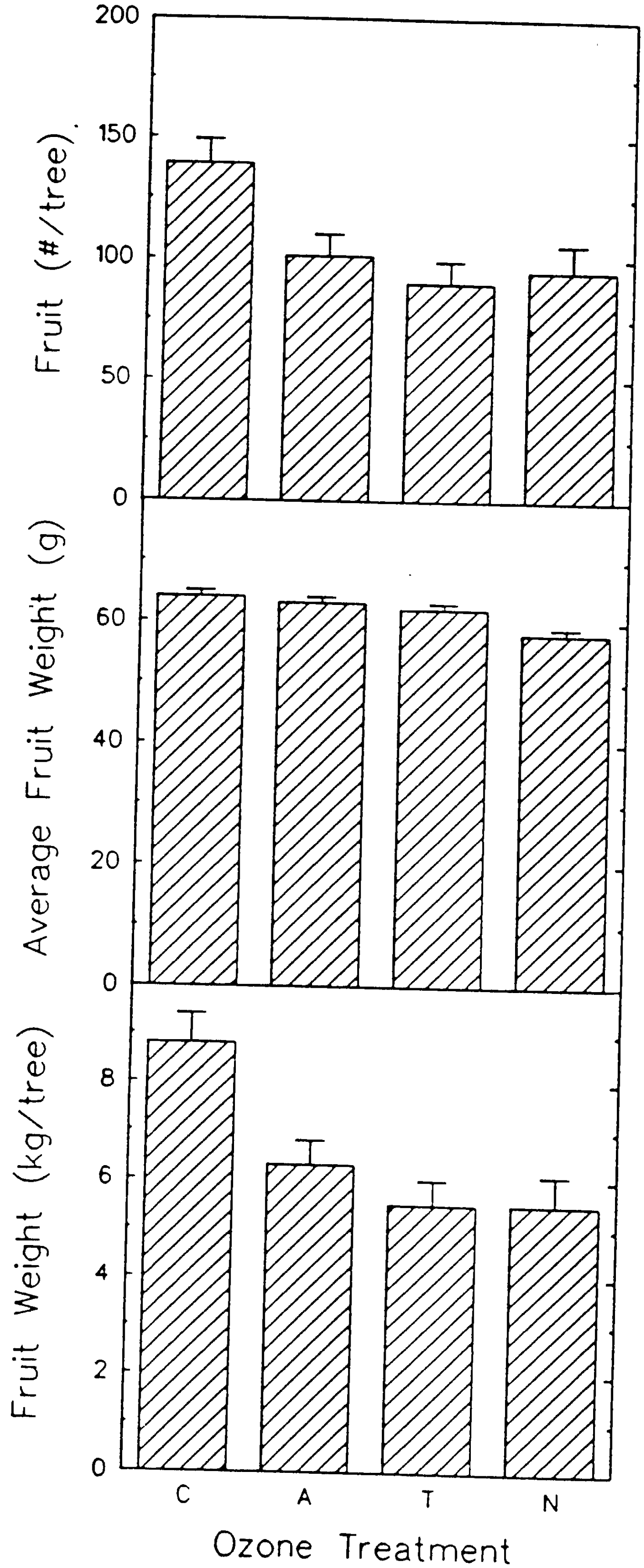

Figure 9. Number of fruit per tree, average fruit weight per tree, and fruit weight per tree of Casselman plum trees picked on 28 August 1990 exposed to different atmospheric ozone concentrations in 1989 and 1990. Other information as found in Figure 4. n = 20.