1996

Influence of ozone on two white clover (Trifolium repens) clones :: a phenotypic investigation /

Michael S. Johnson
University of Massachusetts Amherst

INFLUENCE OF OZONE ON TWO WHITE CLOVER (*TRIFOLIUM REPENS*) CLONES: A PHENOTYPIC INVESTIGATION

A Thesis Presented

by

MICHAEL S. JOHNSON

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

September 1996

Department of Plant Pathology

INFLUENCE OF OZONE ON TWO WHITE CLOVER (*TRIFOLIUM REPENS*) CLONES: A PHENOTYPIC INVESTIGATION

A Thesis Presented

by

MICHAEL S. JOHNSON

Approved as to style and content by:

William J. Manning, Chair

Daniel R. Cooley, Member

Mark S. Mount, Member

Mark S. Mount, Department Head
Department of Plant Pathology

ACKNOWLEDGMENTS

The author wishes to thank Dr. W. J. Manning for allowing him to conduct this research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Tropospheric ozone is one of the most important forms of air pollution (5, 40, 45). Ozone exposure has been associated with reduced yield (28, 37, 51) and growth (2, 32, 44, 64) in agricultural crops. Ozone is formed and destroyed naturally in the troposphere. Ozone formation occurs during periods of high humidity, high temperatures, and high light intensity (31). It is a product of a photochemical reaction cycle involving sunlight nitrogen dioxide, and nitric oxide (40). Sunlight converts nitrogen dioxide to nitric oxide and atomic oxygen. The oxygen atom combines with diatomic oxygen forming ozone. The ozone reacts with nitric oxide to reform nitrogen dioxide. Normally, this cycle results in background ozone concentrations of 25 to 45 ppb (36). However, the presence of hydrocarbons and higher nitrogen oxide concentrations can increase the amount of ozone in the troposphere (31). Hydrocarbons combine with nitric oxide blocking the reaction which breaks down ozone. Increases in nitrogen dioxide concentrations leads to more single oxygen atoms to react with diatomic oxygen. Under these conditions, ambient ozone concentrations can reach 100 to 150 ppb. Ozone concentrations between 40 and 100 ppb is the standard threshold for many sensitive plant species (27).

Ozone exposure can lead to both chronic and acute injury. Chronic injury is a result of exposure to low concentrations of ozone over long periods. Some symptoms are chlorosis and premature senescence of leaves and or fruit. Acute injury occurs when plants are exposed to high concentrations for short periods of time. Symptoms include flecking and stippling of the leaves. Due to the fluctuating concentrations of ambient ozone, both types of injury can occur on plants over their life cycles, leading to reductions in yield (41). These reductions in yield are due to decrease in photosynthesis. In order to compensate for this loss, plants change the pattern in which they partition carbohydrates to sites that will increase photosynthesis. Information of how plants reallocate these resources and alter growth in response to ozone is sparse (17, 20, 49).

Plants can be separated into many different parts, flowers, leaves, stems, roots, etc. To understand how a plant performs under a stress, it is crucial to know the response of individual organs to that stress (1). Kudoh (1995) states that it is necessary to carefully evaluate the effects of environmental factors for each character level and then take into account the integration of the response of all characters as the performance of an individual.

This review will look at how different organs respond to ozone and how these responses interact to affect growth. My research dealt only with vegetative growth. *Trifolium repens* reproduces primarily through vegetative propagation. The plant consists of a series of modules connected by a main stolon. A module consists of a primary leaf, axillary bud, and root meristem. Once the axillary bud and roots develop the module can survive independently. The main stolon senscenses and decomposes acropetally. This severes the connection between module and mother plant. Flowering does occur, but seedlings do not appear to contribute significantly to population growth. For this reason, the effect of ozone on reproductive organs will not be considered.

Leaves

Leaves are the most important source of photosynthate. Biomass production is entirely dependent on how effectively leaves photoassimilate carbon (9). The primary organs that ozone injures are the leaves. Ozone enters the leaves through the stomates during photosynthesis. Ozone or some by-product migrates to the pallisade mesophyll layer, where it compromises the integrity of cell membranes, killing the cells (24, 41).

Ozone induced symptoms are quite characteristic on legumes. Chronic exposure leads to bronzing (59) or stippling (20) of the leaves. Chlorosis may also occur and the leaf may senescence prematurely (2, 21, 61). Injury to leaves due to acute exposure first appears as interveinal, watersoaked lesions. Tissue in these regions dies resulting in white or tan flecking on the leaf (45). Flecking is restricted to the adaxial surface of the leaf (41). If the area of necrosis is extensive, the leaf will die and abscise. Injury occurs almost exclusively on newly mature leaves. Kasana (1991) observed ozone induced injury progressed acropetally from the lower mature leaves to the upper younger ones, but the apical youngest leaves always showed almost complete resistance. The stage of leaf metabolism and differentiation appears to affect ozone sensitivity and consequently, factors affecting leaf physiology will modify the extent and severity of injury (38, 48). Newly mature clover leaves are at their maximum expansion rate, almost fully expanded, and just starting lignification and secondary cell wall synthesis (35). During this time, photosynthesis rates are increased (12, 14) and the leaf switches from being a sink to a source of C-assimilate (13). These factors allow more ozone to enter the leaf. This overloads the repair processes and injury may occur.

Ozone exposure leads to reduced total leaf area. This is a result of premature leaf senescence and reduced leaf production. Field grown alfalfa (17) and soybean plants (20) exhibited a slower leaf growth rate when exposed to ozone. The reduction in growth is thought to be a result of impaired photosynthesis and increased metabolic costs from maintenance and repair activities (3, 18, 55).

Individual leaf area can increase or decrease as a result of ozone exposure. Cooley (1987) observed that alfalfa leaves increased in area on plants exposed to ozone. However, these plants had fewer leaves. Mulchika (1988) found that soybeans exposed to double ambient concentrations of ozone had a reduction in leaf expansion rate of 18 percent.

Ozone exposure results in injury and sometimes death of leaves. This leads to lower carbon assimilation, due to reductions in the area of the photosynthetic surface.

Roots

Ozone can either increase or decrease root growth. The response of roots to ozone is indirect. Ozone cannot penetrate the soil (8). However, ozone can alter the amount of photoassimillate translocated to the roots. Bambridge (1995) found that root growth of *Pisum sativum* was stimulated when plants were exposed to low levels of ozone. Root dry weights of plants exposed to 30 ppb ozone were 22 percent greater than root weights of control plants. As ozone concentrations increase, root growth decreases. This is due to a change in the distribution of assimilates to the organs (3, 58). Roots are the least powerful sinks in ozone stressed plants (17). Ozone stress can cause plants to reallocate assimilates normally destined to the roots to sinks with higher demands. Okano (1984) found that kidney bean plants exposed to 0.2 ul l-1 ozone for four days reduced the export the 13C from the primary leaf to the lower parts of the plant from 67 to 53 percent. The difference presumably was transported to the younger leaves which received an increase of assimilates from 22 to 36 percent. This reallocation of resources often leads to greater shoot to root ratios. Leaves closest to the roots are generally the root's source of assimilates. These leaves are at the mature stage and generally are the most damaged from ozone exposure. The loss of these resources contributes to decreases in root growth.

Ozone alters the morphology of the root. Bambridge (1995) found that pea plants exposed to increasing concentrations of ozone had decreasing numbers of secondary lateral roots. The number of secondary lateral roots was reduced from 200 on control plants to 98 on plants exposed daily to 90 ppb ozone for seven hours.

Nodulation is also affected by ozone stress. Nodule survival is dependent on a continuous supply of photosynthates (23, 52, 53). Ozone stress reduces the flow of photosynthates to the roots. Three week old soybean plants exposed to 75 ppb of ozone for one hour had a reduction in total nodule number by 14 percent (57).

Ozone leads to less assimilates reaching the roots. This leads to lower growth resulting in a decrease in the uptake of water and minerals and a reduction in nitrogen fixation. These changes will ultimately be expressed as a reduction in the growth of the whole plant (45).

Stems and Branches

Increasing the number of sites for leaves and reproductive organs depends on the growth of stems and branches. How these parts respond to ozone has a direct effect on leaf production and yield. Stems are the most tolerant organs to ozone. While whole plant weight may be reduced when exposed to ozone, the percentage of dry matter in the stems remains unchanged or is increased. In soybean plants, ozone reduced total dry weight, but had no effect on the allocation of biomass (2). Kasana (1991) found that plants of *Vigna mungo*, *Trigonella foenumgraecum*, and *Cicer arietinum* had lower stem dry weights when exposed to ozone than control plants. However, the percentage of dry matter in the stems increased. This is in agreement with Cooley (1987) who found that ozone stressed alfalfa plants were partitioning an increased proportion of dry matter to the stems. This may occur because stems are the first site encountered by photosynthates exiting the leaves (17). In some cases, stem dry weights are reduced by ozone. Kidney bean plants decreased the amount of c-assimilate to the stems and increased the amount to the younger leaves (45). White clover plants also exhibit reductions in stolon dry weights when exposed to ozone. White clover stolons are the primary storage organs (19). Assimilates from these reserves make up for reduced production of photosynthate in the leaves (25).

Stem height can also be affected by ozone. Ozone exposure reduced stem height in soybean (58) and field bean (54). However, height of *Trigonella foenumgraecum*, *Cicer arietinum*, and *Vigna mungo* were not affected by ozone (39).

Ozone can reduce, increase, or have no effect on branching. Schenone (1992) found that field beans had fewer branches when exposed to ozone in nonfiltered chambers, when compared to plants grown in carbon filtered chambers. Chick pea plants, however, showed a slight increase in branching (39). The soybean cultivar 'Corsey' (20) had no change in branching when exposed to ozone. This cultivar is indeterminate and ozone may not have the same effect on it as indeterminate plants (20).

White clover (*Trifolium repens*) is a very important forage crop (60). It is often grown in association with various grass species, such as fescue (30) and ryegrass (22). Competition between the species often results in the decline of the white clover population. It has been suggested that ozone sensitivity of white clover may be an important factor in this phenomenon. Studies have shown that tropospheric ozone does have a negative impact on white clover in mixed field populations (6, 7, 34, 63). While investigating the effect of ozone on white clover, Heagle (30) noted a wide range of sensitivity among the genotypes in the commercial line 'Regal'. Upon screening these plants, Heagle selected two clones, one sensitive to ozone (NCS) and one tolerant to ozone (NCR). These plants were used to develop a plant indicator system for tropospheric ozone (33). This system is based on differences in foliar injury, chlorophyll content, and forage production between the two clones due to ambient ozone. Dose-response relationships could also be made by comparing the biomass of the two clones. The lower the biomass ratio of NCS/NCR, the higher the amount of ambient ozone during that growth period.

This system is based on forage production and does not consider the influence of biomass partitioning. When plants are exposed to ozone, the allocation of biomass is frequently altered in favor of the leaves (7, 45). Thus ozone induced effects in other organs may occur before changes in foliage are observed. This lack of understanding of how plants reallocate resources and alter growth in response to ozone thwarts attempts to precisely quantify and predict yield losses caused by ozone stress (17). The objectives of this thesis research were:

1.) To determine the effects of long-term exposure to ozone on biomass production of two clones of white clover, one sensitive to ozone (NCS) and one tolerant to ozone (NCR).

2.) To attempt to explain biomass response to ozone exposure by investigating changes in phenotypic expression of the two clones of white clover.

CHAPTER II

MATERIAL AND METHODS

Plant Origin

NCR and NCS clones of *Trifolium repens* L. ladino were selected in a field experiment investigating the effects of ozone on different genotypes of white clover. The NCS clone is sensitive to ozone and the NCR clone is tolerant to ozone. These clones were used in a biomonitoring system measuring levels of ambient ozone.

Plants of NCR and NCS were obtained for Dr. A. S. Heagle (USDA / ARS). These plants were grown in a carbon filtered air greenhouse at the University of Massachusetts (Amherst) and served as a source of plants used in experiments.

Plant Preparation

Plants for experiments were obtained from explants via stolon tip culture. The propagation of the plants involved the following steps:

1) Stolons are cut off at the third node from the apical meristem and planted in cell packs containing Metro mix 200 (W. R. Grace and Co. Cambridge Ma.).
2) Cuttings are misted daily and shaded from the sun to promote rooting.
3) At the end of two weeks, plants are removed from the cell packs and the roots washed clean.
4) All, but the three youngest leaves are removed and all material below the third node is cut off.
5) Plants are repotted in 4 x 4 square pots filled with Metro mix 200.
6) After 72 hours, leaf number is reduced to the two youngest, fully developed

leaves and the apical meristem. Lateral meristems of the discarded leaves were excised from the plants.

7) Plants are allowed to acclimate for two days before each experiment.

Experimental Design

All experiments were done in a randomized block design involving two air types (carbon filtered air and carbon filtered air plus ozone) and two clones (NCR and NCS). The experiments consisted of eight chambers. Four chambers received carbon filtered air. The other four chambers received carbon filtered air plus ozone. Ozone was generated using a model 03V1-0 ozone generator (Ozone Research and Equipment Corporation, Phoenix, Arizona). Ozone concentrations inside the chambers were maintained at 75 - 85 ppb. Fumigations were carried out seven hours a day for 28 days.

Plants of each cultivar were placed in a random pattern in each chamber. Plants were fertilized with 100 milliliters of Peter's Pete Lite special (15-16-17) at a concentration of one tablespoon per gallon of water at the start of the experiment and weekly thereafter.

Experiments differed in the number of plants used and the number of harvests. Below are descriptions of each experiment.

Experiment One

This experiment used 40 plants of each clone. Five plants of each clone were put in each chamber. At the end of 28 days, plants were removed from all chambers. The soilless media was washed from the roots. The plants were divided into petioles, leaves, stolons, and roots. Tissue was then dried at 110 F for 48 hours. Dry weight values of the organs were then obtained.

Experiment Two

This experiment used 40 plants per clone. Five plants per clone were placed in each chamber. At the end of 28 days, plants were removed from the chambers. Growth media was washed off the roots. Plants were divided into shoot and roots. Main leaf number, secondary leaf number, and secondary stolon number were counted. The area of the mature leaves was measured using a LI - 3000 Li - Cor portable leaf area meter (Li - Cor Ltd., Lincoln, Ne.). Lengths of the main leaf petioles and the main stolon internodes were measured. Shoots were divided into individual petioles, leaves, main stolon internodes, secondary stolons and flowers. Organs were dried at 110 F for 48 hours. Dry weight values for each organ were then obtained.

Experiment Three

This experiment used 96 plants per clone. Twelve plants per clone were placed in each chamber. At weekly harvests, three plants of each clone per chamber were selected at random. Main leaf number, secondary leaf number, and secondary stolon number were obtained. Roots were washed free of soilless media and separated from shoots. The area of the mature leaves was obtained using a LI - 3000 Li - Cor portable leaf area meter (Li - Cor Ltd., Lincoln, Ne.). Lengths of the main leaf petioles and main stolon internodes were obtained. Shoots were divided into individual petioles, leaves, main stolon internodes, secondary stolons, and flowers. Organs were dried at 110 F for 48 hours. Dry weight values of each organ were then obtained.

CHAPTER III

RESULTS

Experiment One

Difference between air treatments within clone

Air treatment has an effect on growth of both NCS and NCR (Table 1) . In NCS, ozone significantly lowered the dry weights of root, shoot, and total plant by 44, 51, and 50 percent, respectively. NCR exhibited a 27 percent reduction in total plant dry weight when compared to ozone. This was a result of decreased in the shoot and root dry weights. Ozone decreased the root and shoot dry weights of NCR by 24 and 28 percent, respectively. However, none of these differences were significant.

Ozone had a negative impact on the dry weights of the stolons, petioles, and leaves in both clones (Table 2). NCS showed a significant decrease in the dry weights of the stolons, petioles, and leaves of 59, 45, and 50 percent, respectively, when exposed to ozone. Ozone induced decreases of 34, 25, and 24 percent in stolons, petioles, and leaves of NCR occurred, but were not significant.

Biomass partitioning was also affected by ozone in both clones. NCS and NCR, both displayed higher root to shoot ratios in the ozone treatment, but neither was significant (Table 3). Ratios of the dry weights of the stolons, petioles, leaves, and roots to the total plant dry weight were also affected by ozone (Table 4). In NCS and NCR, ozone reduced stolon dry weight / total plant dry weight and leaf dry weight / total plant dry weight. The root dry weight / total plant dry weight of NCS was reduced by ozone, but ozone had no effect on the root dry weight / total plant dry weight of NCR. Petiole dry weight / total plant dry weight of NCS increased when exposed to ozone.

In NCR, petiole dry weight / total plant dry weight was not affected by ozone. The root dry weight / total plant dry weight of NCS was reduced by ozone, but ozone had no effect on the root dry weight / total plant dry weight of NCR. Only differences between treatments for the stolon dry weight / total plant dry weight and petiole dry weight / total plant dry weight were significant.

Difference between clones within air treatment

NCS and NCR showed differences in growth, regardless of air treatment (Table 5). In the carbon filtered air treatment, NCS had a larger total plant dry weight and shoot dry weight and a significantly larger root dry weight than NCR. When the clones were exposed to ozone, the total plant dry weight and shoot dry weight were larger for NCR. Root dry weight was highest for NCS. However, none of these differences were significant. Stolon and leaf dry weights of NCS were larger than NCR in the carbon filtered air treatment. This was reversed in the ozone treatment, where NCR had the largest stolon and leaf dry weights. Petiole dry weight of NCS was higher than NCR in both air treatments (Table 6).

The partitioning of biomass within the clones was not the same in either air treatment. The root to shoot ratios of NCS were higher than NCR for both air treatments (Table 7). NCS had a higher percentage of biomass from the roots, stolons, and petioles in the carbon filtered air treatment (Table 8). The percentage of biomass from the leaves was equal between clones in the carbon filtered air treatment. However, none of the differences were significant. In the ozone treatment, stolon dry weight / total plant dry weight and leaf dry weight / total plant dry weight were highest for NCR (Table 8).

The difference for stolon dry weight / total plant dry weight was significant.

NCS had the highest root dry weight / total plant dry weight and petiole dry weight / total plant dry weight. The difference for petiole dry weight / total plant dry weight was significant.

Experiment Two

Difference between air treatments within clone

By the end of the experiment, plants had reached the main leaf 9 stage. Main leaves 1 and 2 had senesced in the majority of plants, making analysis of them impossible.

Ozone had a significant effect on a number of variables. Plants of both clones exhibited significant declines in total plant dry weight when exposed to ozone (Figures 1 and 2). Ozone significantly reduced shoot and root dry weights of NCS and root dry weight of NCR. Shoot dry weight of NCR was also reduced by ozone, but not at a significant level. Shoot were then divided in leaves, petioles, stolons, secondary stolons, ands flowers.

Leaves

Ozone caused reductions in all leaf categories in both NCS and NCR (Table 9). Mature main leaves, immature main leaves, mature secondary leaves, and immature secondary leaves were reduced by ozone in NCS by 3, 29, 40, and 53 percent, respectively and were reduced in NCR by 11, 11, 24, and 20 percent. respectively. Only mature main leaf number was not significantly affected by ozone in NCS. The opposite was true for NCR. Ozone significantly reduced only the number of mature main leaves. These decreases led to lower total leaf numbers in the ozone treatment. Total leaf number was reduced by ozone in NCS and NCR by 31 and 15 percent, respectively. Only the reduction in NCS was significant.

Total leaf area in both clones was affected by ozone (Figures 3 and 4). Ozone reduced total leaf area in NCS and NCR by 45 and 5 percent, respectively. Only NCS was significantly affected by ozone. The main leaf total area of NCS and the secondary leaf total area of NCS and NCR were decreased by ozone (Figures 3 and 4). The impact of ozone of both the main leaf total area and secondary leaf total area of NCS were significant. Ozone significantly decreased the surface area of all main leaves of NCS, but slightly stimulated the area of all the main leaves of NCR, except main leaves 7 and 8 (Figures 5 and 6). Dry weight of individual main leaves was also affected by ozone. All main leaves, except main leaf 4, of NCS had lower dry weights in the ozone treatment. Main leaves 5, 6, 7, and 8 were significantly affected by ozone (Figure 7). In NCR, main leaves 3, 4, and 6 were heavier in the ozone treatment and main leaves 4, 7, and 8 were heavier in the carbon filtered air treatment (Figure 8). The impact of ozone on the main leaves of NCR was not significant. The total main leaf dry weight was depressed by ozone in both clones. Ozone reduced main leaf total dry weight of NCS and NCR by 27 and 8 percent, respectively (Table 10).

Both immature and mature leaf dry weights were negatively affected by ozone (Figures 9 and 10). Only reductions in both for NCS were at a significant level. The changes in immature and mature leaf dry weights led to reductions in total leaf dry weight for both clones. However, the difference was only significant for NCS.

Both clones exhibited greater values for leaf area ratio (LAR) in the carbon filtered air treatment. Values for specific leaf area ratio (SLA) were also greatest in the carbon filtered air treatment for both clones. However, the differences in the values between treatments for LAR and SLA were not significant (Table 11).

Petioles

Total petiole dry weight was heavier in the carbon filtered air treatment compared to the ozone treatment for both clones (Table 12). Differences between air treatments for NCS and NCR were 48 and 13 percent, respectively. Individual petiole dry weights of both clones were reduced in all petioles, except petioles 3 and 4 of NCR (Figures 8 and 9). Petioles 3 and 4 of NCR were slightly stimulated by ozone. Petioles 5, 6, 7, and 8 of NCS and petiole 7 of NCR were significantly heavier in the carbon filtered air treatment.

Length of all NCS petioles were significantly lowered by ozone (Figure 13). NCR petiole lengths of 3, 4, and 5 were stimulated by ozone, while length of petioles of 6, 7, and 8 were depressed by ozone.

Stolons

Total stolon dry weight was reduced by ozone in NCS and NCR clones by 55 and 12 percent, respectively (Table 13). The effect of ozone on NCS was significant.

Internode dry weights of NCS were significantly higher in the carbon filtered air treatment (Figure 15). In general, differences in internode dry weight between air treatments increased acropetally. In NCR, dry weights of internodes 1, 2, 6, 7, and 8 were reduced by ozone (Figure 16). Only internode 8 was affected by ozone at a significant level. Internodes 3, 4, and 5 were stimulated by ozone, but the difference was not significant.

Ozone had a negative impact of total stolon length (Table 14). Ozone reduced the total stolon length of NCS and NCR by 45 and 9 percent, respectively. In NCS, all internodes, except internode 5, were reduced in length by ozone (Figure 17). The loss of length in internodes 6, 7, 8, and 9 was significant.

Ozone stimulated length in internodes 2, 3, 4, 5, and 6 of NCR (Figure 18). Lengths of internodes 1, 7, 8, and 9 were reduced by ozone. Only internode 7 was affected at a significant level.

Flowers

Total flower dry weight increased for NCR and decreased for NCS in response to ozone (Table 15). NCR had a 36 percent increase in total flower dry weight in response to ozone, while NCS reduced total flower dry weight by 14 percent when exposed to ozone. However, none of these differences were at a significant level.

Secondary Stolons

Ozone had a negative impact on total secondary stolon dry weight (Table 16). The total secondary stolon dry weights of NCS and NCR were reduced by 74 and 26 percent, respectively by ozone. The reduction in NCS was significant.

Branching was affected by ozone (Table 17). Both clones had fewer branches when exposed to ozone. The difference in branching between air treatments in NCS was significant. The branch # / node # ratio (BNR) was also reduced by ozone in NCS and NCR. NCR experienced a significant reduction in BNR in response to ozone (Table 18).

Biomass Partitioning

Biomass partitioning was affected by ozone treatment in both clones. Ozone induced decreases in the root to shoot ratio in NCS and NCR by 23 and 8 percent, respectively (Table 19). The difference in NCS was significant.

Ozone affected the weights of the organs in relationship to the total plant dry weight (Table 20). In NCS, the dry weight ratio of the stolons, roots, and secondary stolons to whole plant were significantly reduced by ozone. The other organs, leaves, petioles, and flowers, each provided a bigger percentage to the total plant dry weight when exposed to ozone. However, in the leaves, the ratio of the immature leaves to total plant dry weight was reduced and the mature leaves to total plant dry weight was increased in response to ozone. The difference in mature leaves to total plant dry weight was significant. In NCR, the percentage of total plant dry weight contributed by the stolons, petioles, and flowers was greater in the ozone treatment. Roots, leaves, and secondary stolons contributed less dry weight to the whole plant dry weight, when exposed to ozone. However, in the leaves, the percentage dry weight contributed by the immature leaves was reduced by ozone, while the percentage dry weight contributed by the mature leaves increased when the clone was exposed to ozone.

Difference between clones within air treatment

Differences in growth between NCS and NCR occurred in both air treatments (Figures 19 and 20). In the carbon filtered air treatment, NCS had a significantly larger total plant, root, and shoot dry weight compared to NCR. This was reversed in the ozone treatment.

NCS had a lower root, shoot, and total plant dry weight than NCR. However, the differences between the clones was not significant.

Leaves

Total leaf dry number, mature main leaf number, mature secondary leaf number, and immature secondary leaf number were higher in NCS than NCR, regardless of air treatment (Table 21).

All the differences were significant, except mature secondary leaf number in the ozone treatment. Immature main leaf number in the carbon filtered air treatment was highest, but not significantly, in NCS, but equal to NCR in the ozone treatment (Table 21).

In the carbon filtered air treatment, individual main leaves of NCS had greater surface areas and were heavier than NCR main leaves (Figures 21 and 22). The differences in dry weight and leaf area were significant for all main leaves, except main leaf 8. In the ozone treatment, NCR main leaves 6, 7, and 8 were significantly heavier and had greater surface areas than corresponding NCR main leaves, but only main leaves 4 and 5 were significantly heavier and only main leaf 4 had a significantly greater surface area (Figures 23 and 24).

NCS, in the carbon filtered air treatment, produced a significantly greater total main leaf area, total secondary leaf area, and consequently, a greater total leaf area than NCR (Figure 25). In the ozone treatment, NCS had a lower total main leaf area, total secondary leaf area, and total leaf area than NCR. However, none of the differences were significant (Figure 26).

The total main leaf dry weight of NCS was 27 and 8 percent greater than NCR in the carbon filtered air treatment and ozone treatment, respectively (Table 22). NCS had significantly higher mature, immature, and total leaf dry weights than NCR in the carbon filtered air treatment (Figure 27). In the ozone treatment, mature, immature, and total leaf dry weight was greatest in NCR. However, the differences were not significant (Figure 28).

Leaf area ratio (LAR) of NCS was larger than NCR in the carbon filtered air treatment and ozone treatment (Table 23).

The specific leaf area ratio (SLA) was also highest for NCS in the carbon filtered air treatment, but in the ozone treatment, NCR had the highest value for SLA. None of the differences in LAR and SLA were significant (Table 23).

Petioles

Total petiole dry weight was significantly greater for NCS in the carbon filtered air treatment and greater, but not significantly, for NCR in the ozone treatment (Table 24).

In the carbon filtered air treatment, all NCS petioles were heavier than the petioles of NCR. However, only differences between NCR and NCS petioles 3, 4, and 5 were significant (Figure 29). In the ozone treatment, NCR had significantly greater dry weights for petioles 5, 6, 7, and 8. There was no difference in dry weight for petioles 3 and 4 between clones (Figure 30).

Differences in petiole lengths between NCS and NCR in the carbon filtered air treatment were not significant (Figure 31). NCR had longer lengths for petioles 3, 4, 6, and 7, while petioles 5 and 8 were longer in NCS. All NCR petioles were longer than the

NCS petioles in the ozone treatment (Figure 32). The differences in length of all petioles between the clones were significant, except in petiole 8.

Stolons

Total NCS stolon dry weight was significantly greater than total stolon dry weight of NCR in the carbon filtered air treatment. This was reversed in the ozone treatment, with NCR total stolon dry weight being greater than NCS. However, this was not significant (Table 25).

Differences in internode dry weights between clones occurred in both air treatments. NCS had the greatest dry weights for all internodes in the carbon filtered air treatment. The differences in dry weight were significant for all internodes, except internodes 1 and 7 (Figure 33). NCR produced the heaviest internodes in the ozone treatment, except internodes 2 and 3, which were heaviest in NCS. Only internodes 7 and 9 showed a significant difference in dry weight between clones (Figure 34).

Both air treatments had significant differences between clones in total internode length (Table 26). The total length of NCS stolon was 22 percent longer than NCR in the carbon filtered air treatment. In the ozone treatment, NCR had the greatest length, 22 percent longer than NCS.

All individual internode lengths were greatest in NCS compared to NCR in the carbon filtered air treatment except for internode 9 (Figure 35). Only internode 6 showed a significant between clones. In the ozone treatment, NCR had the greatest lengths for all internodes, except internodes 3 and 5 (Figure 36). Significant differences between clones occurred for internodes 6, 7, and 9. While NCR internode 8 was 33 percent longer than NCS internode 8, the difference was not significant.

Secondary Stolons

There was a significant difference in secondary stolon number in the carbon filtered air treatment between NCR and NCS (Table 27). Secondary stolon number was 21 percent higher in NCS compared to NCR. However, in the ozone treatment, NCS secondary stolon number was lower (3 percent) than NCR (Table 27). This difference was not significant.

The Branch # / node # was also greatest for NCS in the carbon filtered air treatment (Table 28). 63 percent of the NCS nodes had branches, compared to just 52 percent for NCR.

Ozone treatment reduced the number of branched nodes to 40 percent in NCS and 42 percent in NCR (Table 28). None of these values were significantly different between clones.

Total secondary stolon dry weight in NCS was 40 percent greater than the total secondary stolon dry weight of NCR in the carbon filtered air treatment (Table 29). In the ozone treatment, total secondary stolon dry weight of NCS was 59 percent lower than NCR (Table 29). Only the difference between clones in the carbon filtered air treatment was significant.

Flowers

The difference in total flower dry weight between NCS and NCR was not significant for both treatments (Table 30). The flower dry weight of NCS was 15 percent greater than NCR in the carbon filtered air treatment. In the ozone treatment, NCS flower dry weight was 35 percent lower than NCR.

Biomass Partitioning

Biomass partitioning differed between clones in both air treatments. The root to shoot ratio was significantly higher for NCS compared to NCR in the carbon filtered air treatment. NCS and NCR had almost equal root to shoot ratios in the ozone treatment (Table 31).

Ratios of the dry weights of organs to the whole plant in NCS showed that in carbon filtered air treatment, immature leaves, secondary stolons, and roots provided a bigger percentage to the total plant dry weight than NCR (Table 32).

However, mature leaves, petioles, and flowers provided a bigger percentage to total plant dry weight in NCR. The ratio of the stolon dry weight to total plant dry weight was equal between clones in the carbon filtered air treatment. Only the difference between clones in root dry weight / total plant dry weight was significant. In the ozone treatment, mature leaves and flowers provided a bigger percentage of dry weight to the total plant dry weight in NCS compared to NCR (Table 32). Only the difference in mature leaves was significant. Stolon, petiole, immature leaves, roots, and secondary stolons provided a larger percentage to the total dry weight in NCR compared to NCS. Only the difference in the stolon was significant.

Experiment Three

Difference between air treatments within clone

Ozone had an effect on the growth of both NCS and NCR. Both clones exhibited an increase in root, shoot, and total plant dry weights in response to ozone during the first harvest (Tables 33, 34, 35). The differences were only significant for NCR. By harvest two and until the end of the experiment, the stimulatory effect of ozone ceased and ozone depressed root, shoot, and total plant dry weights of both clones. Except the shoot weight of NCR, which was higher in the ozone treatment of harvest 2. At harvest four, ozone significantly reduced the root, shoot and total plant dry weight of NCS.

Shoots were divided into leaves, petioles, stolons, and secondary stolons. Unlike experiment 2, flower production occurred in too few plants to be analyzed.

Leaves

Total leaf number (TLN) was affected by ozone for both clones at every harvest (Table 36). TLN was increased by ozone in NCS and NCR in harvest one. NCS and NCR had an increase in TLN by 10 and 11 percent, respectively in the ozone treatment. At harvest two, TLN was depressed by ozone in NCS. NCR showed no response to ozone in TLN at harvest two. Ozone decreased TLN in NCS and NCR by 12 and 9 percent, respectively in harvest three. At harvest four, ozone continued to depress TLN of NCS, but TLN of NCR increased. Only the difference in TLN between air treatments was significant for NCR in harvest one.

Ozone increased the total main leaf number (TMLN) of NCR in harvest one and four (Table 37). There was no effect on the TMLN for NCR in harvests two and three. NCS showed an increase in TMLN in response to ozone for harvests one and three. Ozone reduced NCS TLMN in harvests two and four (Table 37). Differences in TMLN for either clone was significantly only for NCR at harvest one.

Ozone influenced the number of mature and immature main leaves in both clones (Tables 38 and 39). NCR had a higher number of mature and immature main leaves, while NCS had a greater number of immature leaves in the ozone treatment of the first harvest. Over time NCR had a fewer mature main leaves and more immature main leaves in the ozone treatment, except at harvest four, when NCR had the same number of MML and IMML in both treatments. NCS had the reverse situation, plants progressively had more mature main leaves and fewer immature main leaves in the ozone treatment. Except at harvest four, where ozone reduced NCS MMLN by three percent. None of these differences were significant.

Secondary leaves were apparent by harvest two. There were no significant differences between air treatments in the number of mature and immature secondary leaves in both NCS and NCR in all harvests (Tables 40 and 41). In NCS, mature and secondary leaf numbers were equal between treatments in harvest two. In harvests three and four, NCS in the carbon filtered air treatment had more mature secondary leaves than in the ozone treatment. The greatest number of immature secondary leaves occurred in the carbon filtered air treatment for NCS in all harvests. In NCR, both mature and immature secondary leaf numbers were highest in the ozone treatment of harvests two and four. At harvest three, NCR had the highest numbers of mature and immature secondary leaves in the carbon filtered air treatment.

Total leaf dry weight was highest for both clones in the ozone treatment for harvest one and in the carbon filtered air treatment for the rest of the harvests (Table 42). Differences between air treatments were significant in harvest one for NCR and harvest four for NCS. Mature and immature leaf dry weights of NCS plants were highest in the carbon filtered air treatment for all harvests, except harvest one, where the immature leaf dry weight was greatest in the ozone treatment (Tables 43 and 44). Significant differences occurred in harvest one for the immature leaf dry weight and harvest four for the mature leaf dry weight. NCR had a significantly greater total mature leaf dry weight in the ozone treatment for harvest one. Thereafter, total mature leaf dry weight was greatest in the carbon filtered air treatment (Table 43). However, the differences between air treatments were not significant. Ozone had no effect on the total immature leaf dry weight of NCR at the first harvest. NCR showed an increase in total immature leaf dry weight in the ozone treatment for harvest two and three, but ozone reduced total immature leaf dry weight for harvest four (Table 44). There was no significant effect of ozone for NCR in any harvest.

Ozone increased total main leaf dry weight for both clones in the first harvest. NCR was affected at a significant level. In the rest of the harvests, ozone decreased total main leaf dry weights for both clones (Table 45). Significant differences occurred in harvest two for both clones and in harvest four for NCS.

Ozone increased the dry weight of all main leaves for both clones in harvest one (Table 46a). However, the increase did not occur at a significant level. At harvest two, ozone had a negative impact on all main leaf dry weights of NCS, but continued to increase the dry weights of all the main leaves of NCR, except main leaf 4. Main leaf 4 showed a decrease in dry weight when exposed to ozone (Table 46b). The effect of ozone was not significant for either clone in harvest two. The impact of ozone on main leaf dry weight was not as clear in harvest three (Table 46c). In NCS, ozone decreased the dry weights of main leaves 1,2, and 4, while main leaves 3, 5, and 6 showed an increase in dry weights when exposed to ozone. In NCR, ozone decreased the dry weights of the oldest and youngest main leaves, but increased the dry weights of the rest, except main leaf 4, which showed no effect of ozone. There were no significant differences between air treatment for harvest three. At harvest four, all the main leaves of NCS showed decreased dry weights when exposed to ozone (Table 46d). Ozone had a significant effect on main leaves 4, 5, 6, and 7. Main leaves 2, 3, 5, and 6 of NCR were also negatively affected by ozone. Main leaves 4 and 7 showed an increase in dry weight in the ozone treatment. None of the differences in NCR were significant.

Both clones experienced an increase in the area of all main leaves due to ozone in harvest one (Table 47a). None of these increases were at a significant level. Ozone continued to increase individual main leaf areas of NCR in harvest two. However, NCS exhibited decreases in area for all main leaves when exposed to ozone (Table 47b). The differences in NCS were significant for main leaf 1 and 3. At harvest three, all main leaves of NCS were largest in the carbon filtered air treatment (Table 47c). All the differences were significant except in main leaf 4. In NCR, main leaves 1, 2, and 4 were largest in the carbon filtered air treatment, while main leaves 3 and 5 were largest in the ozone treatment (Table 47c). Main leaf 5 of NCR showed a significant difference between air treatments. All main leaves of NCS and NCR were largest in the carbon filtered air treatment at harvest four (Table 47d). Significant differences in area occurred in all main leaves of NCS except 2 and 7. In NCR, only main leaf 3 showed a significant difference between air treatments.

Total main leaf area of both clones was greatest in the carbon filtered air treatment, except at harvest four for NCR (Table 48). Ozone significantly affected the total main leaf area of NCS at harvest four.

Total secondary leaf area could not be calculated until harvest three (Table 49). NCS showed the greatest total secondary leaf area in the carbon filtered air treatment for harvests three and four. Total secondary leaf area of NCR could only be analyzed in harvest four. Total secondary leaf area of NCR was stimulated by ozone. None of the differences in total secondary leaf area were significant.

Ozone depressed the total leaf area of both clones in all harvests except for NCR at harvest one (Table 50). The total leaf area of NCR was 30 percent greater in the ozone treatment at harvest one. The differences between air treatments for NCR at harvest one and NCS at harvest four were significant.

Ozone decreased the leaf area ratio (LAR) of NCS in harvests one, three, and four. NCS experienced an increase in LAR due to ozone in harvest two (Table 51). NCR had larger LAR values in the ozone treatment for harvests one and four and in the carbon filtered air treatment for harvests two and three (Table 51). None of the differences were significant.

The specific leaf area (SLA) of NCS was greatest in the carbon filtered air treatment for harvests one, three, and four and greatest in the ozone treatment for harvest two

(Table 52). Ozone increased the SLA of NCR in harvest one and four and decreased the SLA in harvest two and three (Table 52). Only the differences between air treatments for NCS at harvest three were significant.

Petioles

Only petiole three was measured in harvest one (Table 53a). The dry weight of petiole 3 was heaviest in the ozone treatment for both clones. However, the differences were not significant. At harvest two, the dry weight of all petioles of both clones was depressed by ozone, except petiole 5 of NCR (Table 53b). This petiole showed an increase in dry weight when exposed to ozone. The decrease in dry weight was only significant for petiole 3 of NCS. The negative impact of ozone on petiole dry weight continued for harvest three (Table 53c). All petioles of NCS, except petiole 6, had a reduced dry weight in the ozone treatment. Petiole 4 was significantly affected by ozone. The influence of ozone on the petiole dry weights of NCR was less clear. Petiole 1 and 3 exhibited declines in dry weight when exposed to ozone and petiole 5 showed a greater dry weight in the ozone treatment. Ozone had a significant effect on the dry weight of petiole 4. None of the differences were significant.

All the petioles of both clones showed decreases in dry weight when exposed to ozone at harvest four (Table 53d). NCS petioles were significantly affected by ozone except petiole 8. Only petiole 1 of NCR showed a significant difference between air treatments.

Total petiole dry weight of NCS and NCR was greatest in the ozone treatment for harvest one (Table 54). The increase in dry weight for NCR was significant. At harvest two, ozone decreased total petiole dry weight in NCS, but increased total petiole dry weight in NCR (Table 54). However, none of the differences were significant. Both clones exhibited ozone induced reductions in total petiole dry weight in harvests three and four (Table 54). Only the decreases in NCS were significant.

Petiole length was stimulated by ozone in both clones at harvest one (Table 55a). However, none of the differences occurred at a significant level. At harvest two, petioles of both clones displayed shorter lengths when exposed to ozone (Table 55b). The difference in length for petiole 3 was significant. NCS continued to have decreases in petiole length for all petioles except petiole 6 in harvest three (Table 55c). The length of petiole 6 was longest in the ozone treatment. The difference between the air treatments for petiole 4 was significant. The longest petiole lengths of NCR were found in the carbon filtered air treatment for petioles 3 and 6 and in the ozone treatment for petioles 4 and 5 at harvest three (Table 55c). Petioles of NCS showed a negative effect of ozone in terms of length, except petiole 6. Petiole 6 was stimulated by ozone in harvest four. NCR petioles three and six showed reduced lengths when exposed to ozone, but petioles 4, 5, 7 and 8 exhibited greater lengths in the ozone treatment (Table 55d). Differences in length between air treatments for petioles 3 and 4 of NCS were significant.

Stolons

Individual internode dry weights were not measured in harvest one. Data for internode 1 is not available for harvest two. All internodes were heaviest in the carbon filtered air treatment for both clones, except internode 4 in NCR at harvest two (Table 56a). None of the differences were significant. In harvest three, NCS internodes continued to be heaviest in the carbon filtered air treatment (Table 56b). Ozone had a significant effect on internode two. However, in NCR, all internodes, except internode 1, were heaviest in the ozone treatment (Table 56). The differences in dry weights between air treatments were not significant for NCR. Ozone reduced the dry weights of all the internodes of NCS and NCR at harvest four (Table 56c). Significant differences between air treatments occurred for NCS in internodes 4 ,5, 6, 7, and 8.

The total stolon dry weight of both clones increased when exposed to ozone in harvest one (Table 57). The difference in total stolon dry weight was at a significant level for NCR. At harvest two and for the rest of the experiment, ozone reduced total stolon dry weight in NCS, but increased total stolon dry weight in NCR, except at harvest four, when the total stolon dry weight of NCR was greatest in the carbon filtered air treatment (Table 57). Ozone had a significant effect on the total stolon dry weight of NCS in harvest four.

Internode lengths were not measured at harvest one. Internode 1 length is unavailable for harvest two.

Ozone stimulated the length of internode 2 in NCS and all internodes in NCR at harvest two (Table 58a). Internodes 3 and 4 of NCS were longer in the carbon filtered air treatment. The effect of ozone did not result in any significant difference.

All internodes of NCS, except internode 1, had greater length in the carbon filtered air treatment for harvest three (Table 58b). Internode 2 showed a significant difference between air treatments. There was no clear indication of influence of air treatment on the NCR internode lengths (Table 58b). Internodes 1, 2, 5 and 6 were longest in the carbon filtered air treatment, but internodes 3 and 4 were longest in the ozone treatment.

In harvest four, internode lengths of NCS continued to be depressed by ozone (Table 58c). One exception was internode 2, which had an increase in length in the ozone treatment. Significant differences in length occurred for internodes 5, 6, 7 and 8. NCR also exhibited reduced internode length in the ozone treatment at harvest four (Table 58c). All internodes, except internode 5, were longer in the carbon filtered air treatment. The length of internode 5 was greatest in the ozone treatment.

Total stolon length was not available for harvest one. Ozone depressed the total stolon length of both clones in all harvests (Table 59). The differences in lengths for NCS at harvest four were significant.

<u>Secondary Stolons</u>

Secondary stolons could not be analyzed until harvest three. NCS had significantly higher total secondary stolon dry weights in the carbon filtered air treatment at harvests three and four (Table 60). NCR had a higher total secondary stolon dry weight in the ozone treatment at harvest four, but it was not significant (Table 60). Total secondary stolon dry weight of NCR could not be analyzed in harvest three.

The number of branches and the BNR were also adversely affected by ozone exposure in both clones except at harvest four (Tables 61 and 70). NCR had more branches and a higher BNR in the ozone treatment. However, none of the differences in branch number or BNR was significant in either clone.

<u>Biomass Partitioning</u>

The root to shoot ratio (RSR) was highest in the ozone treatment for both clones at harvest one (Table 63). The ozone treatment continued to have the highest value for NCR at harvest two, but RSR for NCS was highest in the carbon filtered air treatment (Table 63). In harvests three and four, ozone depressed RSR in both clones. Only the difference in NCS at harvest four was significant.

Total stolon dry weight / total plant dry weight of NCS was reduced by ozone for all harvests (Table 64). In NCR, total stolon dry weight / total plant dry weight was greatest in the ozone treatment for harvest one, three, and four. The total stolon dry weight / total plant dry weight of NCR at harvest two was highest in the carbon filtered air treatment. None of these differences were significant.

Petiole dry weight / total plant dry weight in NCS was highest in the carbon filtered air treatment at harvest one and three and in the ozone treatment for harvests two and four (Table 65). Ozone increased petiole dry weight / total plant dry weight of NCR for harvests one and two, but decreased it for harvests three and four (Table 65). None of the differences were significant.

Total root dry weight / total plant dry weight for NCS was highest in the ozone treatment at the first harvest. Thereafter, it was highest in the carbon filtered air treatment (Table 66). The ozone treatment had the highest total root dry weight / total plant dry weight for NCR at harvest one and two. At harvest three and four, total root dry weight / total plant dry weight of NCR was highest in the carbon filtered air treatment (Table 66). None of these differences were significant.

The mature leaf dry weight / total plant dry weight of NCS was depressed by ozone in harvests 1 and 4. Ozone increased the mature leaf dry weight / total plant dry weight of NCS in harvests two and three (Table 67). In harvest three, there was a significant difference between air treatments. Ozone increased the mature leaf dry weight / total plant dry weight of NCR in harvests one, three, and four and decreased the mature leaf dry weight / total plant dry weight in harvest two (Table 67). There were no significant differences between air treatments.

In harvests one and four, ozone decreased the immature leaf dry weight / total plant dry weight of NCS and increased it in NCR. In harvests two and three, ozone increased the immature leaf dry weight / total plant dry weight of NCS and decreased it in NCR (Table 68). There were no significant differences between air treatments.

Ozone had a negative impact on total leaf dry weight / total plant dry weight on NCS at harvests one and three and on NCR at harvests two and three. Ozone increased total leaf dry weight / total plant dry weight of NCS at harvest two and four and for NCR at harvests 1 and 4. None of the differences between air treatments was significant for either clone (Table 69).

Difference between clones within air treatment

Growth differences occurred between clones in both air treatments. NCS had a greater total plant dry weight than NCR in both air treatments at all harvests (Table 70). Significant differences in total plant dry weight between NCS and NCR in the carbon filtered air treatment occurred at harvests one, three, and four. Total root dry weight was greatest in NCS in both treatments for all harvests except harvest one. NCR had a greater root dry weight in the ozone treatment at harvest one (Table 71). Significant differences between the clones occurred in the carbon filtered air treatment for harvests two, three, and four. NCS also had the greatest shoot dry weight in both air treatments at all harvests, except at harvest two, where NCR had the greatest shoot dry weight in the ozone treatment (Table 72). Differences in total shoot dry weight between the clones in the carbon filtered air treatment at harvests one, three, and four were significant.

Leaves

NCS had more leaves than NCR in the carbon filtered air treatment for all harvests, except harvest one (Table 73). There was no difference in the total leaf number (TLN) between clones in the carbon filtered air treatment for harvest one. In the ozone treatment, the highest TLN in harvests one and four was for NCR and for NCS in harvests two and three. Significant differences in harvest three occurred between clones in both air treatments and in the carbon filtered air treatment of harvest two.

Total main leaf number was greatest for NCS in the carbon filtered air treatment in harvests one, two, and four. In harvest three, NCR had a higher number of main leaves (Table 74). NCR had the greatest total main leaf numbers in the ozone treatment for all harvests (Table 74). Differences between clones were significant in the ozone treatment of harvest four.

The total number of mature main leaves in the carbon filtered air treatment was greatest for NCS in harvests one and four and for NCR in harvests two and three (Table 75). The reverse occurred in the ozone treatment. NCS had the greatest total number of mature main leaves in harvests two and three and NCR had the greatest total number of mature main leaves in harvests one and four (Table 75). Significant differences between clones occurred in the carbon filtered air treatment of harvest two and in the ozone treatment for harvests one and four. NCS had the greatest number of immature main leaves in both air treatments in all harvests, except harvest two. NCR had the greater number of immature main leaves in the ozone treatment of harvest two (Table 76). None of the differences between clones were significant.

Secondary leaves did not appear until harvest two. NCS had the greatest numbers of mature and immature secondary leaves in the carbon filtered air treatment for all harvests (Tables 77 and 78). Significant differences in the number of mature secondary leaves occurred in harvests three and four and in the number of immature secondary leaves for harvests two and three. In the ozone treatment, NCR had more mature secondary leaves, but significantly fewer immature secondary leaves than NCS in harvest two (Tables 77 and 78). At harvest three, NCS had the greatest number of immature and mature secondary leaves in the ozone treatment (Tables 77 and 78). The difference between clones in the number of mature secondary leaves was significant. NCS had more mature secondary and fewer immature secondary leaves than NCR in the ozone treatment of harvest four (Tables 77 and 78).

Total leaf dry weight was greatest for NCS in the carbon filtered air treatment for all harvests (Table 79). Significant differences occurred in harvests three and four. In the ozone treatment, NCR had the greatest total leaf dry weight in the harvests one and two and total leaf dry weight was greatest for NCS in harvests three and four (Table 79). None of the differences were significant.

Total mature leaf dry weights and total immature leaf dry weights were greatest for NCS in the carbon filtered air treatment for all harvests, except harvest one (Tables 80 and 81). The immature leaf dry weight of NCR was heavier than NCS in harvest one. In the ozone treatment, NCR had the greatest total mature leaf dry weight in all harvests, except harvest three (Table 80). NCS had the greatest immature leaf dry weight in all harvests, except harvest two (Table 81). Only the differences between clones in the carbon filtered air treatment for harvests one and four were significant.

NCS had higher total main leaf dry weights than NCR in the carbon filtered air treatments of harvests one, three, and four and in the ozone treatment of harvest three (Table 82). Significant differences between clones occurred in the carbon filtered air treatments of harvests one and two.

Main leaf dry weights differed between clones in both air treatments in all harvests. In harvest one, NCS had heavier main leaves in the carbon filtered air treatment and ozone treatment except main leaf three, which was heavier in NCR in the ozone treatment (Table 83a). The difference in main leaf one in the carbon filtered air treatment was at a significant level.

Main leaves 1, 2, and 3 in the carbon filtered air treatment and main leaves 1 and 2 in the ozone treatment were heaviest in NCS in harvest two. The remaining leaves were heaviest in NCR (Table 83b). There were no significant differences in main leaf dry weights between clones. All main leaves, except main leaf 6, of NCS were heavier than NCR in the carbon filtered air treatment of harvest three (Table 83c). In the ozone treatment , main leaves 1, 2, 3, and 4 were heaviest in NCS. Difference between clones for main leaves 2 and 3 were significant in both air treatments. At harvest four, NCS had the heaviest main leaves in the carbon filtered air treatment and the heaviest main leaves 2, 3, 4, and 5 in the ozone treatment (Table 83d). All main leaves, except main leaf 7, in the carbon filtered air treatment were different at a significant level and main leaves 2 and 3 had a significant difference in the ozone treatment.

Individual main leaves of NCS all had a greater area than NCR in the carbon filtered air treatment for all harvests (Tables 84a, 84b, 84c, 84d). Significant differences occurred in all but the youngest leaves at harvests two, three, and four. In general, NCS continued to have larger leaf areas than NCR in the ozone treatment. Exceptions included main leaves 1 and 4 in harvest two, main leaf 4 in harvest three, and main leaf 7 in harvest four. All of these main leaves were larger for NCR. None of the differences in the ozone treatment were significant.

Total main leaf area of NCS was greatest in the carbon filtered air treatment for all harvests. In the ozone treatment, NCR had the greatest total main leaf areas in harvests one and four and NCS had the greatest total main leaf areas in harvests two and three (Table 85). Only the difference between clones in the carbon filtered air treatment of harvest one was significant.

Total secondary leaf area could only be analyzed in harvest four. NCS had the greatest secondary leaf area in both treatments (Table 86). In the carbon filtered air treatment, the difference between the clones was significant.

NCS had the greatest total leaf area in the carbon filtered air treatment of all harvests (Table 87). Harvest one, two, and four showed significant differences between clones. In the ozone treatment, NCR had the greatest total leaf area in harvests one and four and NCS had the greatest total leaf area in harvests two and three (Table 87). However, none of the differences were significant.

The LAR in the carbon filtered air treatment was highest in NCS for harvests one and three and highest for NCR in harvests two and four (Table 88). Differences between clones in harvest one were significant. NCS had the highest LAR in the ozone treatment at harvest two and three, while the LAR of NCR was highest for harvests one and four (Table 88). None of the differences between clones were significant.

The SLA of NCS was highest in both air treatments for the first three harvests. At harvest four, NCR had the highest SLA in both air treatments (Table 89). Significant differences between clones occurred in the carbon filtered air treatment of harvests one and two.

Petioles

Total petiole dry weight was greatest for NCS in all air treatments for all harvests, except harvest two. NCR had the greatest total petiole dry weight in the ozone treatment of harvest two (Table 90). Significant differences occurred only in the carbon filtered air treatment of harvests one, three, and four.

Individual petiole dry weights in the carbon filtered air treatment were heaviest for NCS in all harvests except in harvest four. Petiole number 8 in harvest four was heavier for NCR. The difference in dry weights between clones for all other petioles in harvest four was significant. In the ozone treatment, NCS had the greatest individual petiole dry weight in harvest one (Table 91a). At harvest two, petioles 3 and 5 were heaviest for NCR and petiole 4 was heaviest for NCS (Table 91b). All petioles, except petiole 4, were heaviest for NCS in harvest three (Table 91c). Individual petiole dry weight was greatest for NCS in all petioles, except petiole 8 in harvest four (Table 91d). Only petiole 3 in harvest four was heavier at a significant level.

Neither clone showed a clear pattern of greater petiole length over the other in either air treatment at any harvest. At harvest one, the length of petiole 3 was greatest for NCR in either air treatment (Table 92a). Petiole 3 was still longer for NCR at harvest two, but petiole 4 was longer for NCS (Table 92b). In the carbon filtered air treatment, the difference between clones for petiole 4 was significant. The length of petioles 3 and 4 was highest for NCR in both air treatments of harvest three (Table 92c). The differences between clones in the ozone treatment were significant. Petiole 5 was longest for NCS in both air treatments Petiole 6 was longest for NCR in the carbon filtered air treatment and for NCS in the ozone treatment. None of these differences was significant. At harvest four, lengths of petioles 3, 4, and 8 were greatest for NCR and petioles 5, 6, and 7 were greatest for NCS in the carbon filtered air treatment. In the ozone treatment, all petioles of NCR, except petiole 6, had longer lengths than NCS (Table 92d). Differences between lengths of petioles 3 and 4 in the ozone treatment were significant.

Stolons

Total stolon dry weight in the carbon filtered air treatment was highest for NCS in all harvests (Table 93). Significant differences occurred for harvests one, three and four. In the ozone treatment, NCR had the heaviest total stolon dry weight in harvests two and four and NCS had the heaviest total stolon dry weight in harvests one and three (Table 93).

Internode dry weights were not measured in harvest one. Internode 1 dry weight was not measured in harvest two. Internodes of NCS were heavier than NCR in the carbon filtered air treatment of all harvests (Table 94a). Significant differences occurred in harvest two for internode 4, in harvest three for internodes 2, 4, 5. and 6 (Table 94b) and in harvest four for internodes 1, 2, 4, 5, 6, and 7 (Table 94c). In general, the level of significance for internode dry weight increased acropetally in harvest four. In the ozone treatment, NCR had the greatest dry weights of internodes 2 and 4 in the ozone treatment of harvest two (Table 94a). There was no difference between clones in the dry weight of internode 3. None of the differences were significant. At harvest three, NCS had the heaviest internodes, except internode 3, in the ozone treatment. Internode 4 of NCS was significantly heavier than NCR at harvest three in the ozone treatment (Table 94b). Internodes 1, 2, 4, 5, and 6 were heaviest for NCS and internodes 3, 7, and 8 were heaviest for NCR at harvest four (Table 94c). However, none of the differences were significant.

Internode lengths were not measured for harvest one. The length of internode 1 was not recorded in harvest two. Internode 2 was largest in NCR for both air treatments. Internodes 3 and 4 were largest in NCS for both air treatments (Table 95a). The difference in internode 4 between clones in the carbon filtered air treatment was significant. At harvest three, NCS had the longest lengths in all internodes in both air treatments, except internode 1 in the carbon filtered air treatment and internode 3 in the ozone treatment (Table 95b). Significant differences between clones occurred in the carbon filtered air treatment for all internodes, except internodes 1 and 3. Differences between clones in the ozone treatment only occurred at a significant level for internode 4. All internodes of NCS were longer than NCR in both air treatments for harvest four, except internode 8 in the ozone treatment (Table 95c). Significant differences between clones occurred in the carbon filtered air treatment for internodes 4, 5, 6, and 7 and in the ozone treatment for internodes 4, 5, and 6.

Total internode length was not measured in harvest one. The total internode length was longest for NCS in both air treatments for all harvests (Table 96). Significant differences occurred in the carbon filtered air treatment of harvests 3 and 4.

Secondary Stolons

The number of secondary stolons per plant was highest for NCS in the carbon filtered air treatment of harvests three and four and in the ozone treatment of harvest three. NCR had the most secondary stolons in the ozone treatment of harvest four (Table 97). None of the differences between clones was significant.

NCS had the greatest branch to node ratio in both air treatments for all harvests (Table 98). Only the difference between clones in the ozone treatment of harvest three was not significant.

Total secondary stolon dry weight was only analyzed in harvest four. NCS had a significantly greater secondary stolon dry weight than NCR in the carbon filtered air treatment. In the ozone treatment, NCR had the greatest secondary stolon dry weight, but not at a significant level (Table 99).

Biomass Partitioning

The root to shoot ratio was highest for NCR in both air treatments of harvest one. In harvests two and three, NCS had the highest values for RSR in both air treatments. NCS continued to have the highest value for RSR in the carbon filtered air treatment of harvest four, but in the ozone treatment NCR had the highest value for RSR (Table 100). None of the differences were significant.

The percentage of biomass represented by the stolon dry weight was highest in both air treatments for NCS in harvest one and three and for NCR for harvests two and four (Table 101). The difference between clones in the ozone treatment of harvest four was significant.

Petiole/total plant dry weight was highest in NCS in both air treatments at harvest one. At harvests two and three, NCR had the highest petiole / total plant dry weight in both air treatments. Petiole / total plant dry weight at harvest four was highest in NCR in the carbon filtered air treatment and in NCS in the ozone treatment (Table 102). None of the differences were significant.

NCR had the highest root / total plant dry weight in both air treatments of harvest one. At harvest two, NCS had the highest root / total plant dry weight in both air treatments. The differences in the carbon filtered air treatment were significant. NCS had the highest root / total plant dry weight in the carbon filtered air treatment of harvest four and NCR had the highest root / total plant dry weight in the ozone treatment (Table 103).

The mature dry leaf weight / total plant dry weight was highest for NCS in the carbon filtered air treatment of harvest one. Thereafter, NCR had the highest mature leaf dry weight / total plant dry weight in the carbon filtered air treatment. The difference between clones in harvest two was significant. In the ozone treatment, NCS had the highest mature leaf dry weight / total plant dry weight in harvest three. The mature leaf dry weight / total plant dry weight of NCR was highest in the rest of the harvests (Table 104). There were no significant differences between clones in any harvest.

Immature leaf dry weight / total plant dry weight in the carbon filtered air treatment was highest for NCS at harvests two and three and for NCR at harvests one and four. The exact opposite occurred in the ozone treatment. NCS had the highest immature leaf dry weight / total plant dry weight at harvests one and four and NCR had the highest immature leaf dry weight / total plant dry weight at harvests two and three (Table 105). There were no significant differences between clones in any harvest.

NCS had the highest total leaf dry weight / total plant dry weight in the carbon filtered air treatment of harvest one. Thereafter, the total leaf dry weight / total plant dry weight was highest for NCR in the rest of the harvests. In the ozone treatment, NCR had the highest total leaf dry weight / total plant dry weight for harvests one, two, and four. NCS was highest for harvest three (Table 106).

Regression Analysis

Regression lines were fitted for the natural logarithms of the total dry weights of the plant (Figure 37), shoot (Figure 38), root (Figure 39), stolon (Figure 40), petioles (Figure 41), and leaves (Figure 42) for both clones in both air treatments. Regression lines were also fitted for the natural logarithms of total dry weights of the main leaves (Figure 43), immature leaves (Figure 44), and the mature leaves (Figure 45).

At the first week, NCS in both air treatments and NCR in the ozone treatment had similar values for all total dry weights. Values for NCR grown in carbon filtered air were consistently lower for all categories.

At the second week and thereafter, NCS grown in carbon filtered air had higher values for all total dry weights. For all total dry weights, the regression line for NCR grown in carbon filtered air was about parallel to NCS grown in carbon filtered air, but values were lower. When exposed to ozone, the regression lines of NCS and NCR had a reduced slope. The outcome at harvest four showed that NCR grown in carbon filtered air and NCS grown in ozone had similar values for all total dry weights, except the stolon and main leaves. NCR grown in ozone had the lowest values for all total dry weights, except for immature leaves, which was similar to NCS grown in ozone and NCR grown in carbon filtered air and for stolon and main leaf total dry weights which were similar to NCS grown in ozone

Table 1: Effect of ozone on root, shoot, and total plant dry weights of NCS and NCR

Clone	Treatment	Dry Weights (grams)		
		total	root	shoot
NCS	CF	2.19**	0.337*	1.85**
NCS	O	1.09	0.189	0.90
NCR	CF	1.65 ns	0.234 ns	1.42 ns
NCR	O	1.21	0.177	1.03

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at $P > .05$
* = significant at $P < .05$
** = significant at $P < .01$

Table 2: Effect of ozone on the stolon, leaf, and petiole weights (grams) of NCS and NCR

Clone	Treatment	Stolon Dry Weight	Leaf Dry Weight	Petiole Dry Weight
NCS	CF	0.492*	0.834**	0.526*
NCS	O	0.200	0.414	0.291
NCR	CF	0.410 ns	0.633 ns	0.374 ns
NCR	O	0.272	0.481	0.281

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at $P > .05$
* = significant at $P < .05$
** = significant at $P < .01$

Table 3: Effect of ozone on the root to shoot ratio of NCS and NCR

Clone	Treatment	RSR
NCS	CF	0.183
NCS	O	0.229 ns
NCR	CF	0.168
NCR	O	0.176 ns

RSR = Root dry weight / Shoot dry weight

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 4: Effect of ozone on biomass partitioning of NCS and NCR

	NCS		NCR	
	CF	O	CF	O
SWR	0.224*	0.179	0.241 ns	0.220
TLWR	0.382 ns	0.370	0.383	0.398 ns
PWR	0.240	0.268**	0.233 ns	0.233
RWR	0.160	0.180 ns	0.150 ns	0.150

SWR = Stolon dry weight / Total plant dry weight
TLWR = Total leaf dry weight / Total plant dry weight
PWR = Petiole dry weight / Total plant dry weight
RWR = Root dry weight / Total plant dry weight

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 5: Differences in root, shoot, and total plant dry weight (grams) between NCS and NCR in two air treatments

Clone	Treatment	Dry Weights (grams)		
		total	root	shoot
NCS	CF	2.19 ns	0.337*	1.85 ns
NCR	CF	1.65	0.234	1.42
NCS	O	1.09	0.90	0.189 ns
NCR	O	1.21 ns	1.03 ns	0.177

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 6: Differences in stolon, leaf, and petiole dry weights (grams) between NCS and NCR in two air treatments

Clone	Treatment	Stolon Dry Weight	Leaf Dry weight	Petiole Dry Weight
NCS	CF	0.492 ns	0.834 ns	0.526 ns
NCR	CF	0.410	0.633	0.374
NCS	O	0.200	0.414	0.291 ns
NCR	O	0.272 ns	0.481 ns	0.281

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 7: Differences in root to shoot ratio between NCS and NCR in two air treatments

Clone	Treatment	RSR
NCS	CF	0.183 ns
NCR	CF	0.168
NCS	O	0.229 ns
NCR	O	0.176

RSR = Root dry weight / Shoot dry weight

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 8: Differences in biomass partitioning between NCS and NCR in two air treatments

	CF		OZONE	
	NCS	NCR	NCS	NCR
SWR	0.224 ns	0.241	0.179	0.220*
TLWR	0.382	0.383 ns	0.370	0.398 ns
PWR	0.240 ns	0.233	0.268**	0.233
RWR	0.160 ns	0.150	0.180	0.150

SWR = Stolon dry weight / Total plant dry weight
TLWR = Total leaf dry weight / Total plant dry weight
PWR = Petiole dry weight / Total plant dry weight
RWR = Root dry weight / Total plant dry weight

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

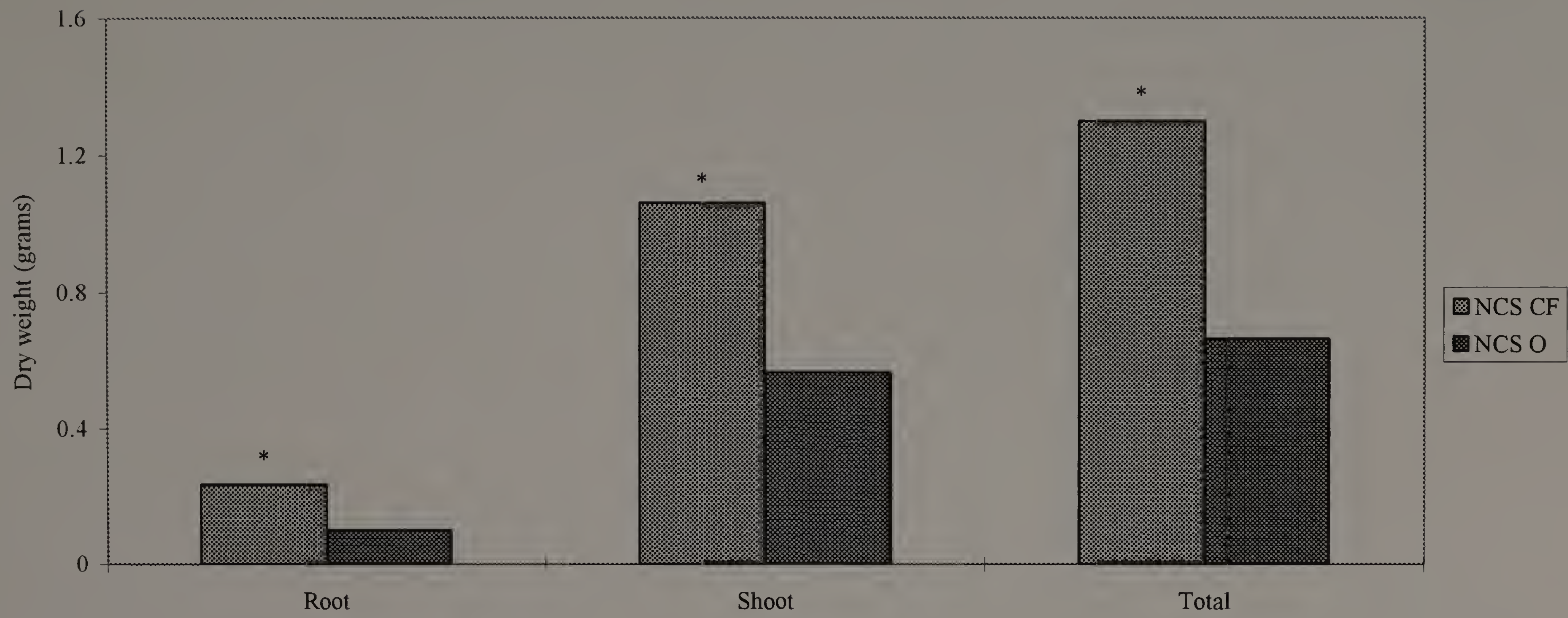

Figure 1: Dry weights (grams) of root, shoot, and total plant of NCS exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days.

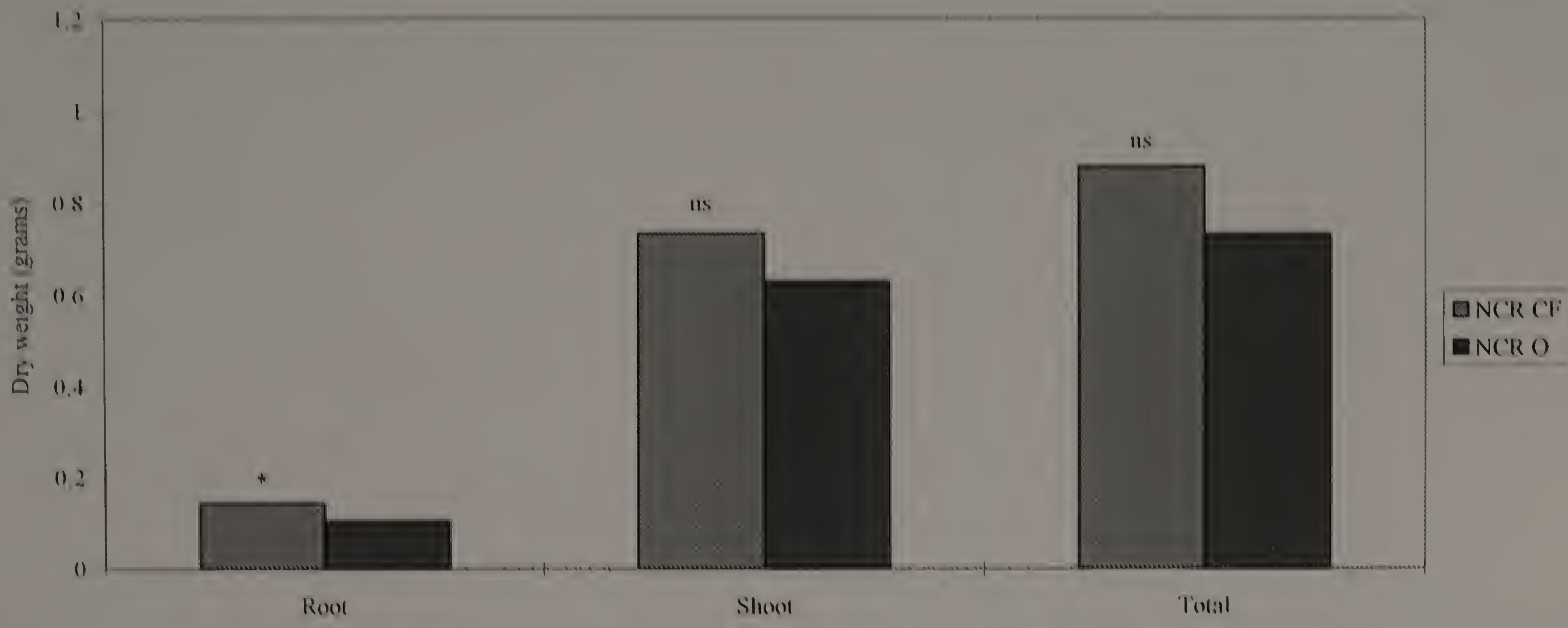

Figure 2: Dry weights (grams) of root, shoot, and total plant of NCR exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days

Table 9: Effect of ozone on leaf numbers of NCS and NCR

Clone	Treatment	MML	IML	MSL	ISL	Total
NCS	CF	7.80 ns	1.75*	10.30*	7.65**	27.50**
NCS	O	7.60	1.25	6.15	4.05	19.05
NCR	CF	7.05**	1.40 ns	5.85 ns	3.65 ns	17.95 ns
NCR	O	6.25	1.25	4.45	2.90	14.85

CF = carbon filtered air   O = carbon filtered air plus ozone

MML = Mature Main Leaf number
IML = Immature Main Leaf number
MSL = Mature Secondary Leaf number
ISL = Immature Secondary Leaf number

ns = not significant at $P > .05$
* = significant at $P < .05$
** = significant at $P < .01$

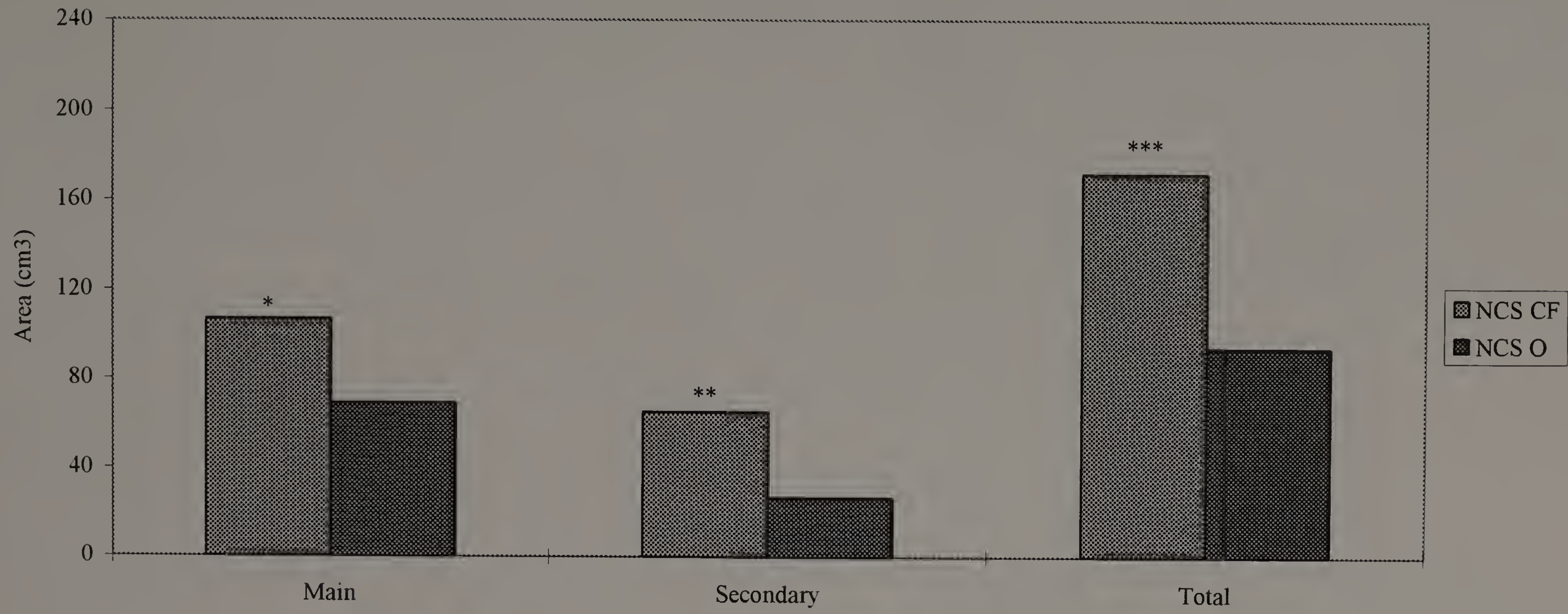

Figure 3: Area (cm3) of main, secondary, and total leaves of NCS exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days.

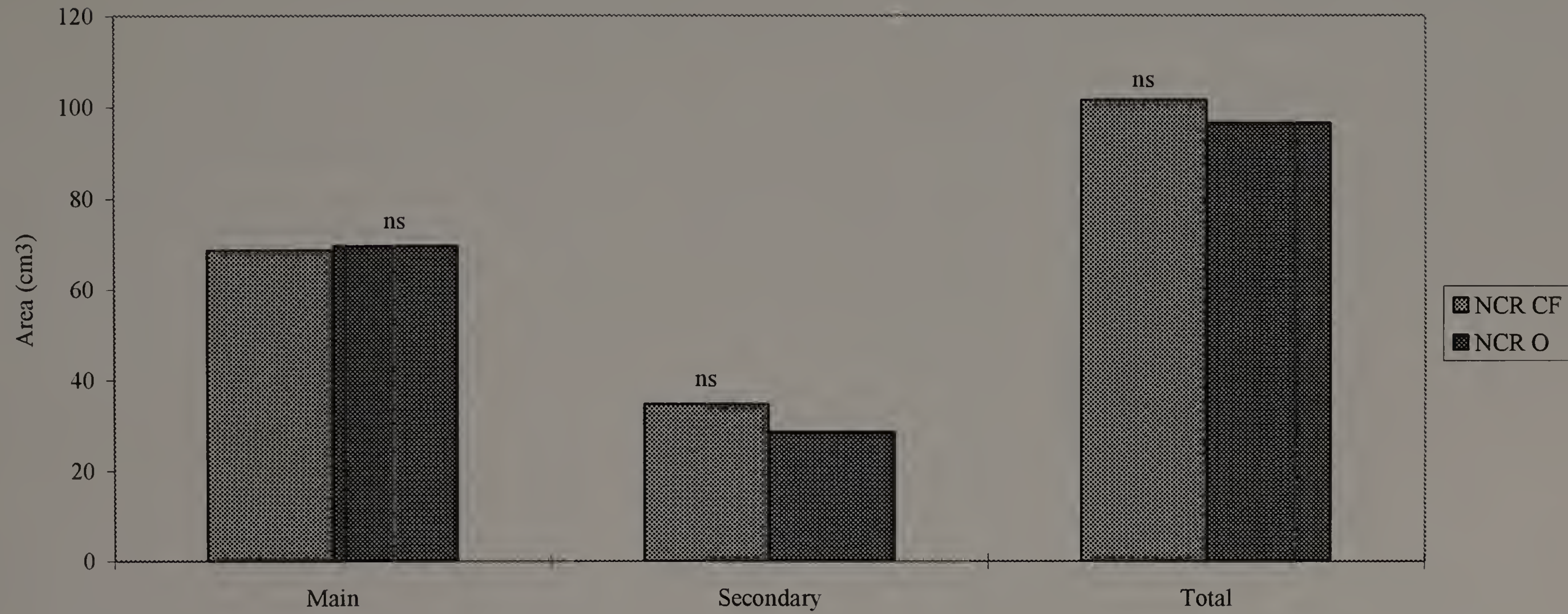

Figure 4: Area (cm3) of main, secondary, and total leaves of NCR exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (ns = not significant)

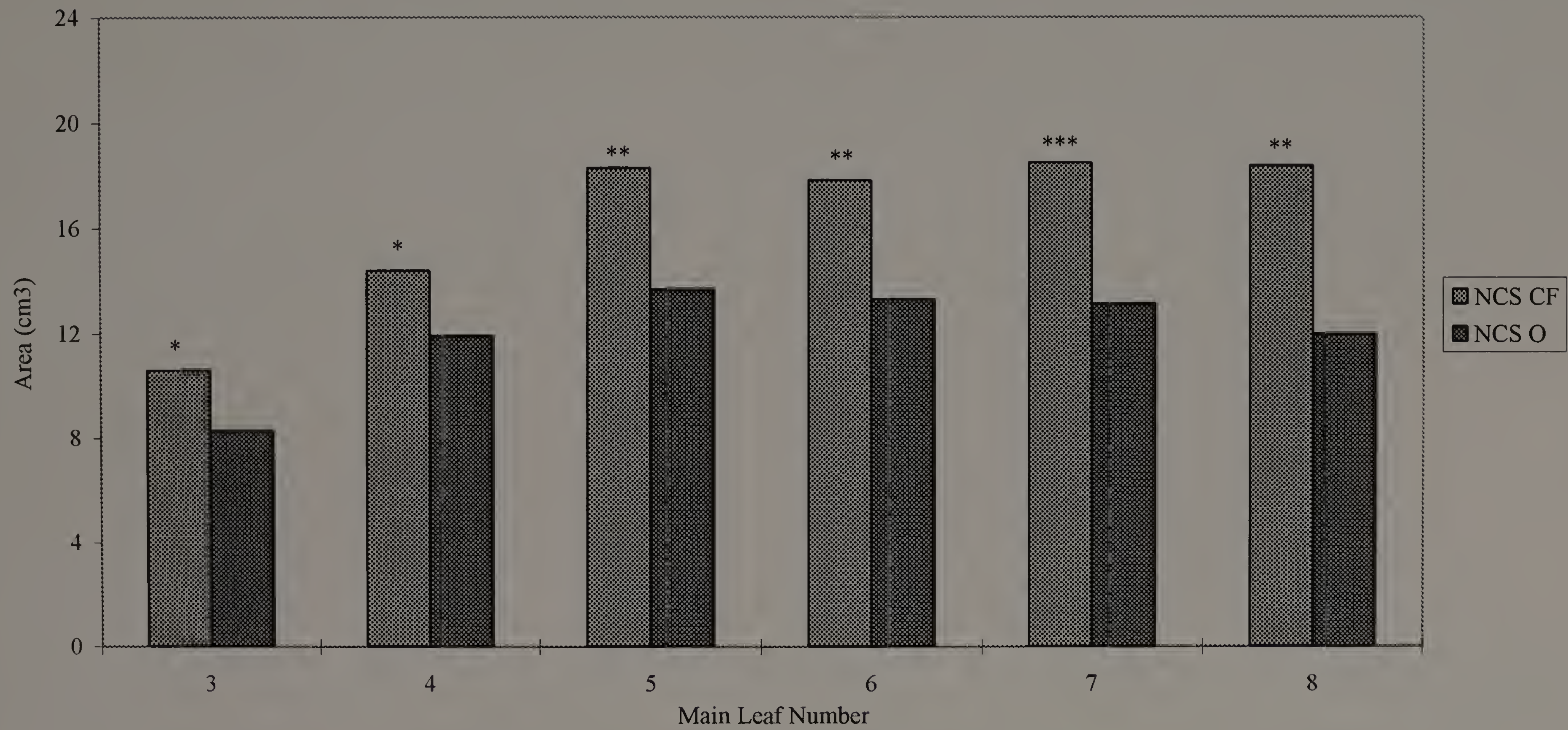

Figure 5: Individual main leaf area (cm3) of NCS exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (* = P < 0.05, ** = P < 0.01, *** = P < 0.001, ns = not significant)

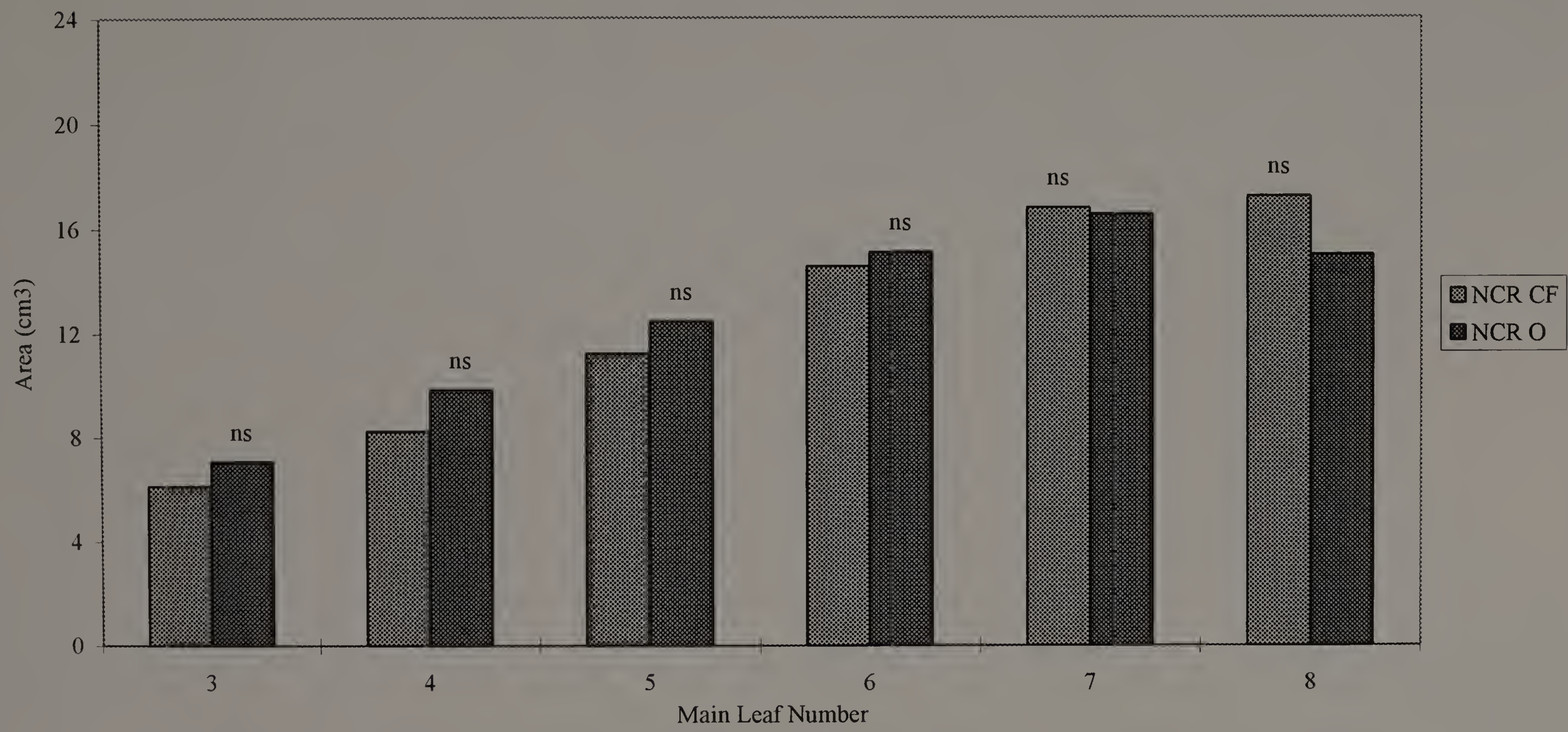

Figure 6: Individual main leaf area (cm3) of NCR exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (* = P < 0.05, ** = P < 0.01, *** = P < 0.001, ns = not significant)

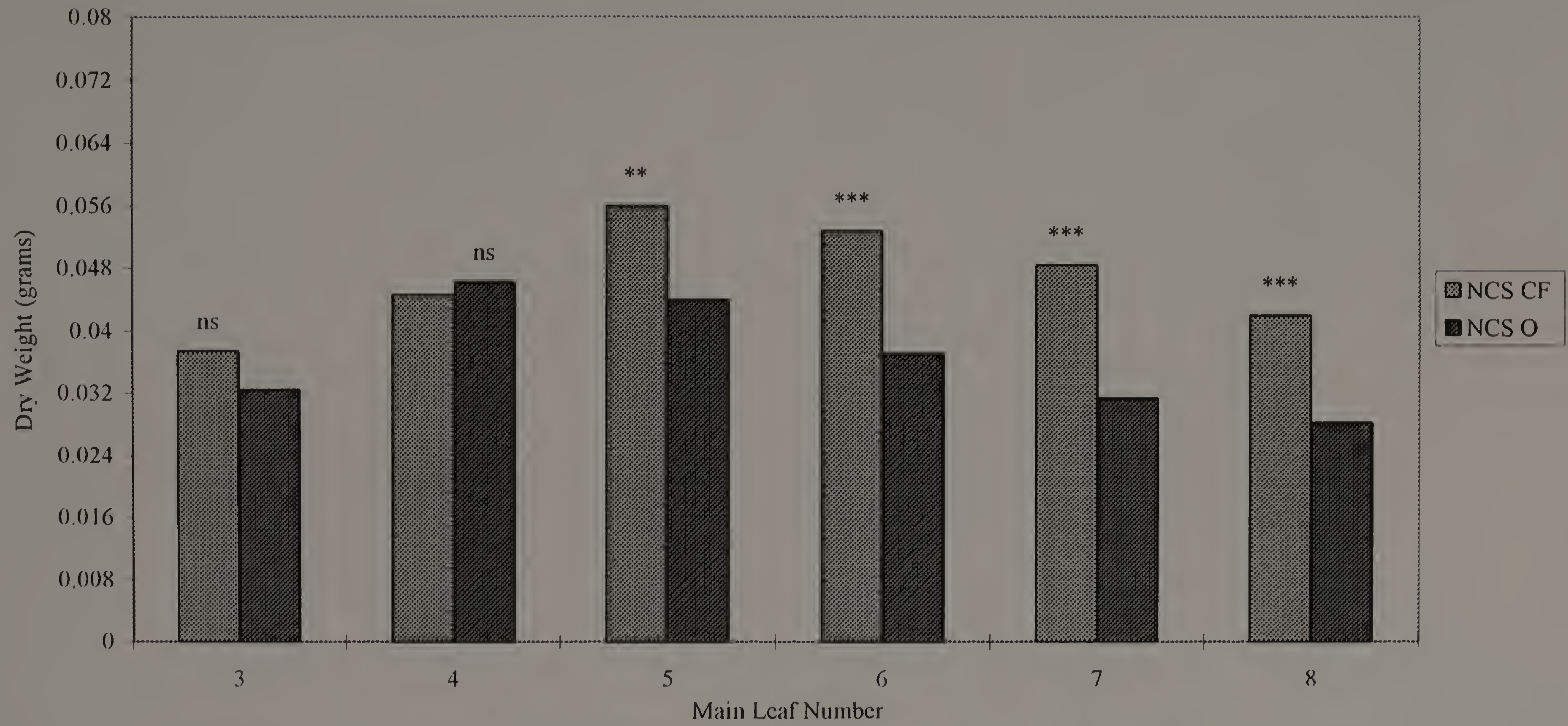

Figure 7: Differences in individual main leaf dry weights (grams) of NCS exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$, ns = not significant)

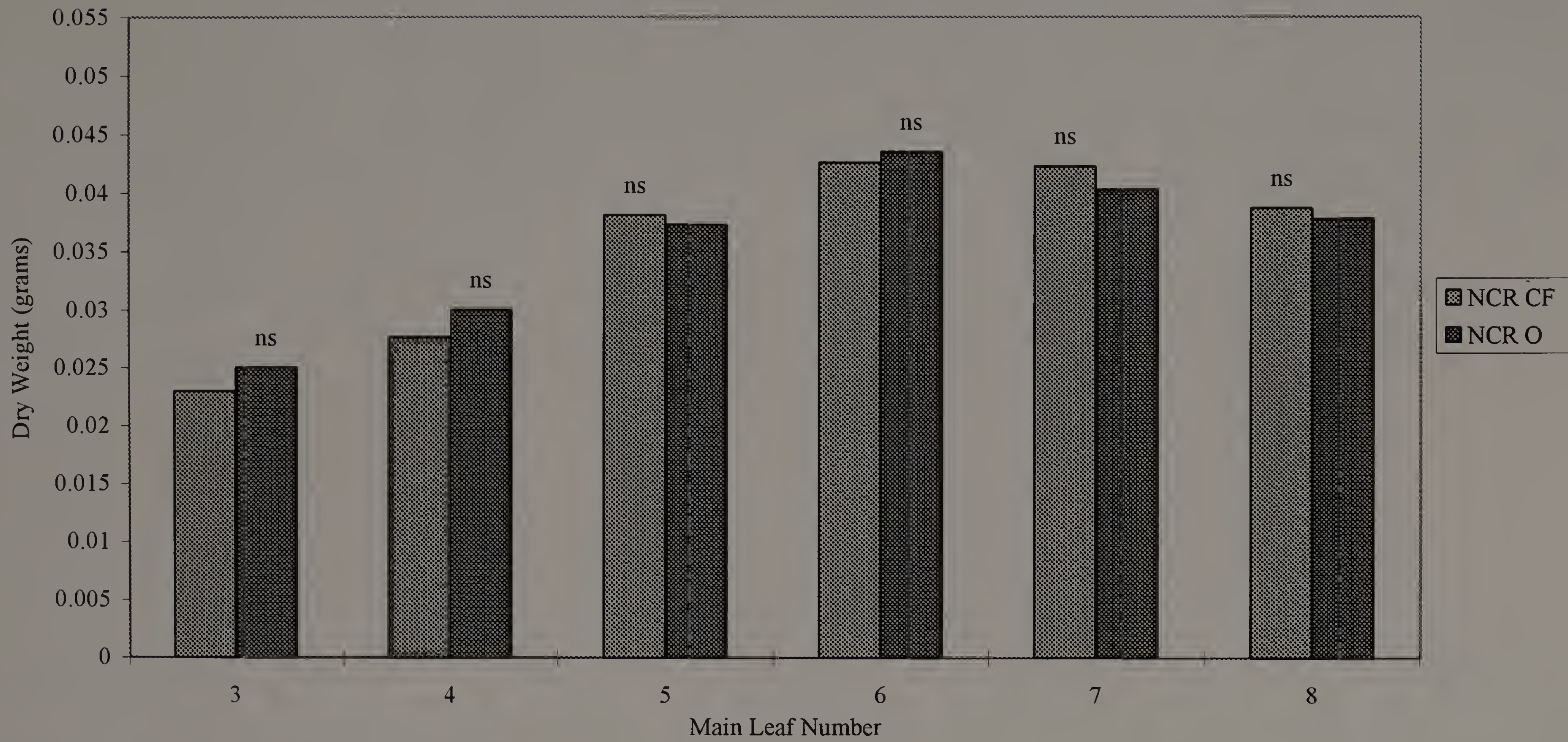

Figure 8: Differences in individual main leaf dry weights (grams) of NCR exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (ns = not significant)

Table 10: Effect of ozone on total main leaf dry weight (grams) of NCS and NCR

Clone	Treatment	Total Main leaf Dry Weight (grams)
NCS	CF	0.307***
NCS	O	0.224
NCR	CF	0.224 ns
NCR	O	0.206

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

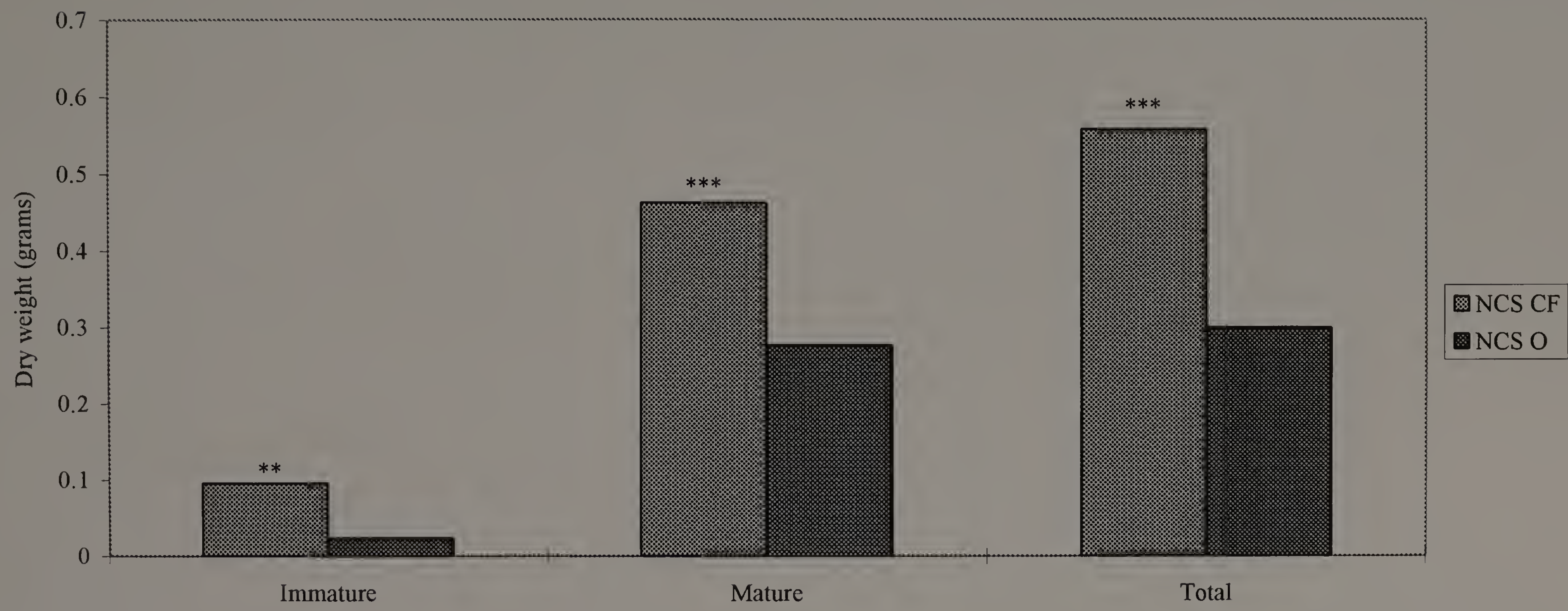

Figure 9: Dry weight of immature, mature, and total leaves of NCS exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days.

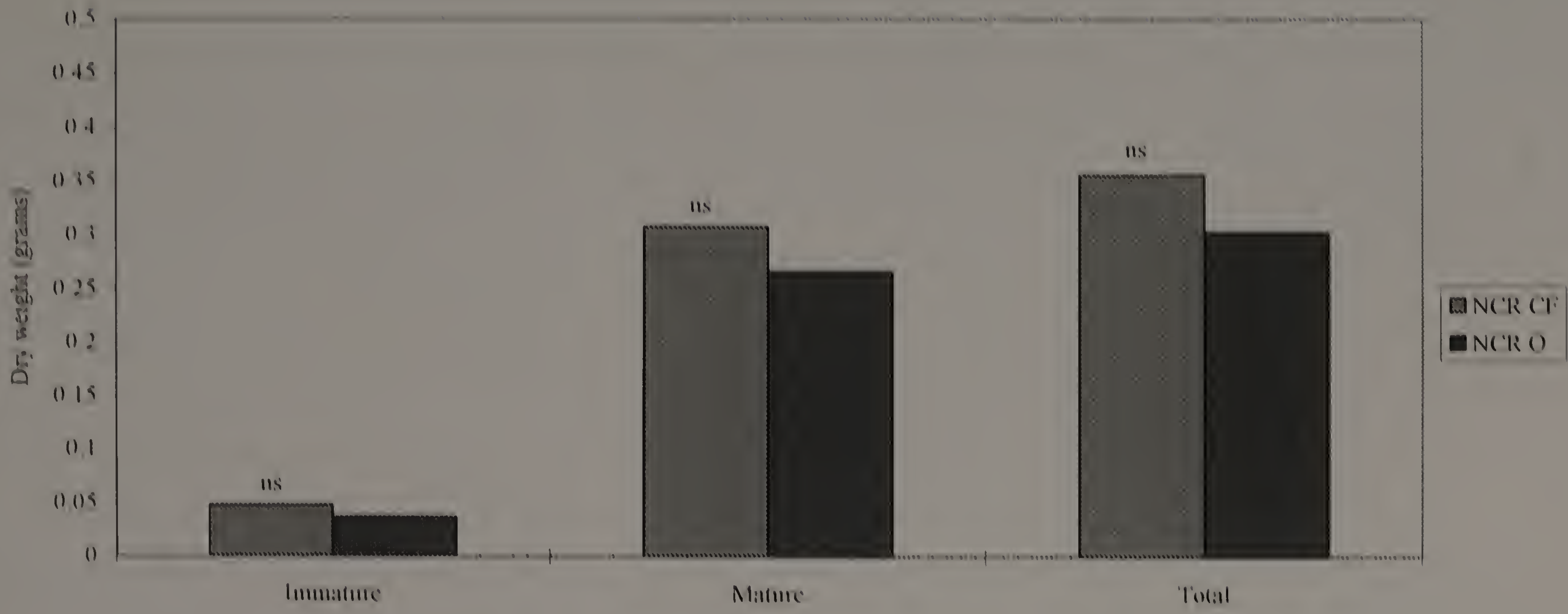

Figure 10. Dry weight of immature, mature, and total leaves of NCR exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (ns = not significant)

Table 11: Effect of ozone on SLA and LAR of NCS and NCR

Clone	Treatment	SLA	LAR
NCS	CF	356.71	131.71
NCS	O	359.72 ns	139.54 ns
NCR	CF	326.34	115.63
NCR	O	371.62 ns	123.37 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 12: Effect of ozone on total petiole dry weight of NCS and NCR

Clone	Treatment	Total Petiole Dry Weight (grams)
NCS	CF	0.321***
NCS	O	0.167
NCR	CF	0.225 ns
NCR	O	0.195

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

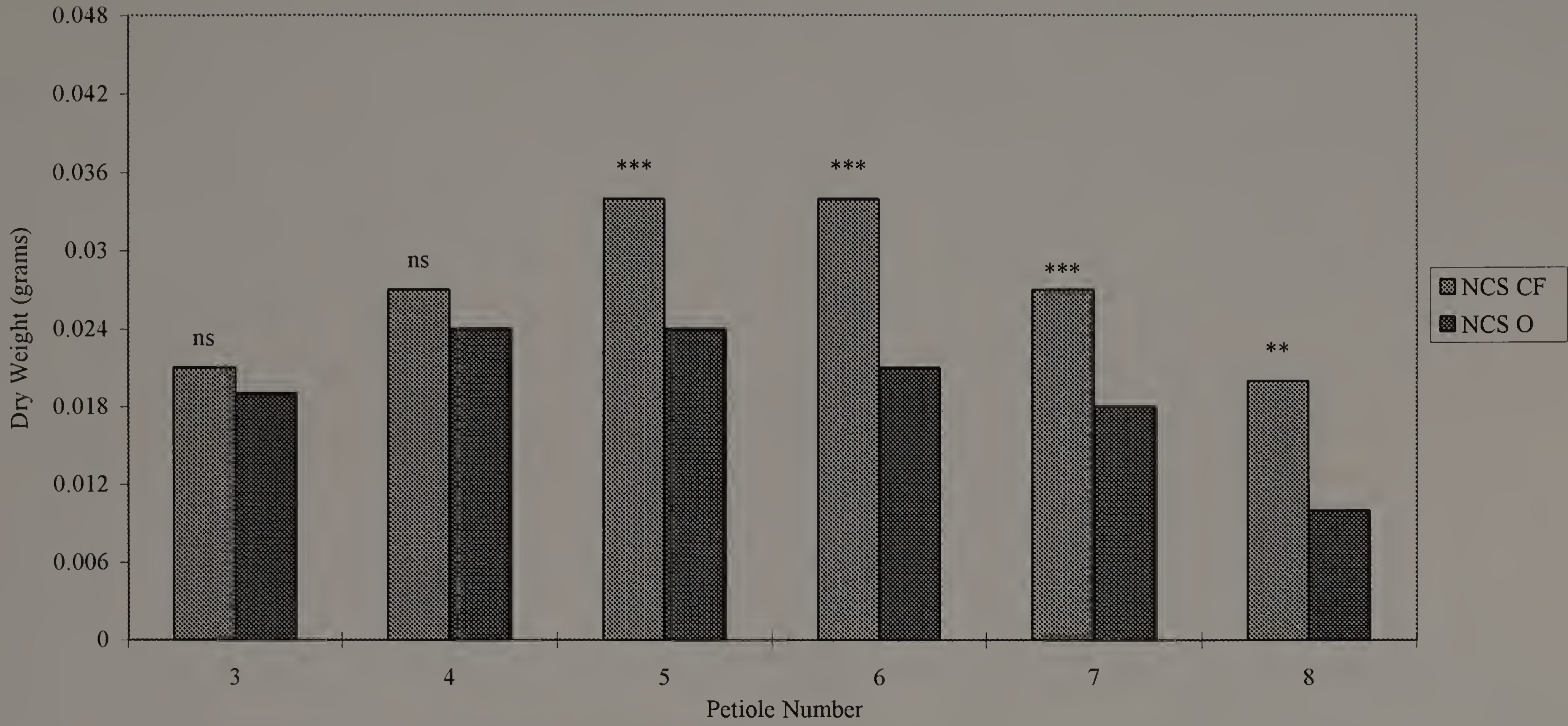

Figure 11: Differences in individual main leaf petiole dry weights (grams) of NCS exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (** = $P < 0.01$, *** = $P < 0.001$, ns = not significant)

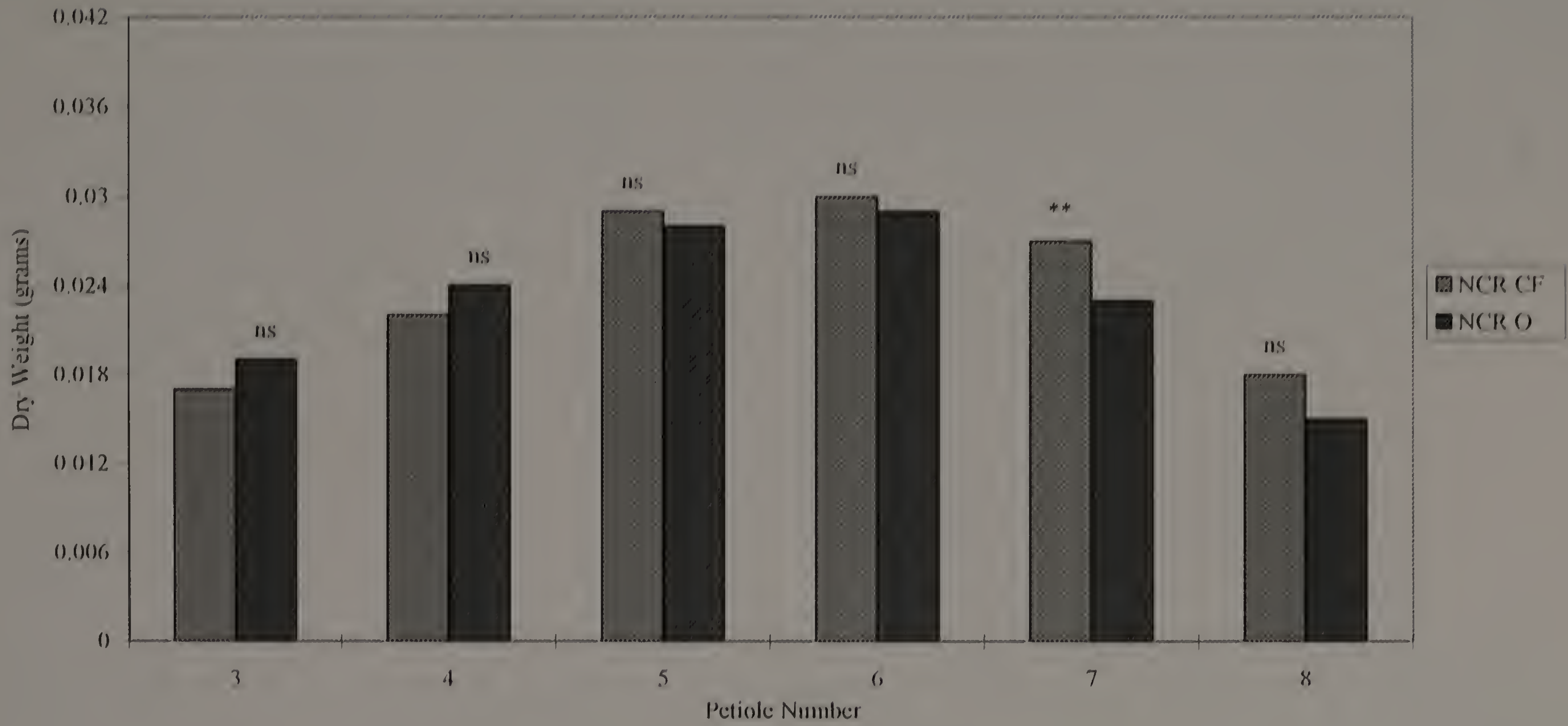

Figure 12: Differences in individual main leaf petiole dry weights (grams) of NCR exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (** = $P < 0.01$, ns = not significant)

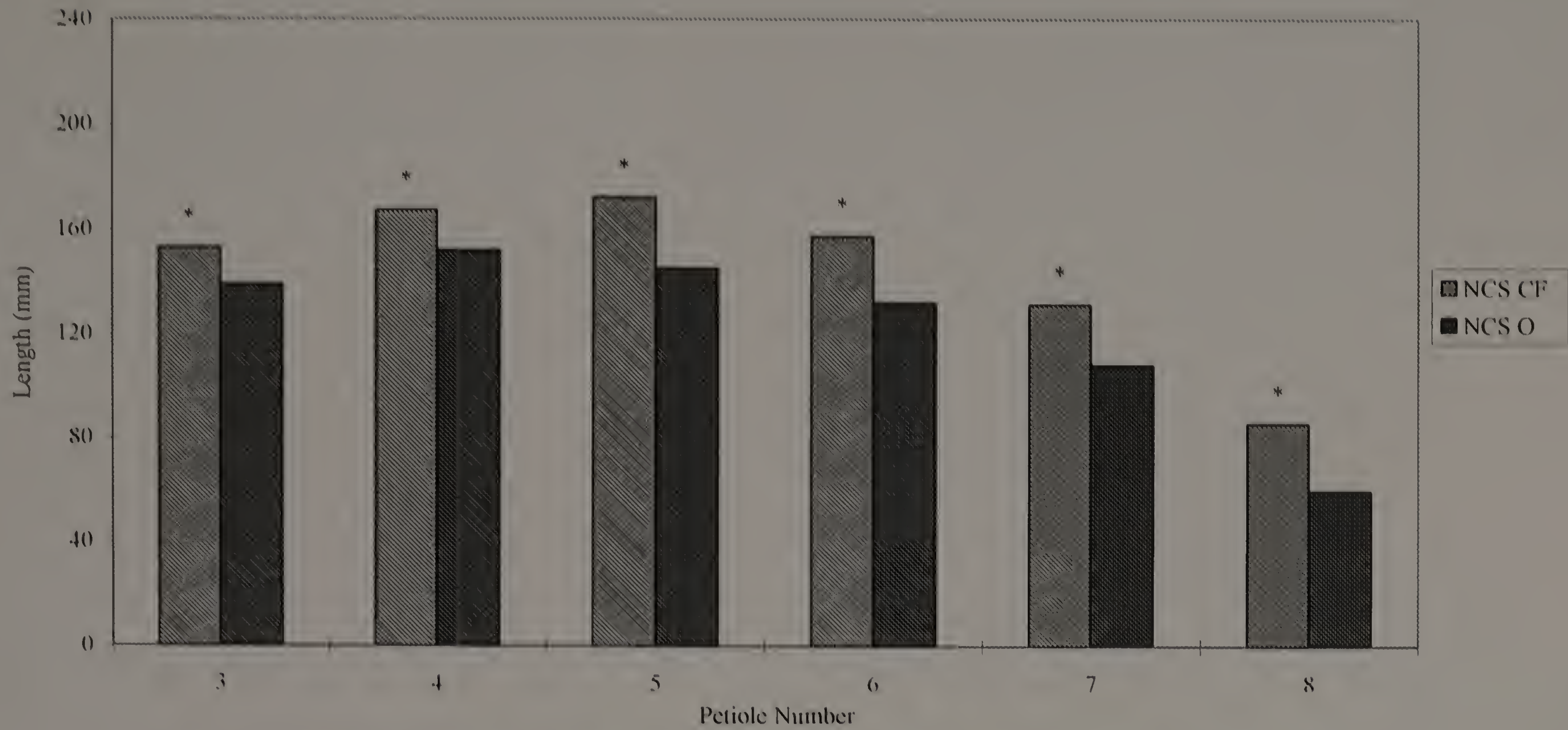

Figure 13: Differences in individual main leaf petiole lengths (mm) of NCS exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (** = $P < 0.01$)

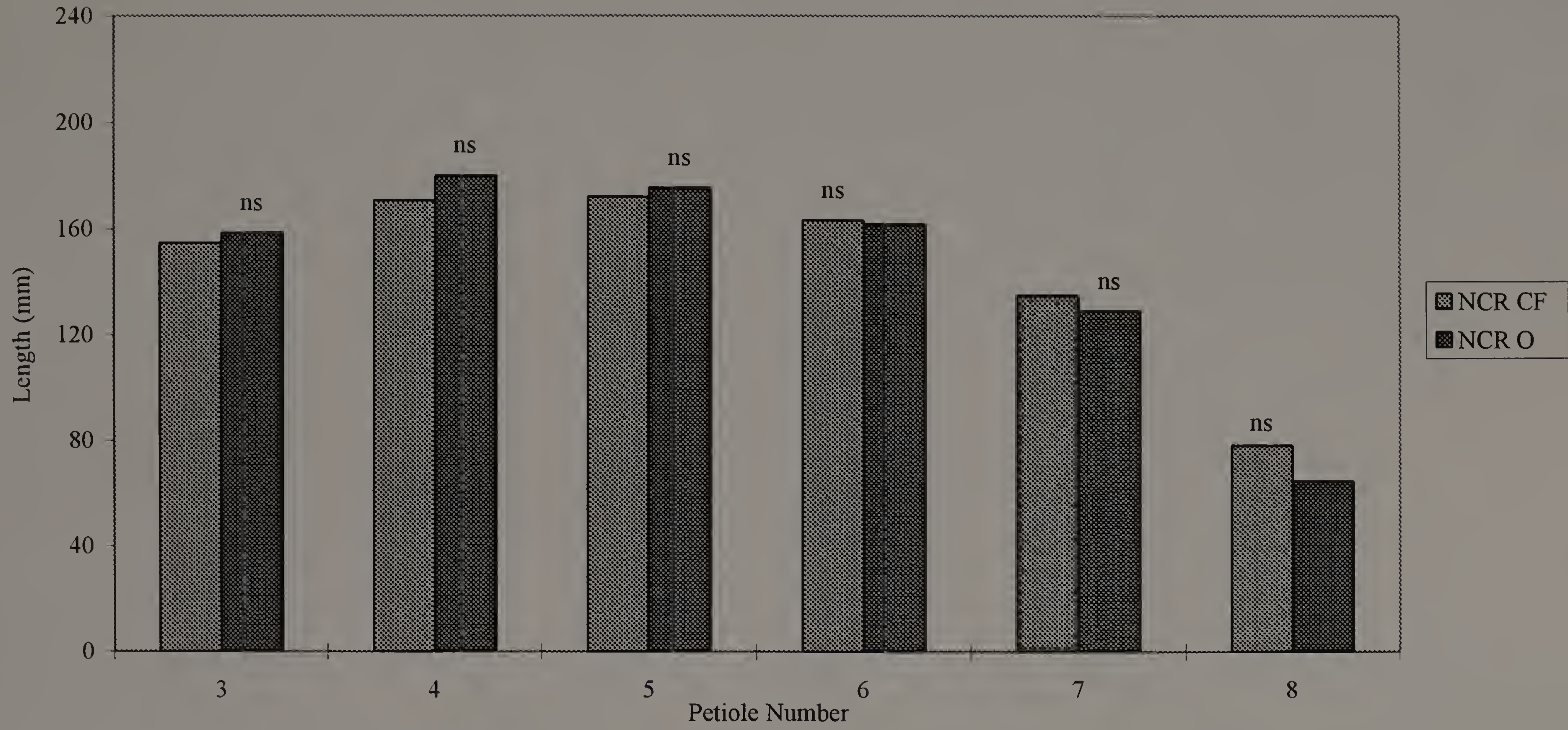

Figure 14: Differences in individual main leaf petiole lengths (mm) of NCR exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (** = $P < 0.01$)

Table 13: Effect of ozone on total stolon dry weight of NCS and NCR

Clone	Treatment	Total Stolon Dry Weight (grams)
NCS	CF	0.106***
NCS	O	0.048
NCR	CF	0.068 ns
NCR	O	0.060

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

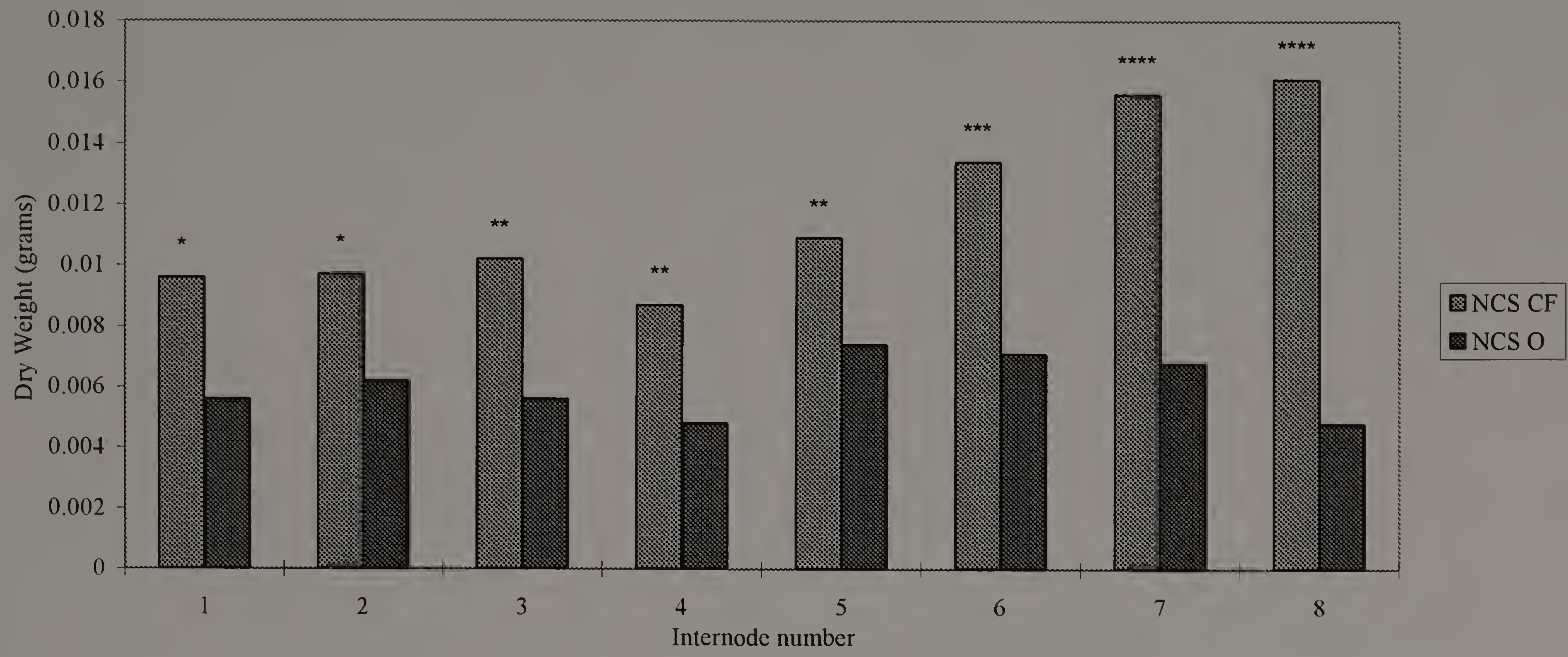

Figure 15: Differences in individual internode dry weights (grams) of NCS exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$, **** = $P < .0001$)

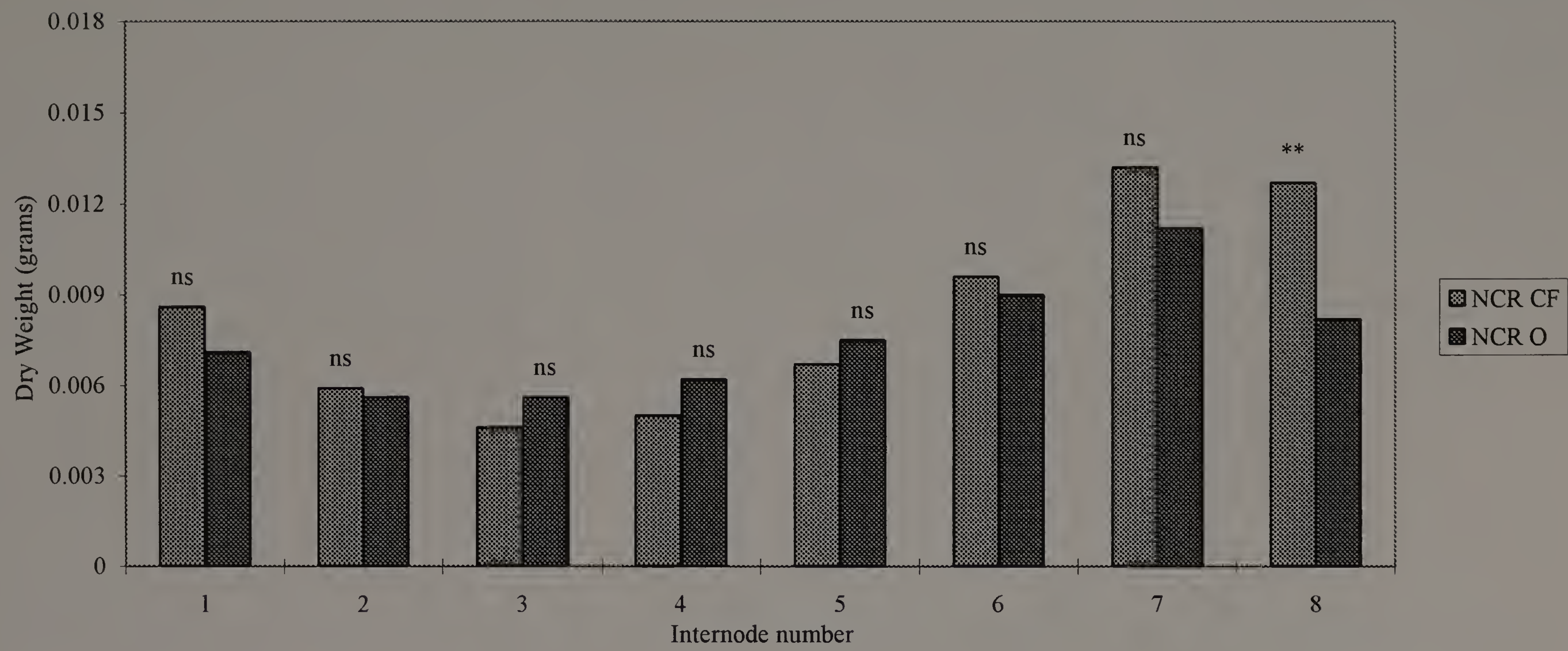

Figure 16: Differences in individual internode dry weights (grams) of NCR exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (** = P < 0.01, ns = not significant)

Table 14: Effect of ozone on total stolon length of NCS and NCR

Clone	Treatment	Total Stolon Length (mm)
NCS	CF	115.80****
NCS	O	63.85
NCR	CF	90.50 ns
NCR	O	82.25

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

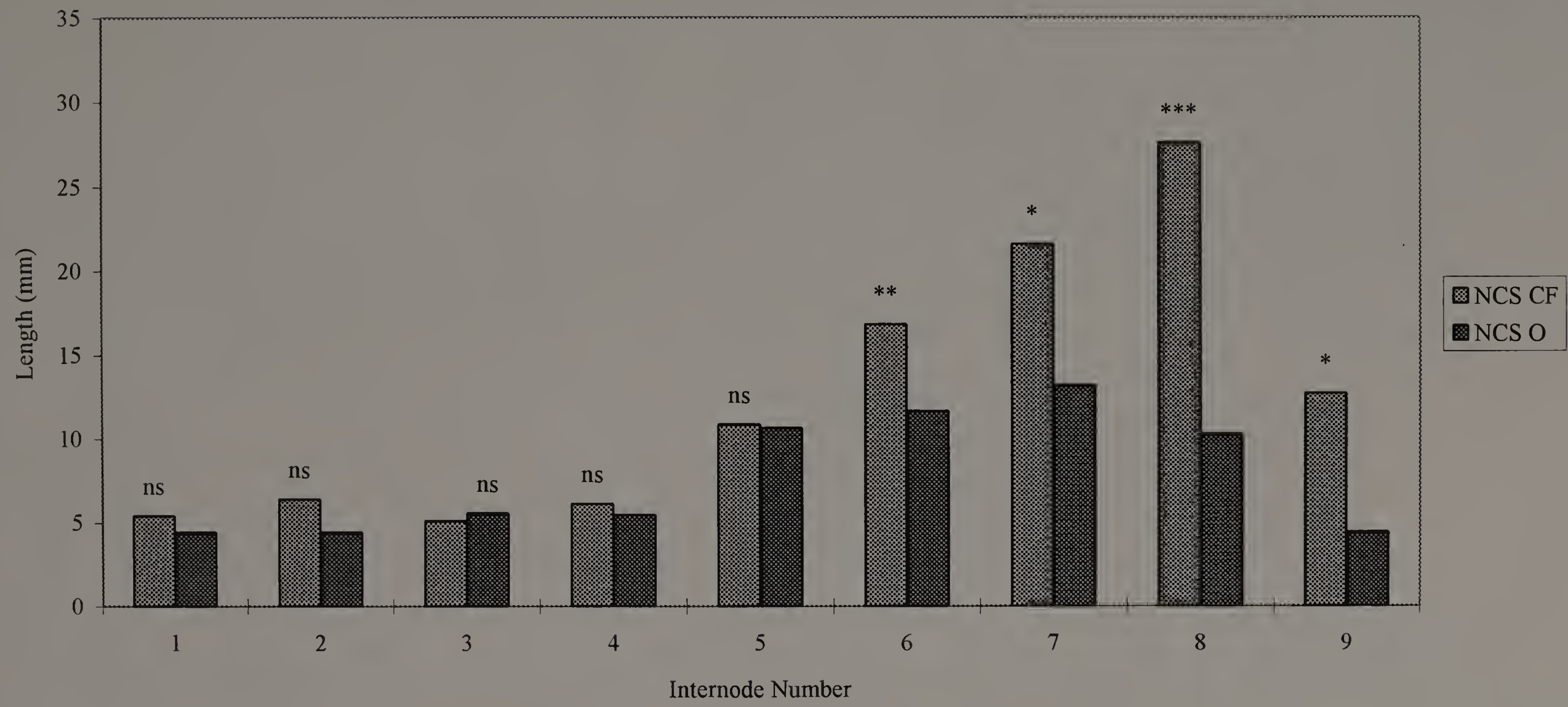

Figure 17: Differences in individual internode lengths (mm) of NCS exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (* = P < 0.05, ** = P < 0.01, *** = P < 0.001, ns = not significant)

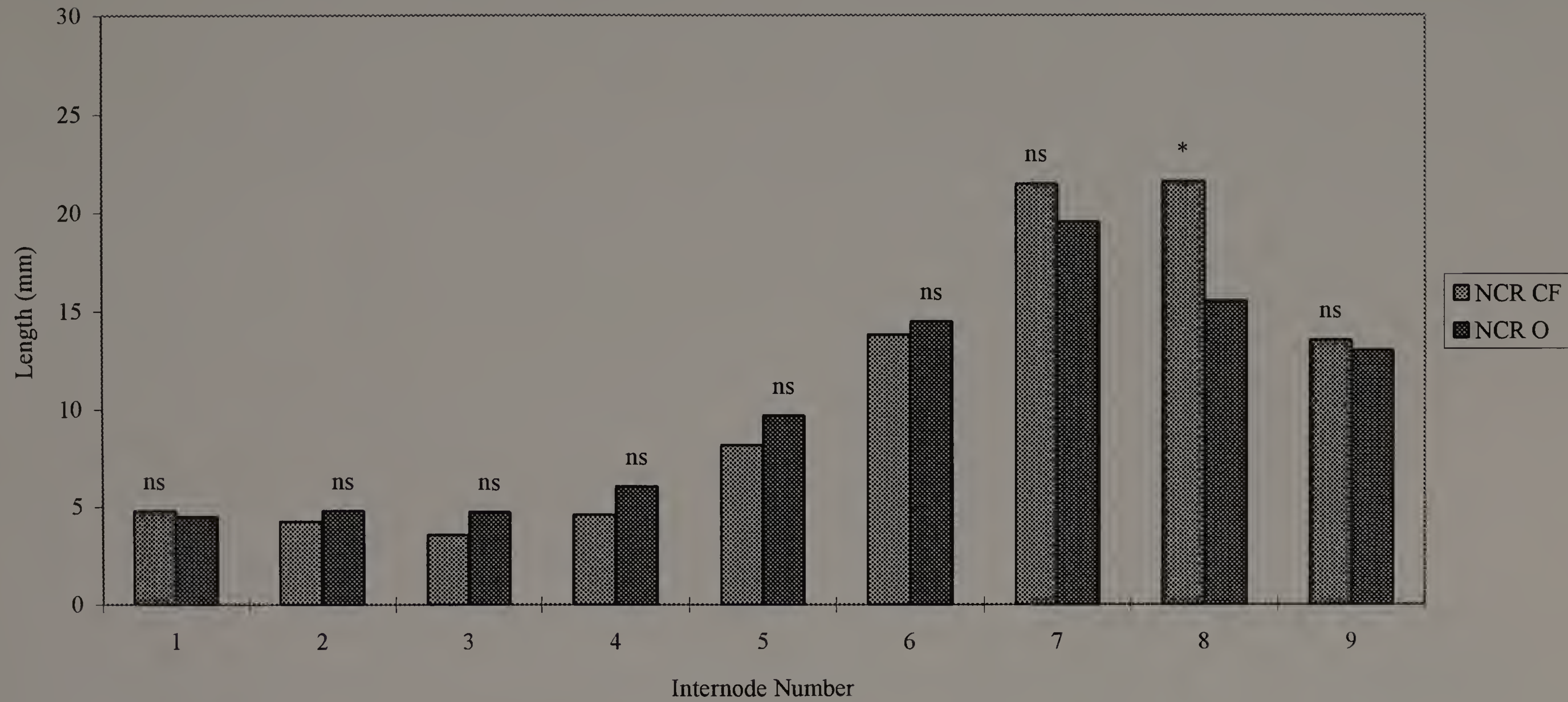

Figure 18: Differences in individual internode lengths (mm) of NCR exposed to carbon filtered air (CF) or carbon filtered air plus ozone (O) for 28 days. (* = P < 0.05, ns = not significant)

Table 15: Effect of ozone on total flower dry weight of NCS and NCR

Clone	Treatment	Total Flower dry weight (grams)
NCS	CF	0.0562 ns
NCS	O	0.0485
NCR	CF	0.0477
NCR	O	0.0746 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 16: Effect of ozone on total secondary stolon dry weight of NCS and NCR

Clone	Treatment	Total Secondary Stolon weight (grams)
NCS	CF	0.0581**
NCS	O	0.0151
NCR	CF	0.0346 ns
NCR	O	0.0256

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 17: Effect of ozone on secondary stolon number of NCS and NCR

Clone	Treatment	Total Secondary Stolon number
NCS	CF	6.00**
NCS	O	3.61
NCR	CF	4.72 ns
NCR	O	3.72

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 18: Effect of ozone on branching of NCS and NCR

Clone	Treatment	BNR
NCS	CF	0.626**
NCS	O	0.404
NCR	CF	0.522 ns
NCR	O	0.425

BNR = Branch number / Node number per plant

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 19: Effect of ozone on root to shoot ratio of NCS and NCR

Clone	Treatment	RSR
NCS	CF	0.226**
NCS	O	0.174
NCR	CF	0.192 ns
NCR	O	0.176

RSR = Root dry weight / Shoot dry weight

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
 * = significant at P < .05
** = significant at P < .01

Table 20: Effect of ozone on biomass partitioning of NCS and NCR

	NCS		NCR	
	CF	O	CF	O
LWR	0.370	0.390 ns	0.388 ns	0.338
SWR	0.082	0.073	0.081	0.084 ns
PWR	0.247	0.251 ns	0.255	0.266 ns
IMLR	0.071 ns	0.034	0.055 ns	0.053
FWR	0.033	0.066 ns	0.048	0.060 ns
RWR	0.183**	0.147	0.160 ns	0.149
TLWR	0.412	0.426 ns	0.445 ns	0.415
SSWR	0.043**	0.019	0.031 ns	0.025

LWR = Mature Leaf dry weight / Total plant dry weight
SWR = Stolon dry weight / Total plant dry weight
PWR = Petiole dry weight / Total plant dry weight
IMLR = Immature leaf dry weight / Total plant dry weight
FWR = Flower dry weight / Total plant dry weight
RWR = Root dry weight / Total plant dry weight
TLWR = Total leaf dry weight / Total plant dry weight
SSWR = Secondary stolon dry weight / Total plant dry weight

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at $P > .05$
* = significant at $P < .05$
** = significant at $P < .01$

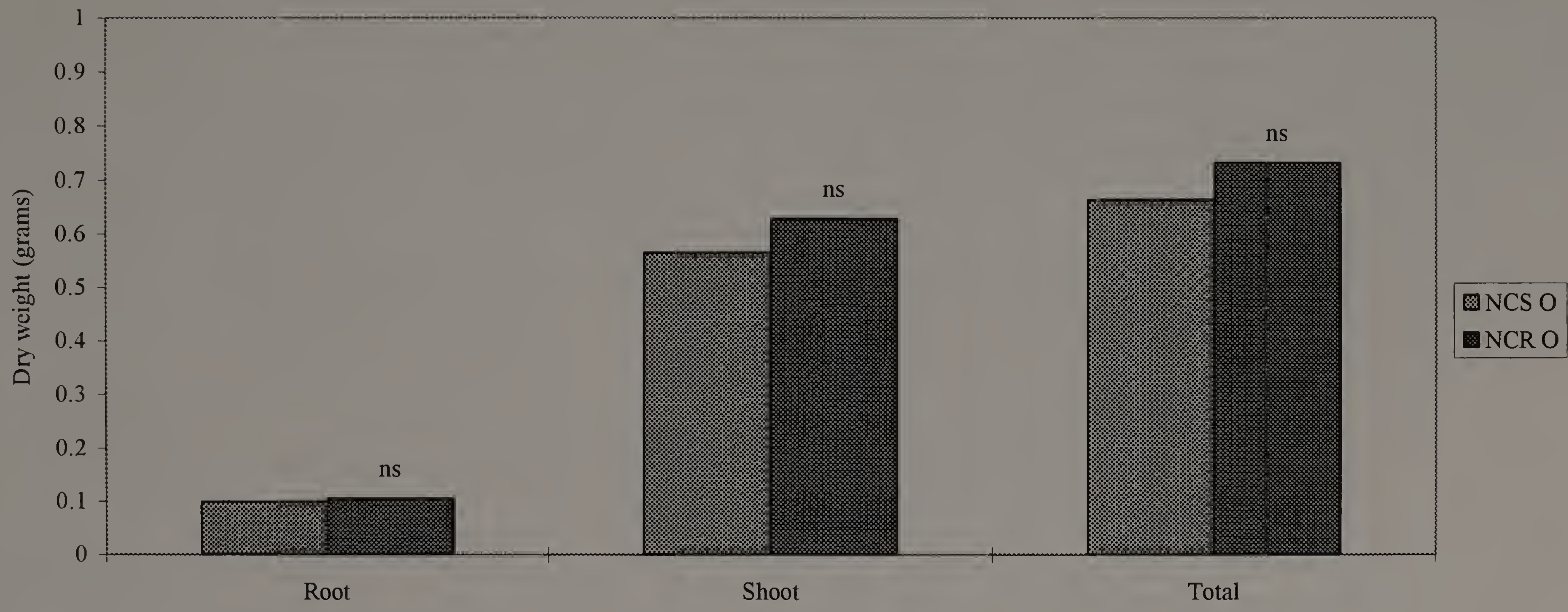

Figure 19: Differences in dry weights (grams) of root, shoot, and total plant between NCS and NCR exposed to carbon filtered air plus ozone (O) for 28 days.

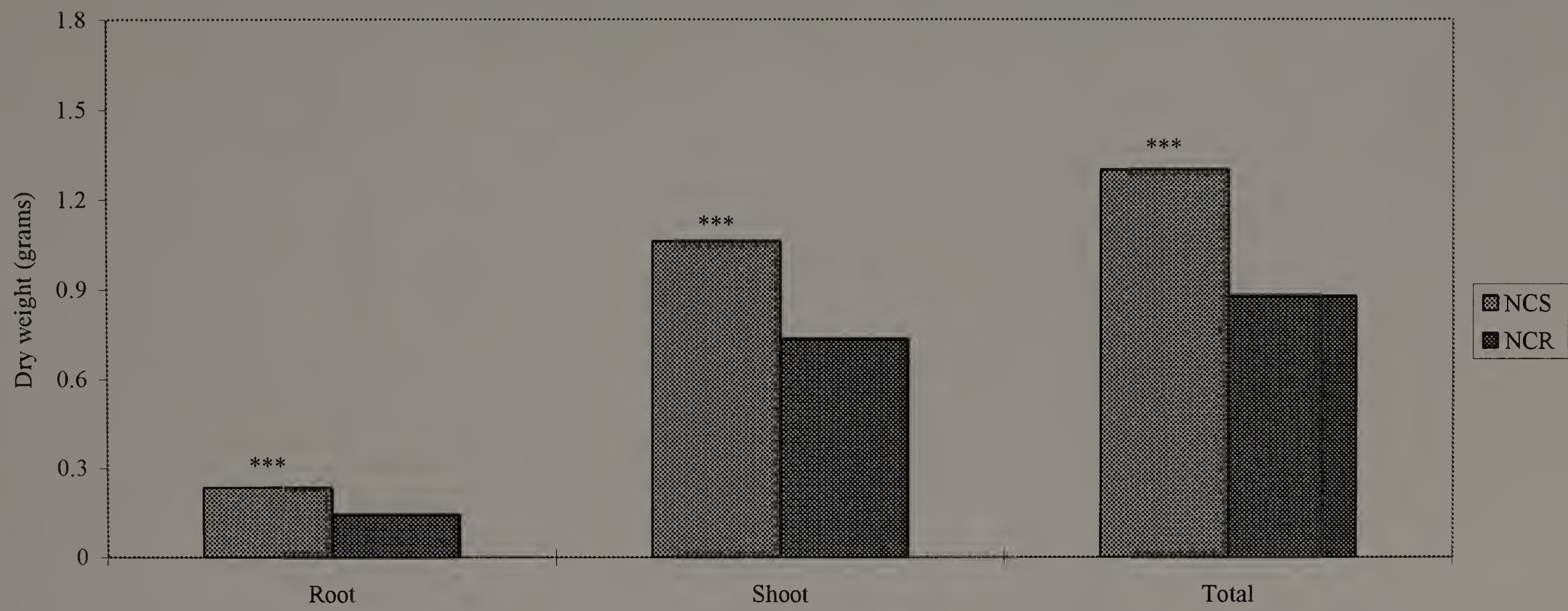

Figure 20: Differences in dry weights (grams) of root, shoot, and total plant between NCS and NCR exposed to carbon filtered air plus ozone for 28 days. (*** = P < 0.001)

Table 21: Difference in leaf numbers between NCS and NCR in two air treatments

Clone	Treatment	MML	IML	MSL	ISL	Total
NCS	CF	7.80 **	1.75 ns	10.30*	7.65***	27.50***
NCR	CF	7.05	1.40	5.85	3.65	17.95
NCS	O	7.60***	1.25 ns	6.15 ns	4.05**	19.05*
NCR	O	6.25	1.25	4.45	2.90	14.85

CF = carbon filtered air O = carbon filtered air plus ozone

MML = Mature Main Leaf number
IML = Immature Main Leaf number
MSL = Mature Secondary Leaf number
ISL = Immature Secondary Leaf number

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

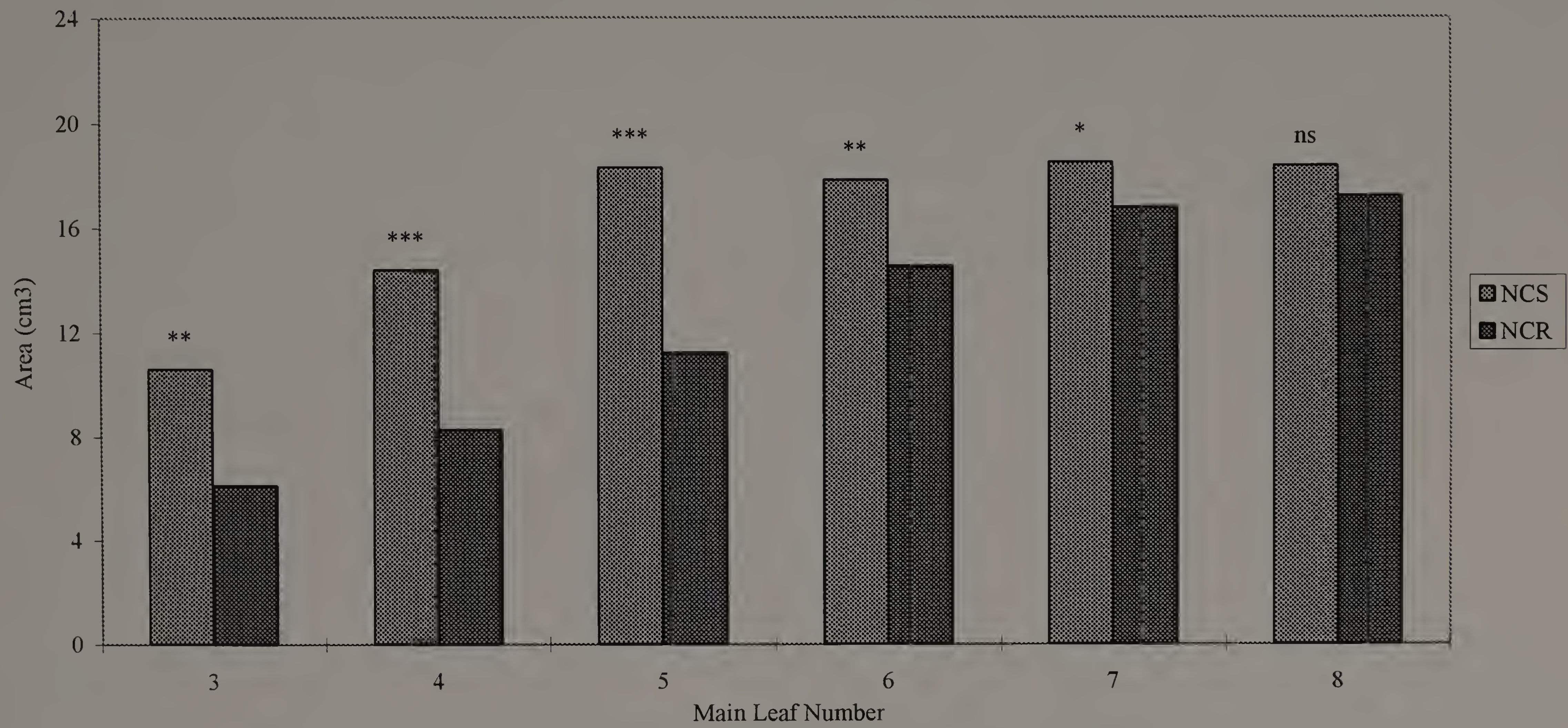

Figure 21: Differences in individual main leaf area (cm3) between NCS and NCR exposed to carbon filtered air for 28 days. (* = P < 0.05, ** = P < 0.01, *** = P < 0.001, ns = not significant)

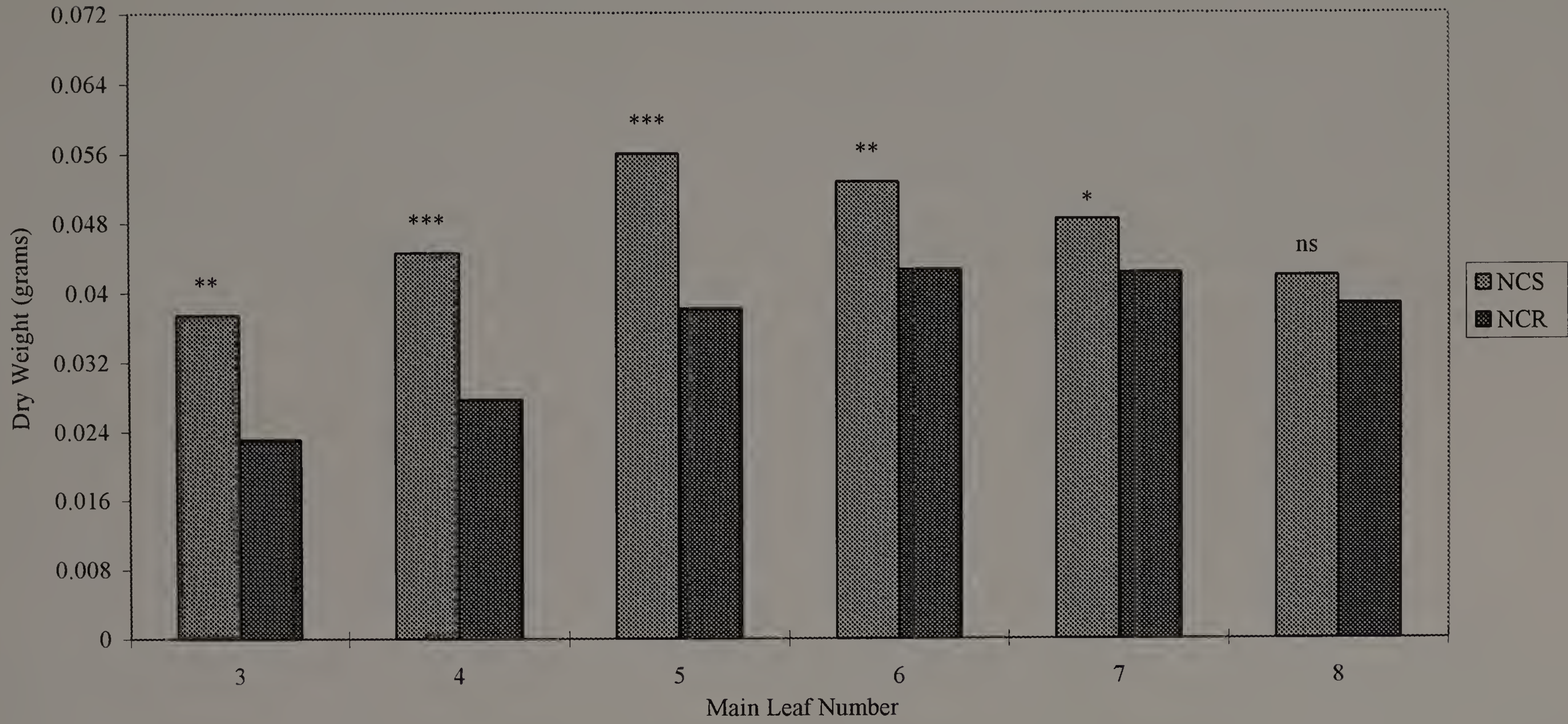

Figure 22: Differences in individual main leaf dry weight (grams) between NCS and NCR exposed to carbon filtered air for 28 days. (* = P < 0.05, ** = P < 0.01, *** = P < 0.001, ns = not significant)

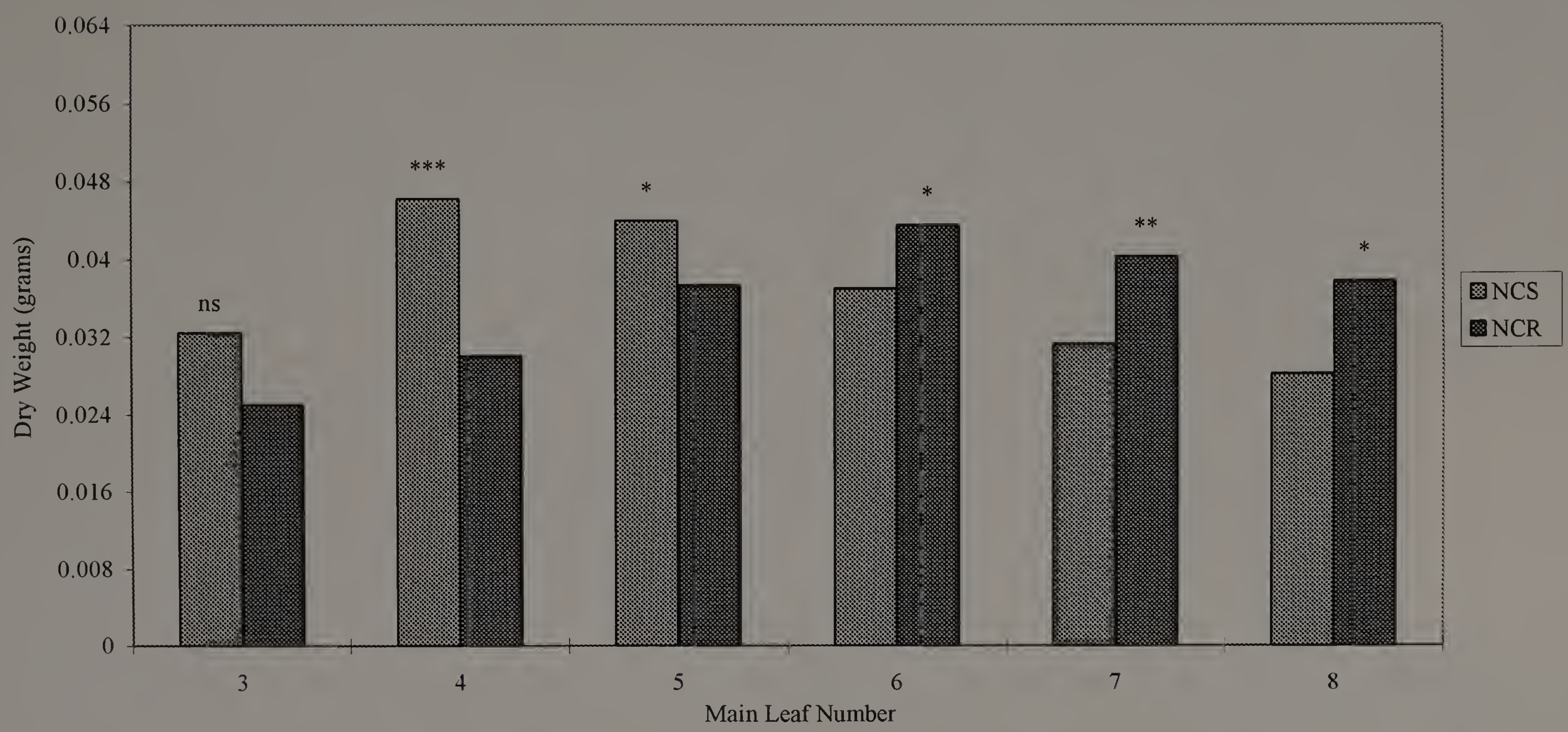

Figure 23: Differences in individual main leaf dry weight (grams) between NCS and NCR exposed to carbon filtered air plus ozone for 28 days. (* = P < 0.05, ** = P < 0.01, *** = P < 0.001, ns = not significant)

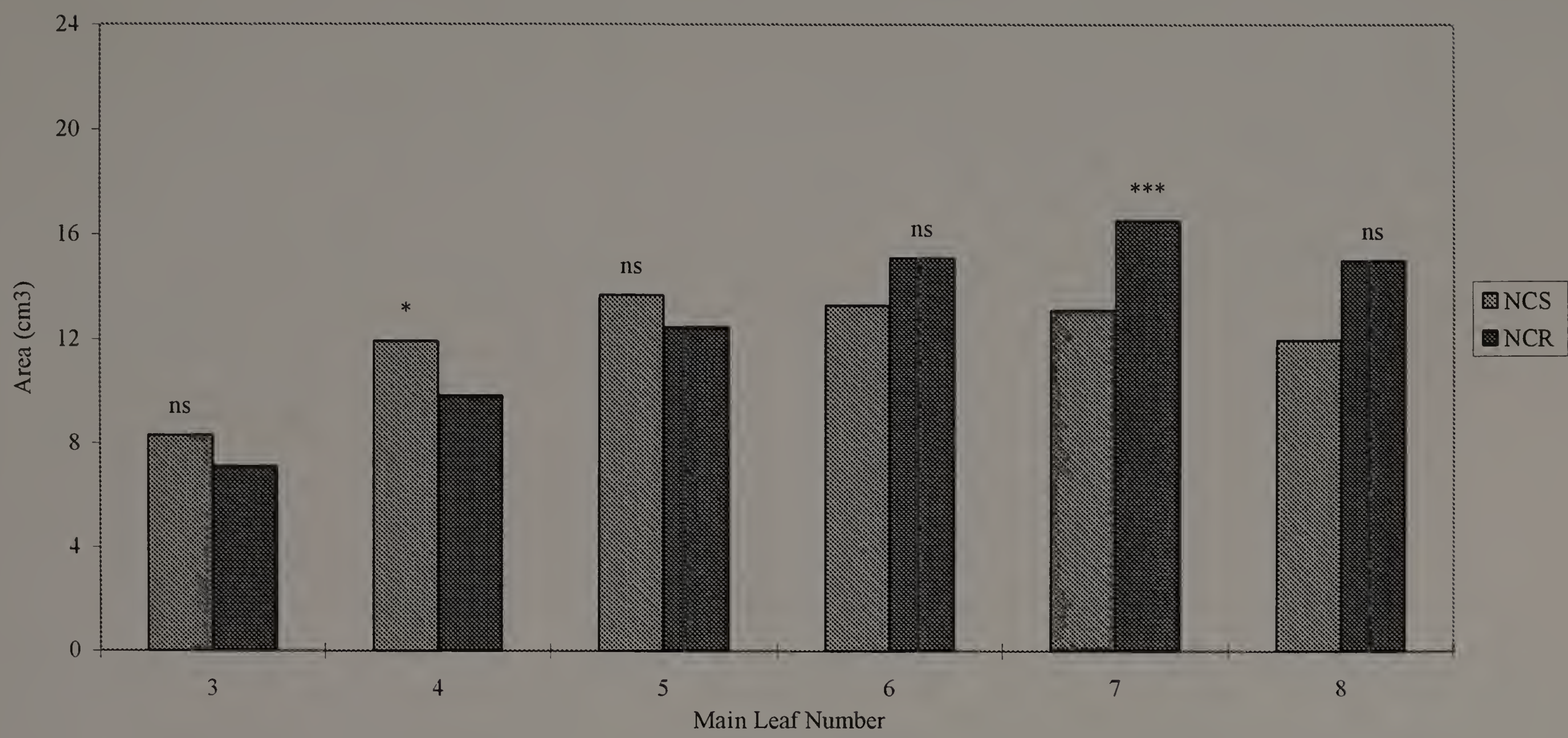

Figure 24: Differences in individual main leaf area (cm3) between NCS and NCR exposed to carbon filtered air plus ozone for 28 days. (* = P < 0.05, ** = P < 0.01, *** = P < 0.001, ns = not significant)

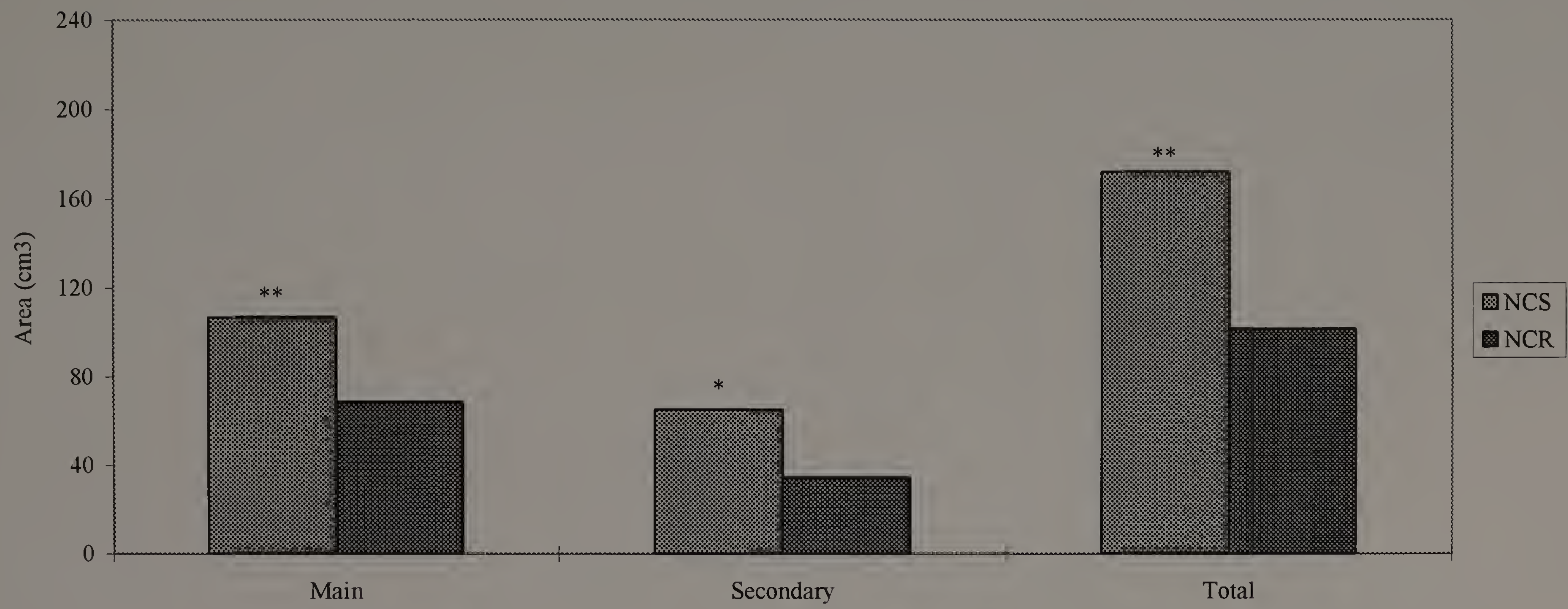

Figure 25: Differences in area (cm3) of main, secondary, and total leaves between NCS and NCR exposed to carbon filtered air for 28 days. (* = P < 0.05, ** = P < 0.01)

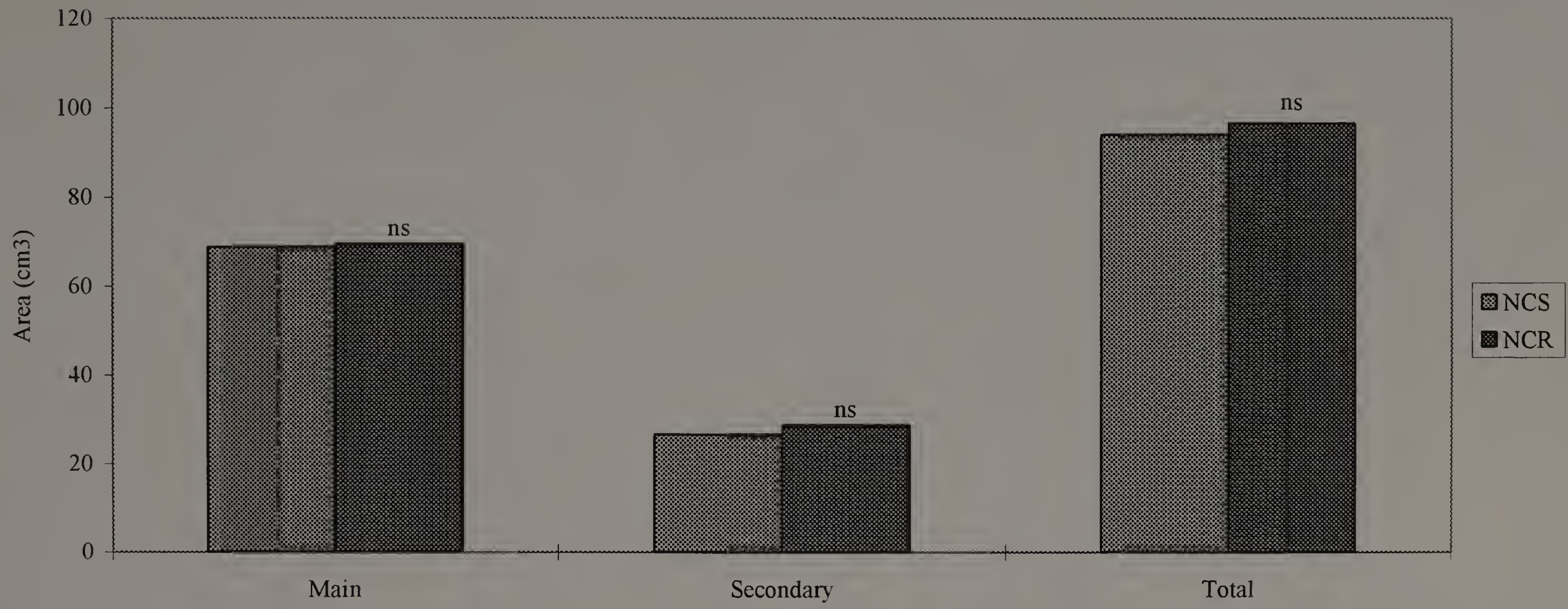

Figure 26: Differences in area (cm3) of main, secondary, and total leaves between NCS and NCR exposed to carbon filtered air plus ozone for 28 days.

Table 22: Differences in the total main leaf dry weights between NCS and NCR in two air treatments

Clone	Treatment	Total Main leaf Dry Weight (grams)
NCS	CF	0.307***
NCR	CF	0.224
NCS	O	0.224 ns
NCR	O	0.206

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

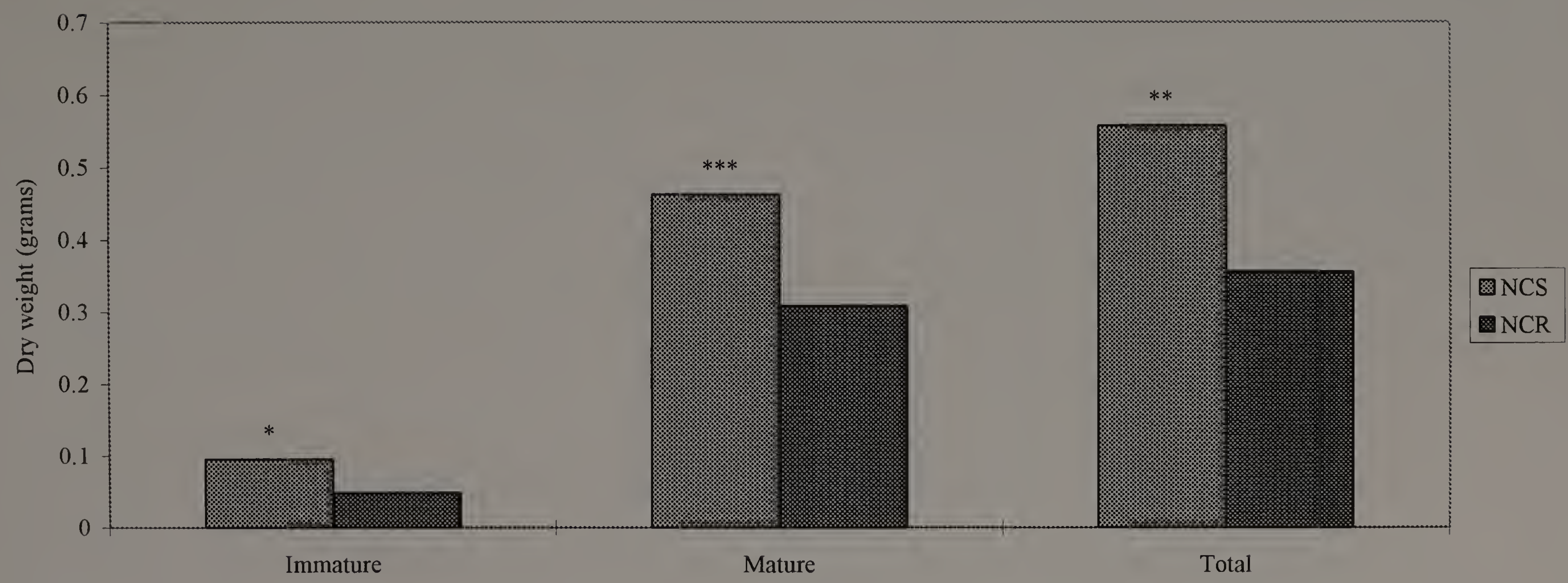

Figure 27: Difference in dry weight of immature, mature, and total leaves between NCS and NCR exposed to carbon filtered air for 28 days. (* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$)

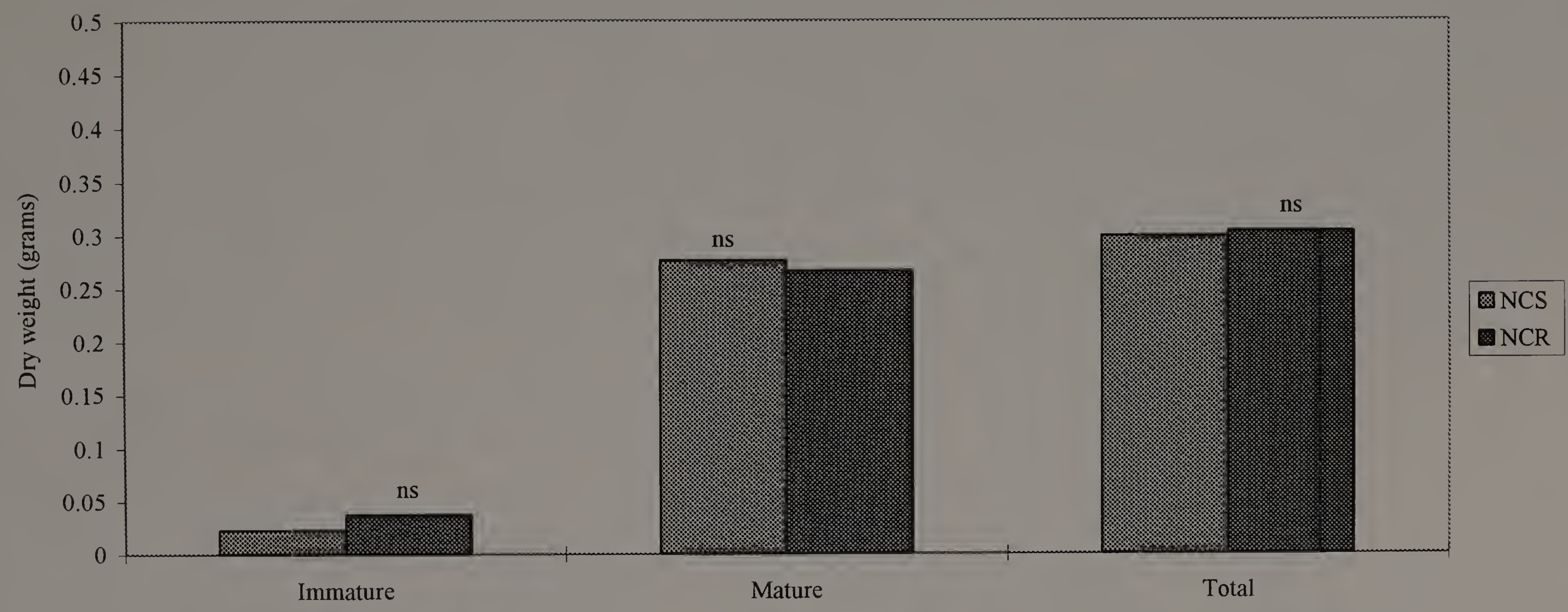

Figure 28: Difference in dry weight of immature, mature, and total leaves between NCS and NCR exposed to carbon filtered air plus ozone for 28 days. (ns = not significant)

Table 23: Differences in SLA and LAR between NCS and NCR in two air treatments

Clone	Treatment	SLA	LAR
NCS	CF	356.71 ns	131.71 ns
NCR	CF	326.34	115.63
NCS	O	359.72	139.54 ns
NCR	O	371.62 ns	123.37

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 24: Differences in the total petiole dry weight between NCS and NCR in two air treatments

Clone	Treatment	Total Petiole Dry Weight (grams)
NCS	CF	0.321**
NCR	CF	0.225
NCS	O	0.167
NCR	O	0.195 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

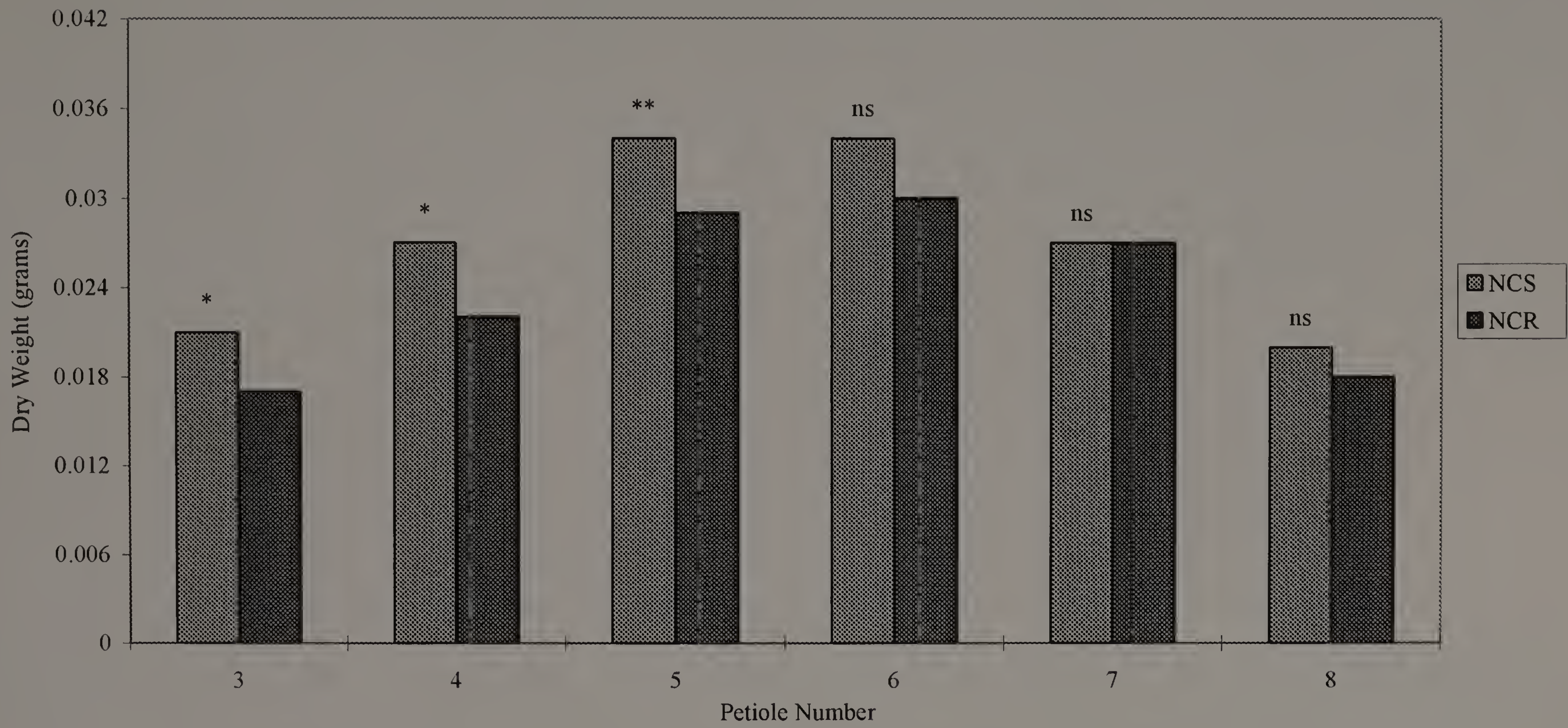

Figure 29: Differences in individual main leaf petiole dry weights (grams) between NCS and NCR exposed to carbon filtered air for 28 days. (* = $P < 0.05$, ** = $P < 0.01$, ns = not significant)

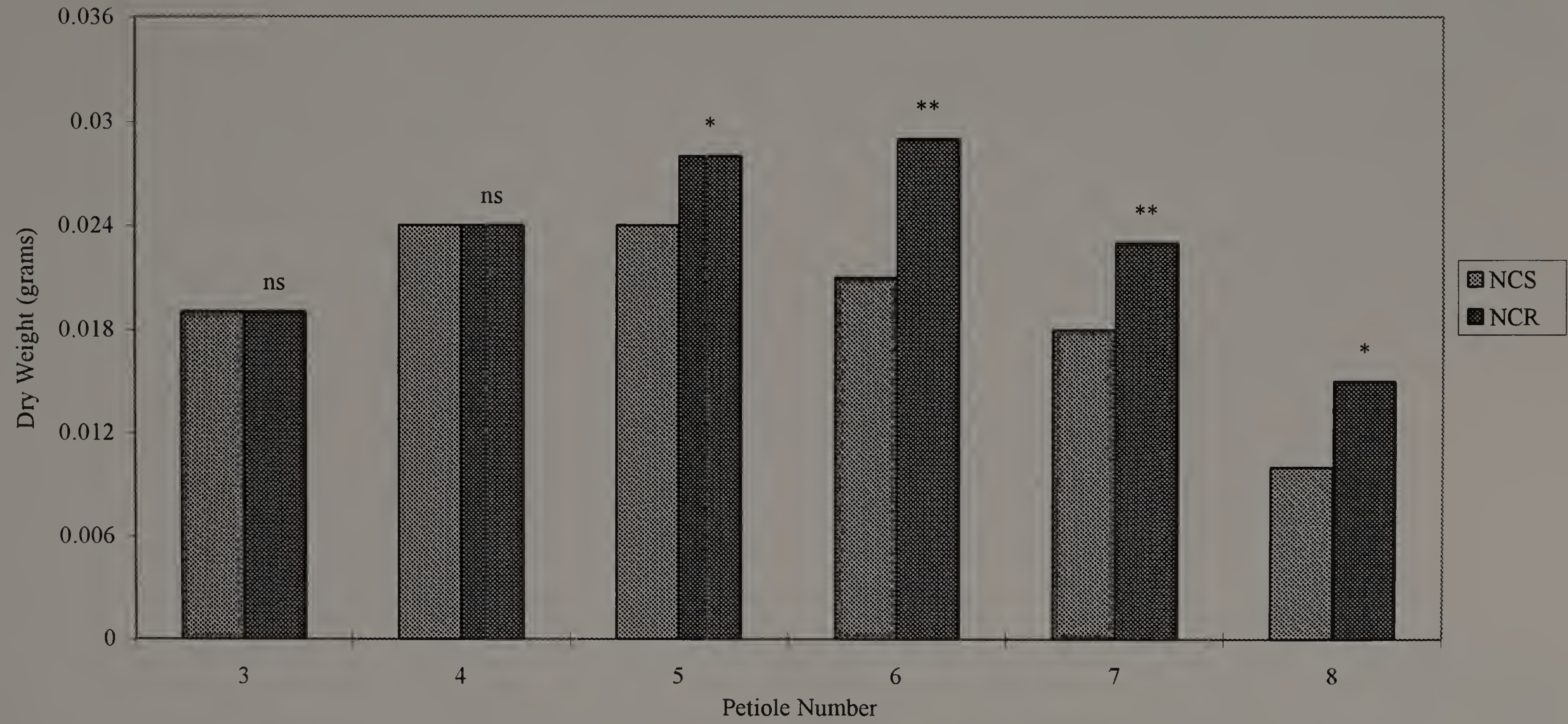

Figure 30: Differences in individual main leaf petiole dry weights (grams) between NCS and NCR exposed to carbon filtered air plus ozone for 28 days. (* = P < 0.05, ** = P < 0.01, ns = not significant)

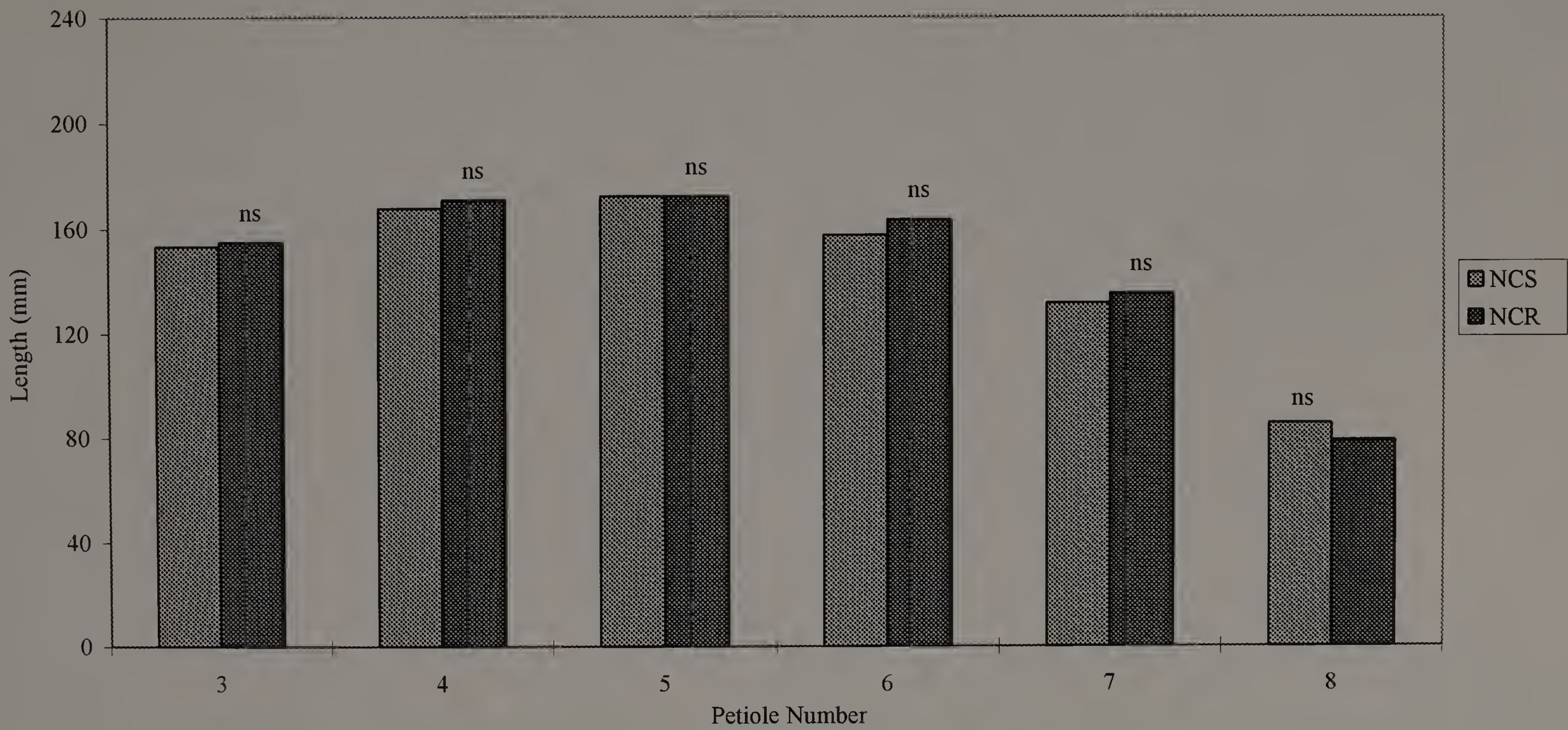

Figure 31: Differences in individual main leaf petiole lengths (mm) between NCS and NCR exposed to carbon filtered air for 28 days. (ns = not significant)

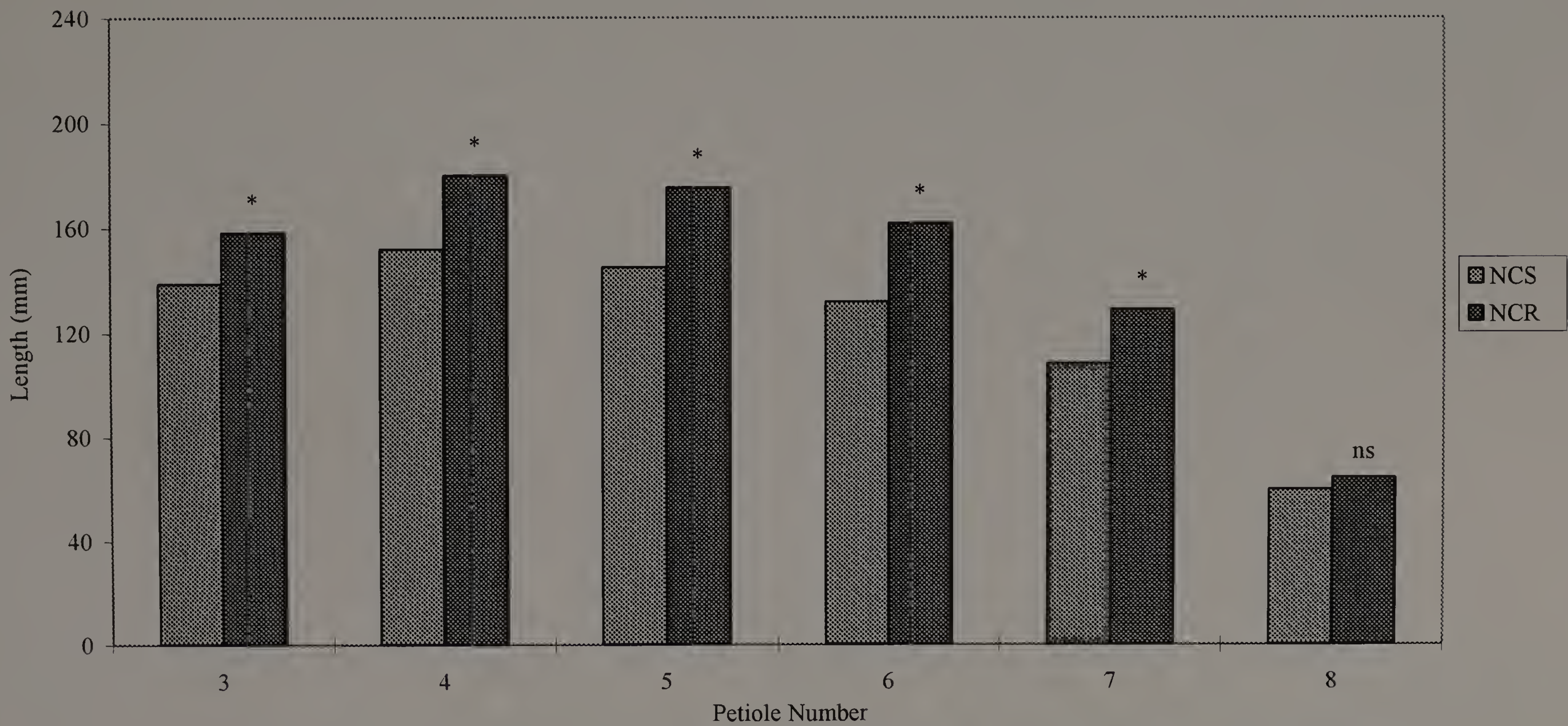

Figure 32: Differences in individual main leaf petiole lengths (mm) between NCS and NCR exposed to carbon filtered air plus ozone for 28 days. (* = P < 0.05, ns = not significant)

Table 25: Differences in total stolon dry weights between NCS and NCR in two air treatments

Clone	Treatment	Total Stolon Dry Weight (grams)
NCS	CF	0.106***
NCR	CF	0.068
NCS	O	0.048
NCR	O	0.060 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

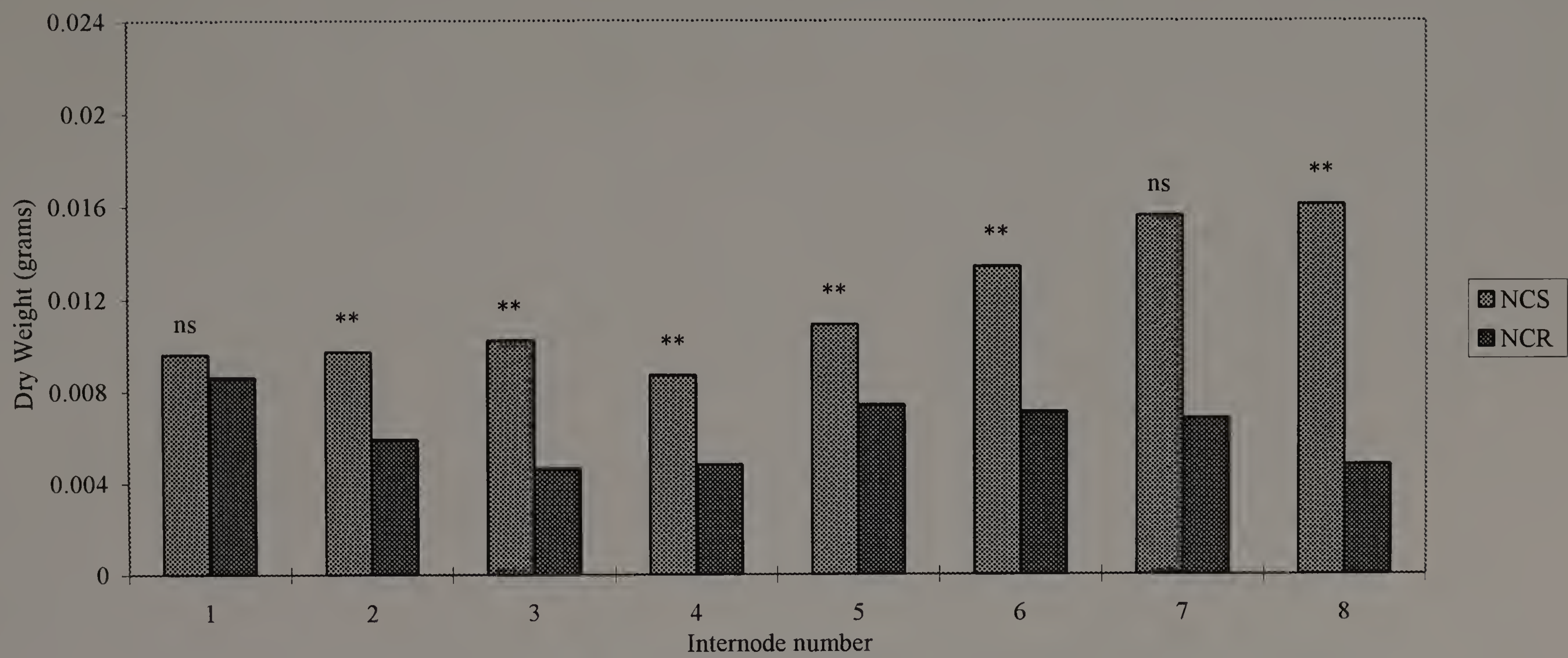

Figure 33: Differences in individual internode dry weights (grams) between NCS and NCR exposed to carbon filtered air (CF) for 28 days. (** = P < 0.01, ns = not significant)

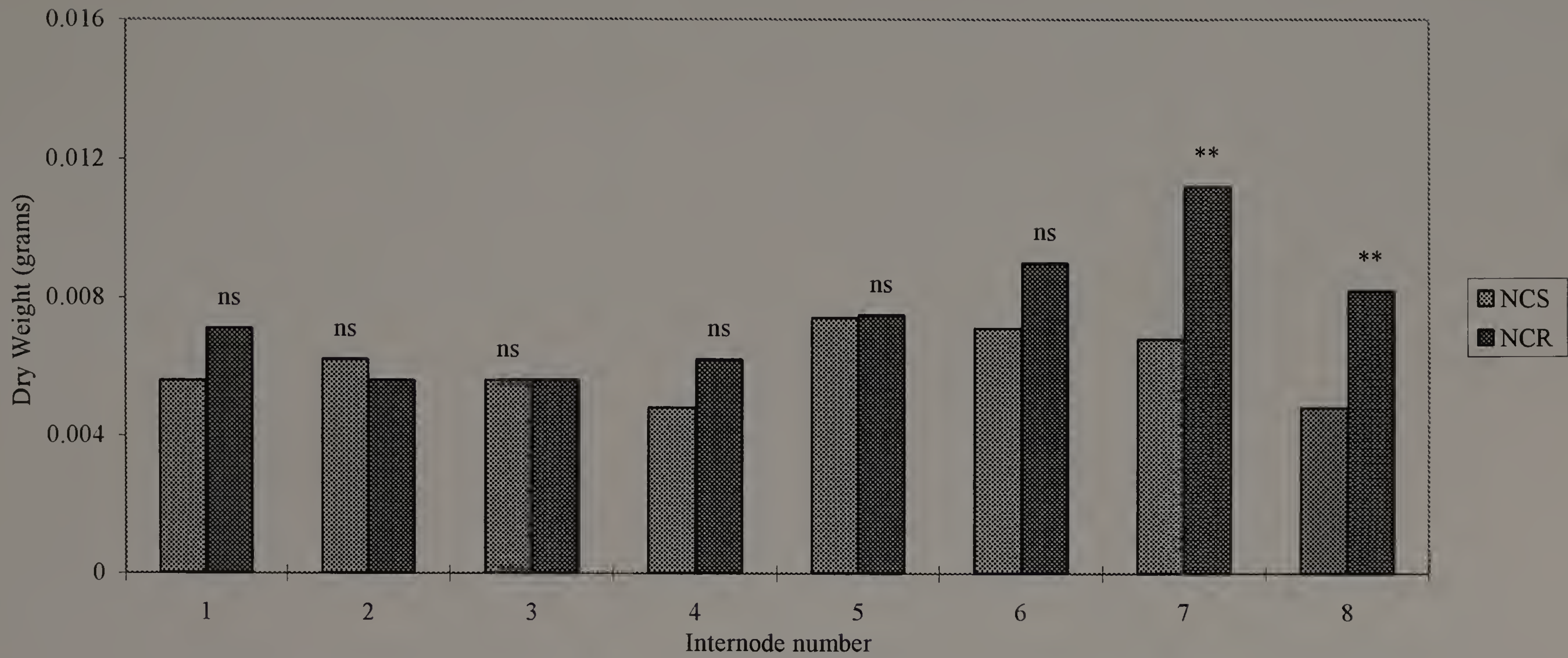

Figure 34: Differences in individual internode dry weights (grams) between NCS and NCR exposed to carbon filtered air plus ozone for 28 days. (** = $P < 0.01$, ns = not significant)

Table 26: Difference in total stolon length between NCS and NCR in two air treatments

Clone	Treatment	Total Stolon Length (mm)
NCS	CF	115.80***
NCR	CF	90.50
NCS	O	63.85
NCR	O	82.25*

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

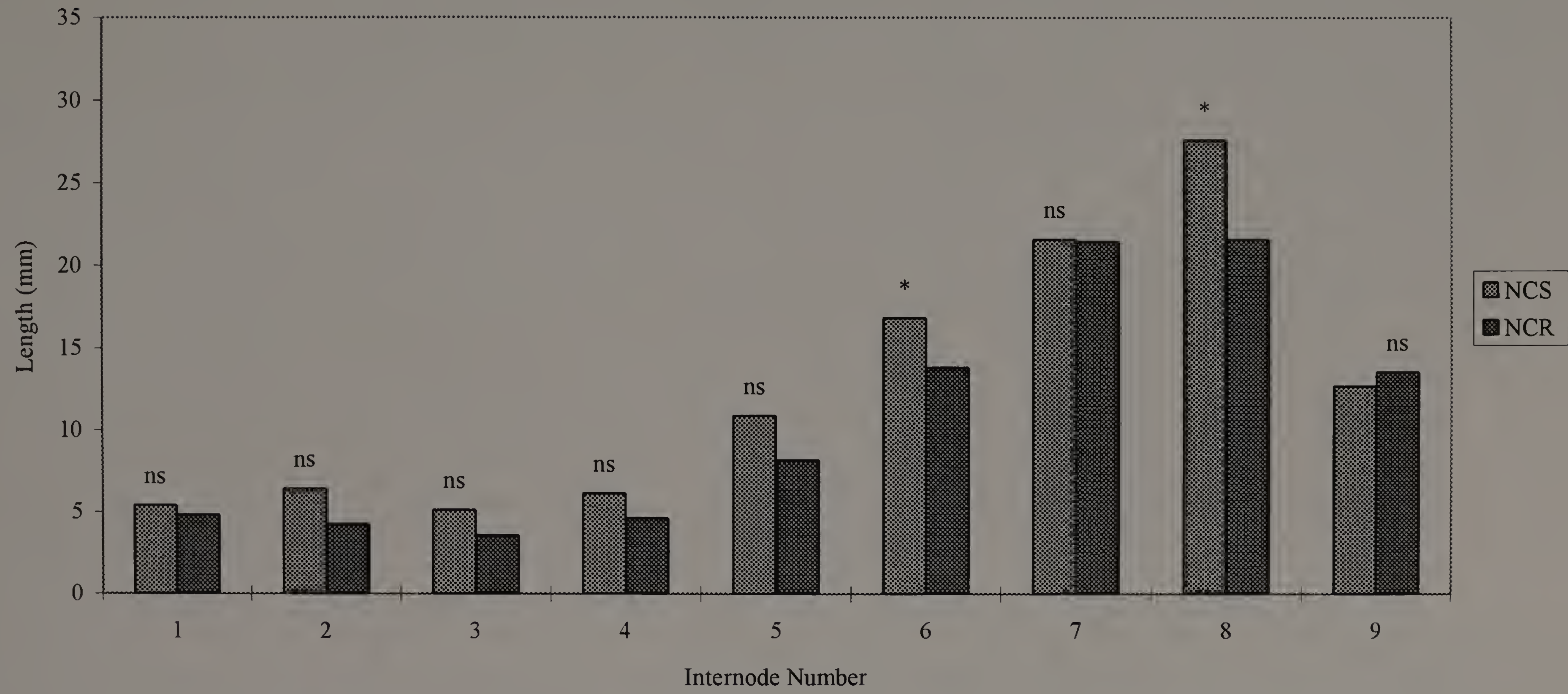

Figure 35: Differences in individual internode lengths (mm) between NCS and NCR exposed to carbon filtered air (CF) for 28 days. (* = P < 0.05, ns = not significant)

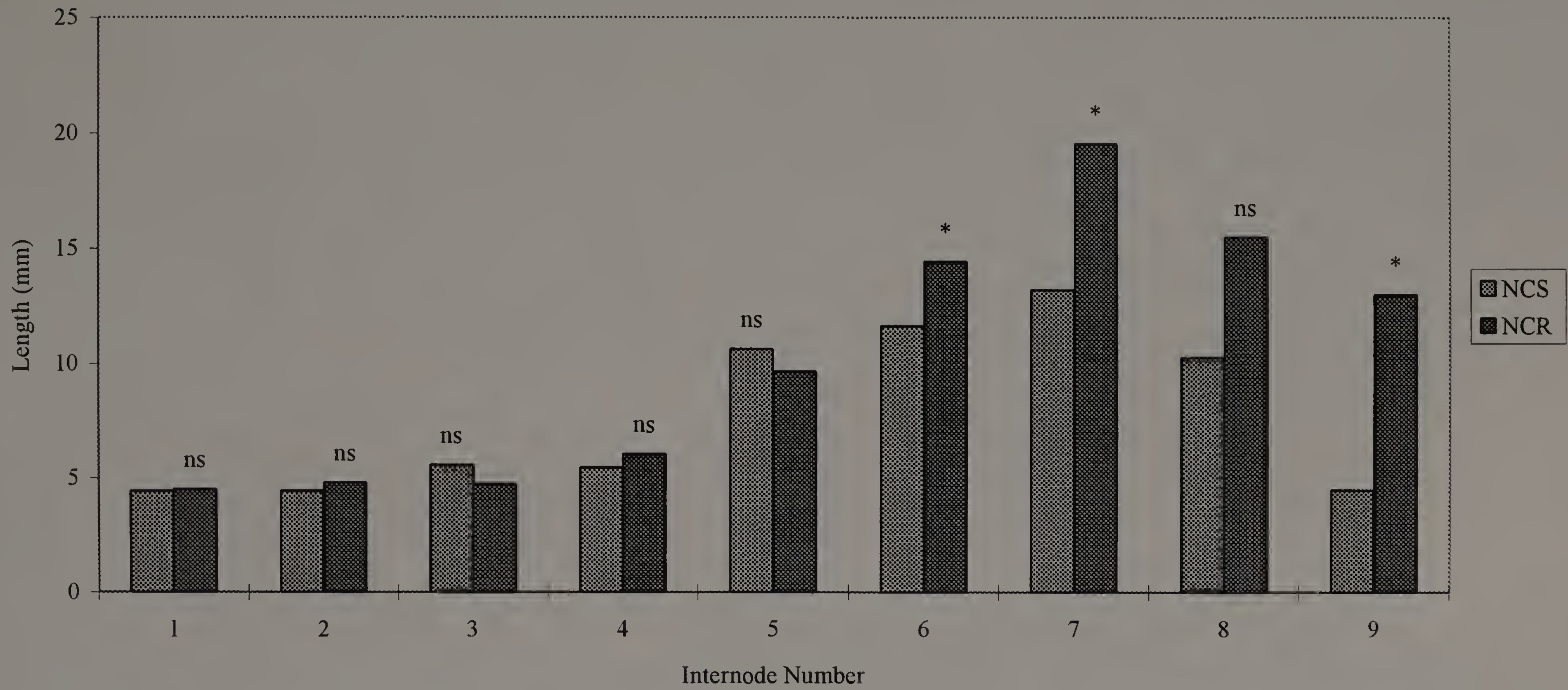

Figure 36: Differences in individual internode lengths (mm) between NCS and NCR exposed to carbon filtered air plus ozone for 28 days. (* = P < 0.05, ns = not significant)

Table 27: Differences in secondary stolon number between NCS and NCR in two air treatments

Clone	Treatment	Total Secondary Stolon number
NCS	CF	6.00 ns
NCR	CF	4.72
NCS	O	3.61
NCR	O	3.72 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 28: Differences in branching between NCS and NCR in two air treatments

Clone	Treatment	BNR
NCS	CF	0.626 ns
NCR	CF	0.522
NCS	O	0.404
NCR	O	0.425 ns

BNR = Branch number / Node number per plant

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 29: Differences in total secondary stolon dry weight between NCS and NCR in two air treatments

Clone	Treatment	Total Secondary Stolon weight (grams)
NCS	CF	0.0581*
NCR	CF	0.0346
NCS	O	0.0151
NCR	O	0.0256 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
 * = significant at P < .05
** = significant at P < .01

Table 30: Differences in total flower dry weight between NCS and NCR in two air treatments

Clone	Treatment	Total Flower dry weight (grams)
NCS	CF	0.0562 ns
NCR	CF	0.0477
NCS	O	0.0485
NCR	O	0.0746 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 31: Differences in root to shoot ratio between NCS and NCR in two air treatments

Clone	Treatment	RSR
NCS	CF	0.226*
NCR	CF	0.192
NCS	O	0.174
NCR	O	0.176 ns

RSR = Root dry weight / Shoot dry weight

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
 * = significant at P < .05
** = significant at P < .01

Table 32: Differences in biomass partitioning between NCS and NCR in two air treatments

	CF		O	
	NCS	NCR	NCS	NCR
LWR	0.370	0.388 ns	0.390 ns	0.338
SWR	0.082 ns	0.081	0.073	0.084*
PWR	0.247	0.255 ns	0.251	0.266 ns
IMLR	0.071 ns	0.055	0.034	0.053 ns
FWR	0.033	0.048 ns	0.066 ns	0.060
RWR	0.183*	0.160	0.147	0.149 ns
TLWR	0.412	0.445 ns	0.426 ns	0.415
SSWR	0.043 ns	0.031	0.019	0.025 ns

LWR = Mature Leaf dry weight / Total plant dry weight
SWR = Stolon dry weight / Total plant dry weight
PWR = Petiole dry weight / Total plant dry weight
IMLR = Immature leaf dry weight / Total plant dry weight
FWR = Flower dry weight / Total plant dry weight
RWR = Root dry weight / Total plant dry weight
TLWR = Total leaf dry weight / Total plant dry weight
SSWR = Secondary stolon dry weight / Total plant dry weight

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at $P > .05$
* = significant at $P < .05$
** = significant at $P < .01$

Table 33: Effect of ozone on total root dry weight (grams) of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.0471	0.0521 ns	0.0378	0.0533*
2	0.0970 ns	0.0680	0.0590 ns	0.0565
3	0.1110 ns	0.0880	0.0730 ns	0.0710
4	0.3030**	0.1930	0.9040 ns	0.1740

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 34: Effect of ozone on total shoot dry weight (grams) of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.1250	0.1336 ns	0.0987	0.1300**
2	0.2290 ns	0.1890	0.1910	0.1920 ns
3	0.4320 ns	0.3560	0.3170 ns	0.3080
4	1.0400*	0.7100	0.7100 ns	0.6760

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 35: Effect of ozone on total plant dry weight (grams) of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.172	0.186 ns	0.137	0.183**
2	0.326 ns	0.257	0.250 ns	0.248
3	0.543 ns	0.446	0.391 ns	0.379
4	1.350**	0.879	0.904 ns	0.851

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 36: Effect of ozone on total leaf number of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	3.17	3.50 ns	3.17	3.58*
2	7.08 ns	6.50	5.50 ns	5.50
3	14.33 ns	12.58	10.67 ns	9.67
4	24.67 ns	20.58	20.33	21.67 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 37: Effect of ozone on total main leaf number of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	3.42	3.42 ns	3.17	3.58*
2	5.33 ns	4.92	5.16 ns	5.16
3	6.92	7.00 ns	7.00 ns	7.00
4	9.00 ns	8.58	9.00	9.25 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 38: Effect of ozone on total mature main leaf number of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	2.08 ns	2.00	2.08	2.33 ns
2	3.75	3.83 ns	4.17 ns	3.83
3	5.17	5.33 ns	5.58 ns	5.33
4	7.08 ns	6.83	7.42 ns	7.42

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 39: Effect of ozone on total immature main leaf number of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	1.08	1.42 ns	1.08	1.25 ns
2	1.58 ns	1.00	1.00	1.33 ns
3	1.75 ns	1.67	1.42	1.67 ns
4	1.92 ns	1.75	1.58 ns	1.58

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 40: Effect of ozone on total immature secondary leaf number of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	--	--	--	--
2	1.50 ns	1.08	0.17	0.25 ns
3	4.17 ns	2.92	2.33 ns	1.92
4	8.25 ns	6.58	6.67	6.83 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 41: Effect of ozone on total mature secondary leaf number over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	--	--	--	--
2	0.33 ns	0.33	0.00	0.08 ns
3	3.08 ns	2.67	1.17 ns	0.83
4	7.50 ns	5.42	4.33	5.33 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 42: Effect of ozone on total leaf dry weight (grams) of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.0688	0.0729 ns	0.0557	0.0739*
2	0.1240 ns	0.0980	0.1100 ns	0.1050
3	0.2170 ns	0.1940	0.1660 ns	0.1650
4	0.5300*	0.3600	0.3680 ns	0.3560

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 43: Effect of ozone on total mature leaf dry weight (grams) of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.0576 ns	0.0566	0.0440	0.0622**
2	0.1080 ns	0.0900	0.1040 ns	0.0963
3	0.1880 ns	0.1740	0.1500 ns	0.1470
4	0.4490*	0.3040	0.3100 ns	0.3040

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 44: Effect of ozone on total immature leaf dry weight (grams) of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.0112	0.0163*	0.0117	0.0117 ns
2	0.0170 ns	0.0082	0.0060	0.0090 ns
3	0.0294 ns	0.0197	0.0160	0.0180 ns
4	0.0810 ns	0.0580	0.0580 ns	0.0520

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 45: Effect of ozone on total main leaf dry weight (grams) of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.0688	0.0736 ns	0.0557	0.0739*
2	0.1160*	0.0980	0.1190*	0.1060
3	0.1780 ns	0.1760	0.1550 ns	0.1540
4	0.3210*	0.2280	0.2560 ns	0.2330

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 46: Effect of ozone on individual main leaf dry weights (grams) of NCS and NCR over four harvests

a. Harvest 1

Main Leaf #	NCS		NCR	
	CF	O	CF	O
1	0.0309	0.0312 ns	0.0243	0.0299 ns
2	0.0236	0.0254 ns	0.0174	0.0235 ns
3	0.0142	0.0169 ns	0.0140	0.0195 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

b. Harvest 2

Main Leaf #	NCS		NCR	
	CF	O	CF	O
1	0.0285 ns	0.0266	0.0254	0.0260 ns
2	0.0230 ns	0.0218	0.0187	0.0194 ns
3	0.0328 ns	0.0281	0.0273	0.0293 ns
4	0.0228 ns	0.0169	0.0389 ns	0.0221
5	0.0079 ns	0.0052	0.0081	0.0124 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Continued, next page.

c. Harvest 3

Main Leaf #	NCS		NCR	
	CF	O	CF	O
1	0.0334 ns	0.0305	0.0248 ns	0.0243
2	0.0266 ns	0.0266	0.0195	0.0198 ns
3	0.0392	0.0414 ns	0.0294	0.0301 ns
4	0.0335 ns	0.0321	0.0294	0.0294 ns
5	0.0277	0.0281 ns	0.0276	0.0292 ns
6	0.0168	0.0169 ns	0.0198 ns	0.0192

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05

d. Harvest 4

Main Leaf #	NCS		NCR	
	CF	O	CF	O
1	-	-	-	-
2	0.0347 ns	0.0325	0.0201 ns	0.0178
3	0.0561 ns	0.0495	0.0336 ns	0.0321
4	0.0500**	0.0394	0.0357	0.0360 ns
5	0.0517**	0.0386	0.0408 ns	0.0358
6	0.0477**	0.0367	0.0411 ns	0.0400
7	0.0464*	0.0383	0.0430	0.0436 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 47: Effect of ozone on individual main leaf areas (cm3) of NCS and NCR over four harvests

a. Harvest 1

Main Leaf #	NCS		NCR	
	CF	O	CF	O
1	10.39	10.52 ns	7.61	9.15 ns
2	9.12	9.72 ns	5.84	7.91 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

b. Harvest 2

Main Leaf #	NCS		NCR	
	CF	O	CF	O
1	11.05*	8.62	8.92	8.98 ns
2	10.05 ns	8.85	7.02	7.21 ns
3	17.18*	14.13	12.15	13.21 ns
4	13.04 ns	11.40	11.32	12.83 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Continued, next page.

c. Harvest 3

Main Leaf #	NCS		NCR	
	CF	O	CF	O
1	12.15*	9.06	8.71 ns	8.71
2	10.98*	8.41	7.18 ns	7.09
3	18.26*	14.74	12.88 ns	18.24**
4	18.29**	13.60	13.73 ns	13.68
5	16.39 ns	15.29	13.67	14.31 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

d. Harvest 4

Main Leaf #	NCS		NCR	
	CF	O	CF	O
1	-	-	-	-
2	9.98 ns	9.31	6.38 ns	5.65
3	18.24***	13.30	12.01*	10.44
4	18.58**	12.70	13.05 ns	12.22
5	20.13**	14.52	15.34 ns	13.82
6	18.81**	15.43	15.88 ns	14.84
7	18.13 ns	16.21	17.06 ns	16.90

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

Table 48: Effect of ozone on main leaf area (cm3) of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	20.67 ns	20.24	14.36	20.58 ns
2	48.06	42.05 ns	41.99 ns	39.52
3	76.43 ns	63.82	63.83 ns	60.88
4	114.18**	77.34	93.91 ns	88.48

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 49: Effect of ozone on secondary stolon leaf area (cm3) of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	--	--	--	--
2	--	--	--	--
3	16.06 ns	10.98	--	--
4	49.84 ns	33.64	21.90	24.00 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 50: Effect of ozone on total leaf area (cm3) of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	20.67 ns	20.24	14.36	20.58*
2	48.03 ns	42.05	41.99 ns	39.47
3	94.29 ns	75.60	67.14 ns	63.18
4	168.57*	109.96	115.76 ns	113.89

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 51: Effect of ozone on leaf area ratio of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	124.24 ns	111.10	106.05	112.54 ns
2	149.74	164.65 ns	169.72 ns	159.39
3	175.81 ns	173.57	173.08 ns	171.13
4	125.81 ns	121.38	128.97	134.81 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 52: Effect of ozone on specific leaf area ratio of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	367.40 ns	356.78	325.98	332.76 ns
2	448.74	474.68 ns	411.81 ns	410.05
3	506.83*	443.31	449.31 ns	439.14
4	376.58 ns	365.99	378.24	382.60 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 53: Effect of ozone on individual petiole dry weights of NCS and NCR over four harvests

a. Harvest 1

Petiole #	NCS		NCR	
	CF	O	CF	O
3	0.0059	0.0076 ns	0.0051	0.0072 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05

b. Harvest 2

Petiole #	NCS		NCR	
	CF	O	CF	O
3	0.0233*	0.0188	0.0205 ns	0.0203
4	0.0183 ns	0.0156	0.0148 ns	0.0141
5	0.0056 ns	0.0048	0.0052	0.0059 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Continued, next page.

c. Harvest 3

Petiole #	NCS		NCR	
	CF	O	CF	O
3	0.0262 ns	0.0218	0.0226 ns	0.0212
4	0.0262*	0.0203	0.0233 ns	0.0233
5	0.0225 ns	0.0221	0.0192	0.0198 ns
6	0.0128	0.0131 ns	0.0116 ns	0.0107

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

d. Harvest 4

Petiole #	NCS		NCR	
	CF	O	CF	O
3	0.0305***	0.0245	0.0232*	0.0206
4	0.0316**	0.0257	0.0260 ns	0.0250
5	0.0353**	0.0276	0.0266 ns	0.0245
6	0.0346**	0.0280	0.0260 ns	0.0248
7	0.0276*	0.0226	0.0228 ns	0.0226
8	0.0146 ns	0.0116	0.0163 ns	0.0162

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

Table 54: Effect of ozone on total petiole dry weight (grams) of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.0373	0.0406 ns	0.0278	0.0388**
2	0.0839 ns	0.0700	0.0678	0.0702 ns
3	0.1520*	0.1180	0.1170 ns	0.1070
4	0.3180*	0.2230	0.2190 ns	0.2040

CF = carbon filtered air　　O = carbon filtered air plus ozone

ns = not significant at P > .05
 * = significant at P < .05
** = significant at P < .01

Table 55: Effect of ozone on individual petiole lengths (mm) of NCS and NCR over four harvests

a. Harvest 1

Petiole #	NCS		NCR	
	CF	O	CF	O
3	15.18	23.27 ns	21.60	25.18 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

b. Harvest 2

Petiole #	NCS		NCR	
	CF	O	CF	O
3	125.10*	108.00	131.00 ns	117.73
4	73.58 ns	68.00	57.08 ns	46.08

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Continued, next page.

c. Harvest 3

Petiole #	NCS		NCR	
	CF	O	CF	O
3	162.75 ns	147.58	169.00 ns	166.67
4	157.25*	137.33	166.83	170.08 ns
5	134.83 ns	128.00	120.25	125.92 ns
6	57.33	63.08 ns	57.75 ns	38.92

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

d. Harvest 4

Petiole #	NCS		NCR	
	CF	O	CF	O
3	168.83**	143.75	169.83 ns	167.58
4	174.42**	151.75	180.58	181.00 ns
5	168.83 ns	164.83	161.58	164.00 ns
6	143.33	145.08 ns	137.83 ns	132.58
7	89.17 ns	84.17	80.58	90.33 ns
8	24.58 ns	23.62	29.00	37.10 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 56: Effect of ozone on individual internode dry weights (grams) of NCS and NCR over four harvests

a. Harvest 2

Main Leaf #	NCS		NCR	
	CF	O	CF	O
1	-	-	-	-
2	0.0052 ns	0.0043	0.0048 ns	0.0046
3	0.0044 ns	0.0036	0.0038 ns	0.0036
4	0.0045 ns	0.0034	0.0029	0.0036 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

b. Harvest 3

Main Leaf #	NCS		NCR	
	CF	O	CF	O
1	0.0068 ns	0.0058	0.0050 ns	0.0047
2	0.0071*	0.0051	0.0043	0.0045 ns
3	0.0056 ns	0.0051	0.0043	0.0046 ns
4	0.0073 ns	0.0063	0.0041	0.0045 ns
5	0.0082 ns	0.0063	0.0050	0.0051 ns
6	0.0086 ns	0.0066	0.0044	0.0053 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Continued, next page.

c. Harvest 4

Main Leaf #	NCS		NCR	
	CF	O	CF	O
1	0.0128 ns	0.0076	0.0077 ns	0.0065
2	0.0124 ns	0.0090	0.0083 ns	0.0073
3	0.0093 ns	0.0071	0.0072 ns	0.0072
4	0.0117*	0.0086	0.0069 ns	0.0061
5	0.0154**	0.0094	0.0080 ns	0.0077
6	0.0164***	0.0099	0.0092 ns	0.0088
7	0.0186***	0.0088	0.0111 ns	0.0092
8	0.0177**	0.0080	0.0137 ns	0.0107

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

Table 57: Effect of ozone on total stolon dry weight (grams) of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.0184	0.0194 ns	0.0127	0.0174*
2	0.0180 ns	0.0135	0.0136	0.0142 ns
3	0.0461 ns	0.0363	0.0296	0.0313 ns
4	0.1110**	0.0620	0.7800	0.6900 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 58: Effect of ozone on individual internode lengths (mm) of NCS and NCR over four harvests

a. Harvest 2

Internode #	NCS		NCR	
	CF	O	CF	O
1	-	-	-	-
2	6.75	7.08 ns	7.25	7.92 ns
3	7.17 ns	6.92	6.18	6.67 ns
4	9.17 ns	8.82	6.25	7.70 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

b. Harvest 3

Internode #	NCS		NCR	
	CF	O	CF	O
1	4.25	4.42 ns	4.33 ns	4.17
2	7.25**	5.42	5.50 ns	4.83
3	6.75 ns	5.83	5.50	6.09 ns
4	12.67 ns	11.50	7.50	7.58 ns
5	18.67 ns	14.58	12.33 ns	12.17
6	20.67 ns	15.91	11.42	11.55 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Continued, next page.

c. Harvest 4

Internode #	NCS		NCR	
	CF	O	CF	O
1	5.17 ns	4.91	4.17 ns	3.55
2	6.25	6.75 ns	5.58 ns	5.00
3	5.42 ns	5.42	4.92 ns	4.92
4	11.17 ns	9.75	6.17 ns	5.08
5	20.33*	14.25	9.33	9.67 ns
6	21.00**	15.92	13.25 ns	12.33
7	25.67**	15.58	16.00 ns	14.58
8	24.67*	12.58	21.18 ns	18.18

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 59: Effect of ozone on total internode length of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	--	--	--	--
2	28.83 ns	26.17	25.25 ns	24.25
3	72.58 ns	58.25	51.75 ns	48.58
4	125.58**	85.92	86.83 ns	78.52

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 60: Effect of ozone on secondary stolon dry weight to total plant dry weight of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	--	--	--	--
2	--	--	--	--
3	0.0146*	0.0088	--	--
4	0.0667*	0.0366	0.0350	0.0374 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 61: Effect of ozone on branching of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	--	--	--	--
2	--	--	--	--
3	3.33 ns	2.67	2.00 ns	1.50
4	6.08 ns	5.33	4.92	5.42 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 62: Effect of ozone on branch # to node # of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	--	--	--	--
2	--	--	--	--
3	0.518 ns	0.401	0.301 ns	0.248
4	0.686 ns	0.667	0.576	0.621 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 63: Effect of ozone on root to shoot ratio of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.358	0.391 ns	0.381	0.411 ns
2	0.414 ns	0.358	0.310	0.316 ns
3	0.264 ns	0.253	0.229 ns	0.228
4	0.289*	0.246	0.277 ns	0.263

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 64: Effect of ozone on stolon dry weight to total plant dry weight of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.1095 ns	0.1044	0.0916	0.0960 ns
2	0.0550 ns	0.0500	0.0562 ns	0.0557
3	0.0840 ns	0.0820	0.0740	0.0800 ns
4	0.0889 ns	0.0800	0.1310	0.1500 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 65: Effect of ozone on petiole dry weight to total plant dry weight of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.2235 ns	0.2187	0.2071	0.2110 ns
2	0.2590	0.2760 ns	0.2720	0.2860 ns
3	0.2820 ns	0.2620	0.3020 ns	0.2870
4	0.2370	0.262 ns	0.2410 ns	0.2410

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 66: Effect of ozone on root dry weight to total plant dry weight of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.262	0.280 ns	0.275	0.291 ns
2	0.291 ns	0.262	0.236	0.227 ns
3	0.208 ns	0.198	0.185 ns	0.185
4	0.223 ns	0.206	0.215 ns	0.208

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 67: Effect of ozone on mature leaf dry weight to total plant dry weight of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.338 ns	0.310	0.324	0.338 ns
2	0.340	0.355 ns	0.415 ns	0.390
3	0.347	0.391*	0.385	0.390 ns
4	0.334 ns	0.331	0.341	0.353 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 68: Effect of ozone on immature leaf dry weight to total plant dry weight of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.0682	0.0839 ns	0.0884 ns	0.0634
2	0.0484 ns	0.0321	0.0233	0.0364 ns
3	0.1052 ns	0.0460	0.0390	0.0470 ns
4	0.0598	0.0637 ns	0.0651 ns	0.0633

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 69: Effect of ozone on total leaf dry weight to total plant dry weight of NCS and NCR over four harvests

Harvest	NCS		NCR	
	CF	O	CF	O
1	0.338 ns	0.310	0.324	0.338 ns
2	0.340	0.355 ns	0.415 ns	0.390
3	0.518 ns	0.401	0.301 ns	0.248
4	0.334 ns	0.349	0.341	0.353 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 70: Difference in total plant dry weight (grams) between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.172*	0.137	0.186 ns	0.183
2	0.326 ns	0.250	0.257 ns	0.248
3	0.543*	0.391	0.446 ns	0.379
4	1.350*	0.904	0.879 ns	0.851

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 71: Difference in total root dry weight (grams) between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.0471 ns	0.0378	0.0521	0.0533 ns
2	0.0970*	0.0590	0.0680 ns	0.0565
3	0.1110**	0.0730	0.0880 ns	0.0710
4	0.3030**	0.1820	0.1930 ns	0.1740

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 72: Difference in total shoot dry weight (grams) between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.1250*	0.0987	0.1336 ns	0.1300
2	0.2290 ns	0.1910	0.1890	0.1920 ns
3	0.4320*	0.3170	0.3560 ns	0.3080
4	1.0400*	0.7100	0.7100 ns	0.6760

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 73: Difference in total leaf number between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	3.17	3.17	3.50	3.58 ns
2	7.08*	5.50	6.50	5.50
3	14.33*	10.67	12.58*	9.67
4	24.67 ns	20.33	20.58	21.67 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 74: Difference in total main leaf number between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	3.42 ns	3.17	3.42	3.58 ns
2	5.33 ns	5.16	4.92	5.16 ns
3	6.92	7.00 ns	7.00	7.00 ns
4	9.00	9.00 ns	8.58	9.25*

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 75: Difference in total mature main leaf number between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	2.08 ns	2.08	2.00	2.33*
2	3.75	4.17*	3.83	3.83 ns
3	5.17	5.58 ns	5.33	5.33 ns
4	7.08	7.42 ns	6.83	7.42*

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 76: Difference in total immature main leaf number between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	1.08 ns	1.08	1.42 ns	1.25
2	1.58 ns	1.00	1.00	1.33 ns
3	1.75 ns	1.42	1.67	1.67 ns
4	1.92 ns	1.58	1.75 ns	1.58

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 77: Difference in total mature secondary leaf number between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	--	--	--	--
2	0.33 ns	0	0.33	0.08 ns
3	3.08*	1.17	2.67*	0.83
4	7.50*	4.33	5.42 ns	5.33

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 78: Difference in total immature secondary leaf number between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	--	--	--	--
2	1.50**	0.17	1.08*	0.25
3	4.17*	2.33	2.92 ns	1.92
4	8.25 ns	6.67	6.58	6.83 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 79: Difference in total leaf dry weight (grams) between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.0688 ns	0.0557	0.0729	0.0739 ns
2	0.1240 ns	0.1100	0.0980	0.1050 ns
3	0.2170*	0.1660	0.1940 ns	0.1650
4	0.5300*	0.3680	0.3600 ns	0.3560

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 80: Difference in total mature leaf dry weight (grams) between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.0576*	0.0440	0.0566	0.0622 ns
2	0.1080 ns	0.1040	0.0900	0.0963 ns
3	0.1880 ns	0.1500	0.1740 ns	0.1470
4	0.4490*	0.3100	0.3040	0.3040 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 81: Difference in total immature leaf dry weight (grams) between NCS and NCR in two air treatments over four_harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.0112	0.0117 ns	0.0163 ns	0.0117
2	0.0170 ns	0.0060	0.0082	0.0090 ns
3	0.0294 ns	0.0160	0.0197 ns	0.0180
4	0.0810 ns	0.0580	0.0580 ns	0.0520

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 82: Difference in total main leaf dry weight (grams) between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.0688*	0.0557	0.0736	0.0739 ns
2	0.1160	0.1190*	0.0980	0.1060 ns
3	0.1780 ns	0.1550	0.1760 ns	0.1540
4	0.3210 ns	0.2560	0.2280	0.2330 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 83: Difference in individual main leaf dry weights (grams) between NCS and NCR in two air treatments over four harvests

a. Harvest 1

Main Leaf	CF		O	
#	NCS	NCR	NCS	NCR
1	0.0309*	0.0243	0.0312 ns	0.0299
2	0.0236 ns	0.0174	0.0254 ns	0.0235
3	0.0142 ns	0.0140	0.0169	0.0195 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

b. Harvest 2

Main Leaf	CF		O	
#	NCS	NCR	NCS	NCR
1	0.0285 ns	0.0254	0.0266 ns	0.0260
2	0.0230 ns	0.0187	0.0218 ns	0.0194
3	0.0328 ns	0.0273	0.0281	0.0293 ns
4	0.0228	0.0389 ns	0.0169	0.0221 ns
5	0.0079	0.0081 ns	0.0059	0.0124 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Continued, next page.

c. Harvest 3

Main Leaf	CF		O	
#	NCS	NCR	NCS	NCR
1	0.0334 ns	0.0248	0.0305 ns	0.0243
2	0.0266*	0.0195	0.0266*	0.0198
3	0.0392*	0.0294	0.0414*	0.0301
4	0.0335 ns	0.0294	0.0321 ns	0.0294
5	0.0277 ns	0.0276	0.0281	0.0292 ns
6	0.0168	0.0198 ns	0.0169	0.0192 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

d. Harvest 4

Main Leaf	CF		O	
#	NCS	NCR	NCS	NCR
1	-	-	-	-
2	0.0347**	0.0201	0.0325**	0.0178
3	0.0561***	0.0336	0.0495***	0.0321
4	0.0500***	0.0357	0.0394 ns	0.0360
5	0.0517**	0.0408	0.0386 ns	0.0358
6	0.0477*	0.0411	0.0367	0.0400 ns
7	0.0464 ns	0.0430	0.0383	0.0436 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

Table 84: Difference in individual main leaf areas (cm3) between NCS and NCR in two air treatments over four harvests

a. Harvest 1

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	10.39**	7.61	10.52 ns	9.15
2	9.12*	5.84	9.72 ns	7.91

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

b. Harvest 2

Main Leaf	CF		O	
#	NCS	NCR	NCS	NCR
1	11.05*	8.92	8.62	8.98 ns
2	10.05**	7.02	8.85 ns	7.21
3	17.18**	12.15	14.13 ns	13.21
4	13.04 ns	11.32	11.40	12.83 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Continued, next page.

c. Harvest 3

Main Leaf	CF		O	
#	NCS	NCR	NCS	NCR
1	12.15*	8.71	9.06 ns	8.71
2	10.98**	7.18	8.41 ns	7.09
3	18.26**	12.88	14.74	18.24 ns
4	18.29**	13.73	13.60	13.68 ns
5	16.39 ns	13.67	15.29 ns	14.31

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

d. Harvest 4

Main Leaf	CF		O	
#	NCS	NCR	NCS	NCR
1	--	--	--	--
2	9.98**	6.38	9.31**	5.65
3	18.24****	12.01	13.30**	10.44
4	18.58**	13.05	12.70 ns	12.22
5	20.13**	15.34	14.52 ns	13.82
6	18.81*	15.88	15.43 ns	14.84
7	18.13 ns	17.06	16.21	16.90 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001
**** = significant at P < .0001

Table 85: Difference in main leaf area (cm3) between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	20.67*	14.36	20.24	20.58 ns
2	48.06 ns	41.99	42.05 ns	39.52
3	76.43 ns	63.83	63.82 ns	60.88
4	114.18 ns	93.91	77.34	88.48 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 86: Difference in secondary stolon leaf area (cm3) between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	--	--	--	--
2	--	--	--	--
3	--	--	--	--
4	49.84*	21.90	33.64 ns	24.00

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 87: Difference in total leaf area (cm3) between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	20.67*	14.36	20.24	20.58 ns
2	48.03 ns	41.99	42.05 ns	39.47
3	94.29*	67.14	75.60 ns	63.18
4	168.57	115.76	109.96	113.89 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 88: Difference in leaf area ratio between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	124.24*	106.05	111.10	112.54 ns
2	149.74	169.72 ns	164.65 ns	159.39
3	175.81 ns	173.08	173.57 ns	171.13
4	125.81	128.97 ns	121.38	134.81 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 89: Difference in specific leaf area ratio between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	367.40**	325.98	358.08*	332.76
2	448.74 ns	411.81	471.89*	410.05
3	506.83*	449.31	449.31ns	439.14
4	376.58	378.24 ns	365.99	382.60 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 90: Difference in total petiole dry weight (grams) between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.0373*	0.0278	0.0406 ns	0.0388
2	0.0839 ns	0.0678	0.0700	0.0702 ns
3	0.1520*	0.1170	0.1180 ns	0.1070
4	0.3180*	0.2190	0.2230 ns	0.2040

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 91: Difference in individual petiole dry weights (grams) between NCS and NCR in two air treatments over four harvests

a. Harvest 1

Petiole #	CF		O	
	NCS	NCR	NCS	NCR
3	0.0059 ns	0.0051	0.0076 ns	0.0072

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

b. Harvest 2

Petiole #	CF		O	
	NCS	NCR	NCS	NCR
3	0.0233 ns	0.0205	0.0188	0.0203 ns
4	0.0183 ns	0.0148	0.0156 ns	0.0141
5	0.0056 ns	0.0052	0.0048	0.0059 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Continued, next page.

c. Harvest 3

Petiole #	CF		O	
	NCS	NCR	NCS	NCR
3	0.0262 ns	0.0226	0.0218 ns	0.0212
4	0.0262 ns	0.0233	0.0203	0.0233 ns
5	0.0225 ns	0.0192	0.0221 ns	0.0198
6	0.0128 ns	0.0116	0.0131 ns	0.0107

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05

d. Harvest 4

Petiole #	CF		O	
	NCS	NCR	NCS	NCR
3	0.0305***	0.0232	0.0245**	0.0206
4	0.0316*	0.0260	0.0257 ns	0.0250
5	0.0353**	0.0266	0.0276 ns	0.0245
6	0.0346**	0.0260	0.0280 ns	0.0248
7	0.0276*	0.0228	0.0226 ns	0.0226
8	0.0146	0.0163 ns	0.0116	0.0162 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001
**** = significant at P < .0001

Table 92: Difference in individual petiole lengths (mm) between NCS and NCR in two air treatments over four harvests

a. Harvest 1

Petiole #	CF		O	
	NCS	NCR	NCS	NCR
3	15.18	21.60 ns	23.27	25.18 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05

b. Harvest 2

Petiole #	CF		O	
	NCS	NCR	NCS	NCR
3	125.10	131.00 ns	108.00	117.73 ns
4	73.58*	57.08	68.00 ns	46.08

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Continued, next page.

c. Harvest 3

Petiole #	CF		O	
	NCS	NCR	NCS	NCR
3	162.75	169.00 ns	147.58	166.67*
4	157.25	166.83 ns	137.33	170.08**
5	134.83 ns	120.25	128.00 ns	125.92
6	57.33	57.75 ns	63.08 ns	38.92

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

d. Harvest 4

Petiole #	CF		O	
	NCS	NCR	NCS	NCR
3	168.83	169.83 ns	143.75	167.58**
4	174.42	180.58 ns	151.75	181.00***
5	168.83 ns	161.58	164.83 ns	164.00
6	143.33 ns	137.83	145.08 ns	132.58
7	89.17 ns	80.58	84.17	90.33 ns
8	24.58	29.00 ns	23.62	37.10 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < . 001

Table 93: Difference in total stolon dry weight (grams) between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.0184**	0.0127	0.0194 ns	0.0174
2	0.0180 ns	0.0136	0.0135	0.0142 ns
3	0.0461*	0.0296	0.0363 ns	0.0313
4	0.1110*	0.7800	0.0620	0.6900 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 94: Difference in individual internode dry weights (grams) between NCS and NCR in two air treatments over four harvests

a. Harvest 2

Internode #	CF		O	
	NCS	NCR	NCS	NCR
1	-	-	-	-
2	0.0052 ns	0.0048	0.0043	0.0046 ns
3	0.0044 ns	0.0038	0.0036	0.0036 ns
4	0.0045*	0.0029	0.0034	0.0036 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

b. Harvest 3

Internode #	CF		O	
	NCS	NCR	NCS	NCR
1	0.0068 ns	0.0050	0.0058 ns	0.0047
2	0.0071**	0.0043	0.0051 ns	0.0045
3	0.0056 ns	0.0043	0.0051 ns	0.0046
4	0.0073**	0.0041	0.0063 *	0.0045
5	0.0086*	0.0050	0.0063 ns	0.0051
6	0.0086*	0.0044	0.0066 ns	0.0053

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Contiued, next page.

c. Harvest 4

Internode #	CF		O	
	NCS	NCR	NCS	NCR
1	0.0128*	0.0077	0.0076 ns	0.0065
2	0.0124*	0.0083	0.0090 ns	0.0073
3	0.0093 ns	0.0072	0.0071	0.0072 ns
4	0.0117**	0.0069	0.0086 ns	0.0061
5	0.0154**	0.0080	0.0094 ns	0.0077
6	0.0164***	0.0092	0.0099 ns	0.0088
7	0.0186***	0.0111	0.0088	0.0092 ns
8	0.0177 ns	0.0137	0.0088	0.0107 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

Table 95: Difference in individual internode lengths (mm) between NCS and NCR in two air treatments over four harvests

a. Harvest 2

Internode #	CF		O	
	NCS	NCR	NCS	NCR
1	--	--	--	--
2	6.75	7.25 ns	7.08	7.92 ns
3	7.17 ns	6.18	6.92 ns	6.67
4	9.17**	6.25	8.82 ns	7.70

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

b. Harvest 3

Internode #	CF		O	
	NCS	NCR	NCS	NCR
1	4.25	4.33 ns	4.42 ns	4.17
2	7.25**	5.50	5.42 ns	4.83
3	6.75 ns	5.50	5.83	6.09 ns
4	12.67**	7.50	11.50*	7.58
5	18.67*	12.33	14.58 ns	12.17
6	20.67*	11.42	15.91 ns	11.55

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Continued, next page.

c. Harvest 3

Internode #	CF		O	
	NCS	NCR	NCS	NCR
1	5.17 ns	4.17	4.91 ns	3.55
2	6.25 ns	5.58	6.75 ns	5.00
3	5.42 ns	4.92	5.42 ns	4.92
4	11.17*	6.17	9.75*	5.08
5	20.33***	9.33	14.25*	9.67
6	21.00**	13.25	15.92*	12.33
7	25.67**	16.00	15.58 ns	14.58
8	24.67 ns	21.18	12.58	18.18 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01
*** = significant at P < .001

Table 96: Difference in total internode length (mm)between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	--	--	--	--
2	28.83 ns	25.25	26.17 ns	24.25
3	72.58*	51.75	58.25 ns	48.58
4	125.58*	86.83	85.92 ns	78.52

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 97: Difference in branching between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	--	--	--	--
2	--	--	--	--
3	3.33 ns	2.00	2.67 ns	1.50
4	6.08 ns	4.92	5.33	5.42 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 98: Difference in branch number to node number between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	--	--	--	--
2	--	--	--	--
3	0.518**	0.301	0.401*	0.248
4	0.686*	0.576	0.667 ns	0.621

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 99: Difference in secondary stolon dry weight (grams) between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	--	--	--	--
2	--	--	--	--
3	--	--	--	--
4	0.0667**	0.0350	0.0366	0.0374 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 100: Difference in root to shoot ratio between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.358	0.381 ns	0.391	0.411 ns
2	0.414 ns	0.310	0.358 ns	0.316
3	0.264 ns	0.229	0.253 ns	0.228
4	0.289 ns	0.277	0.246	0.263 ns

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 101: Difference in stolon dry weight to total plant dry weight between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.1095 ns	0.0916	0.1044 ns	0.0960
2	0.0550	0.0562 ns	0.0500	0.0557 ns
3	0.0840 ns	0.0740	0.0820 ns	0.0800
4	0.0889	0.1310 ns	0.0800	0.1500*

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 102: Difference in petiole dry weight to total plant dry weight between NCS and NCR in two air treatments over four_harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.2235 ns	0.2071	0.2187 ns	0.2110
2	0.2590	0.2720 ns	0.2760	0.2860 ns
3	0.2820	0.3020 ns	0.2620	0.2870 ns
4	0.2370	0.2410 ns	0.2620 ns	0.2410

CF = carbon filtered air O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 103: Difference in root dry weight to total plant dry weight between NCS and NCR in two air treatments over four_harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.262	0.275 ns	0.280	0.291 ns
2	0.291**	0.236	0.262 ns	0.227
3	0.208*	0.185	0.198 ns	0.185
4	0.223 ns	0.215	0.206	0.208 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

Table 104: Difference in immature leaf dry weight to total plant dry weight between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.0682	0.0884 ns	0.0839 ns	0.0634
2	0.0484 ns	0.0233	0.0321	0.0364 ns
3	0.0520 ns	0.0390	0.0460	0.0470 ns
4	0.0598	0.0651 ns	0.0637 ns	0.0633

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05

Table 105: Difference in mature leaf dry weight to total plant dry weight between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.338 ns	0.324	0.310	0.388 ns
2	0.340	0.415*	0.355	0.390 ns
3	0.347	0.385 ns	0.391 ns	0.390
4	0.334	0.341 ns	0.331	0.353 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05

Table 106: Difference in total leaf dry weight to total plant dry weight between NCS and NCR in two air treatments over four harvests

Harvest	CF		O	
	NCS	NCR	NCS	NCR
1	0.338 ns	0.324	0.310	0.388 ns
2	0.340	0.415*	0.355	0.390 ns
3	0.518**	0.301	0.401*	0.248
4	0.334	0.341 ns	0.349	0.353 ns

CF = carbon filtered air   O = carbon filtered air plus ozone

ns = not significant at P > .05
* = significant at P < .05
** = significant at P < .01

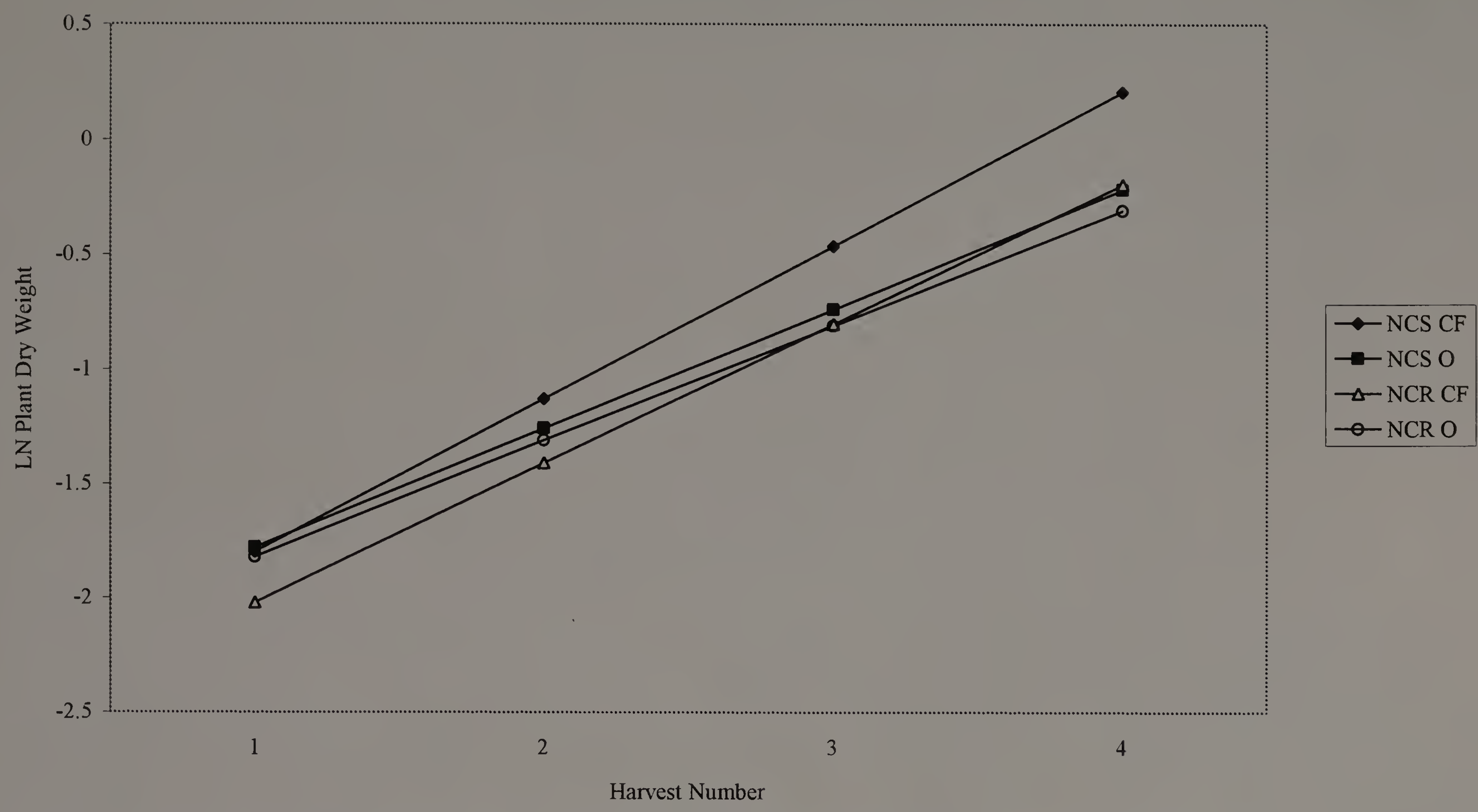

Figure 37: Plant total dry weight (grams) from NCS and NCR grown in carbon filtered air (CF) or carbon filtered air plus ozone (O) as a function of harvests.

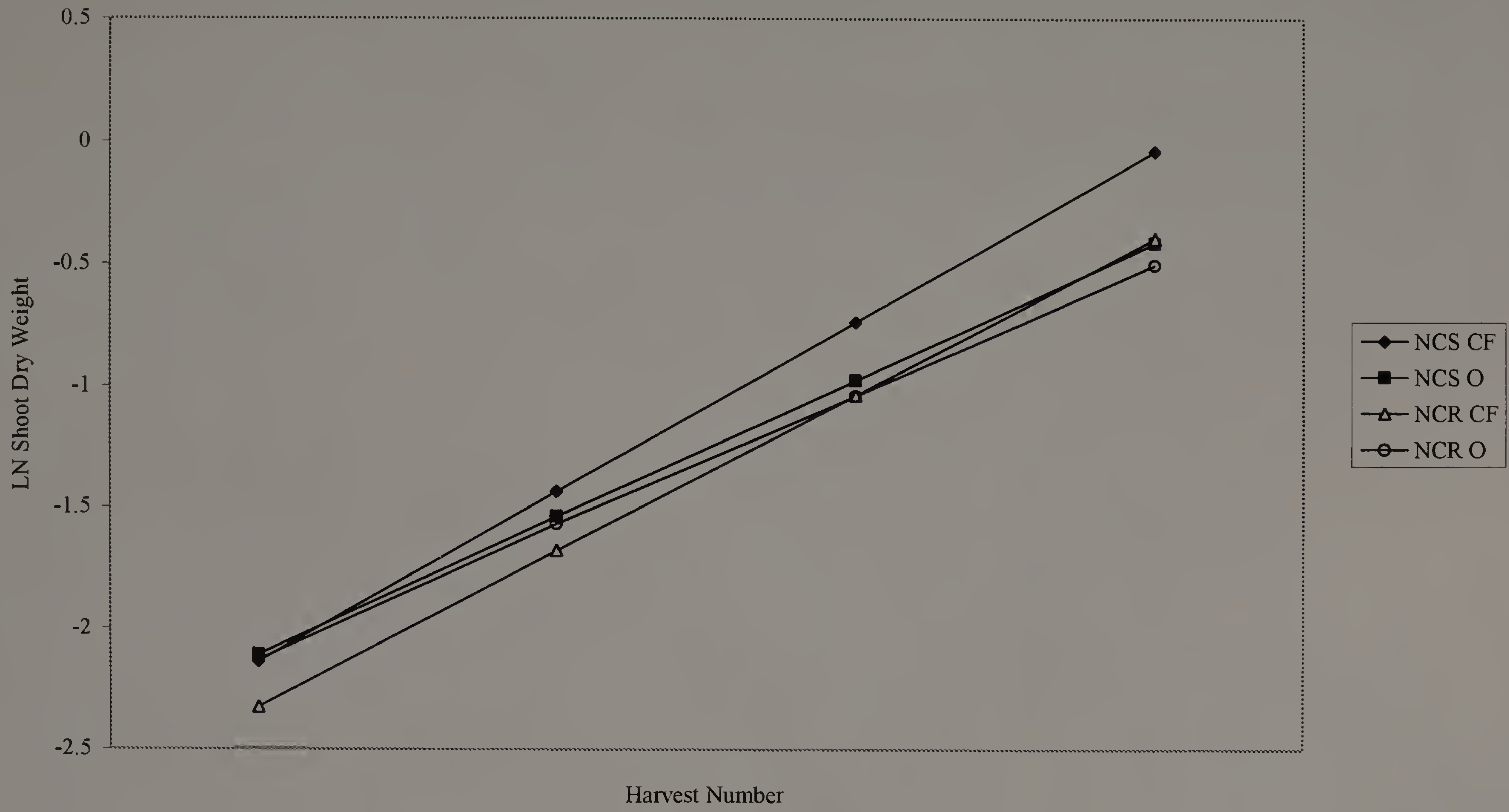

Figure 38: Shoot total dry weight (grams) from NCS and NCR grown in carbon filtered air (CF) or carbon filtered air plus ozone (O) as a function of harvests.

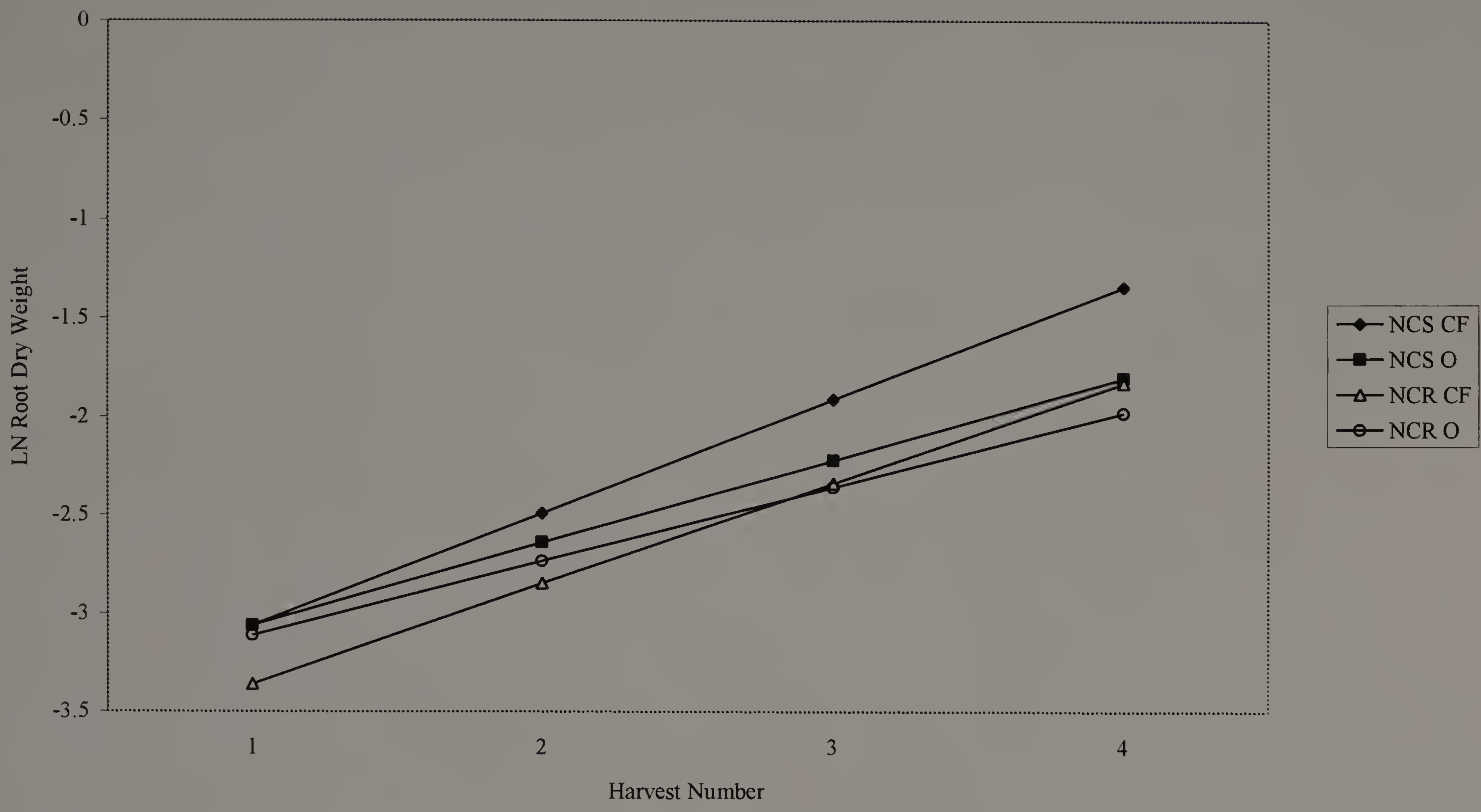

Figure 39: Root total dry weight (grams) from NCS and NCR grown in carbon filtered air (CF) or carbon filtered air plus ozone (O) as a function of harvests.

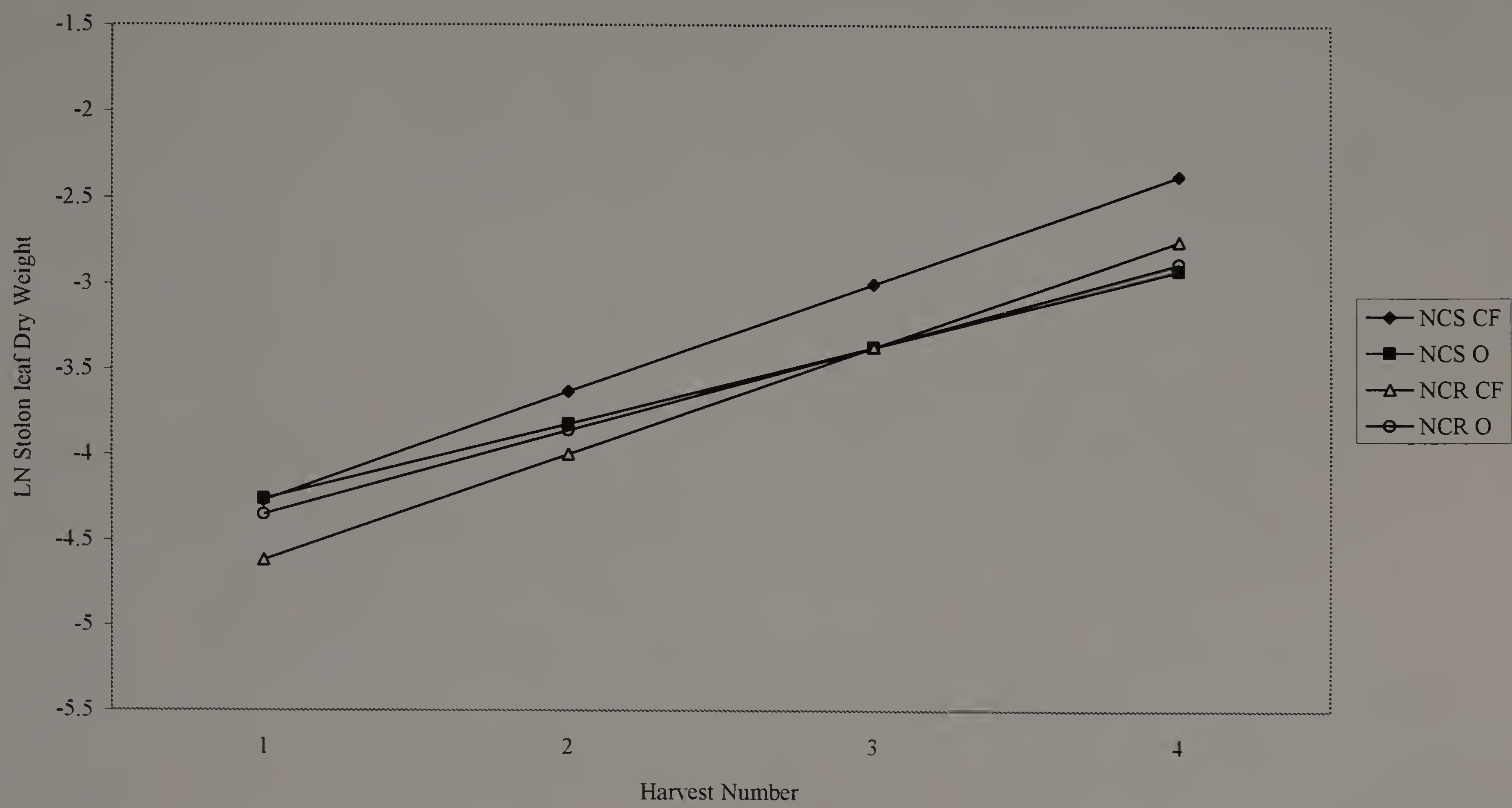

Figure 40: Stolon total dry weight (grams) from NCS and NCR grown in carbon filtered air (CF) or carbon filtered air plus ozone (O) as a function of harvests.

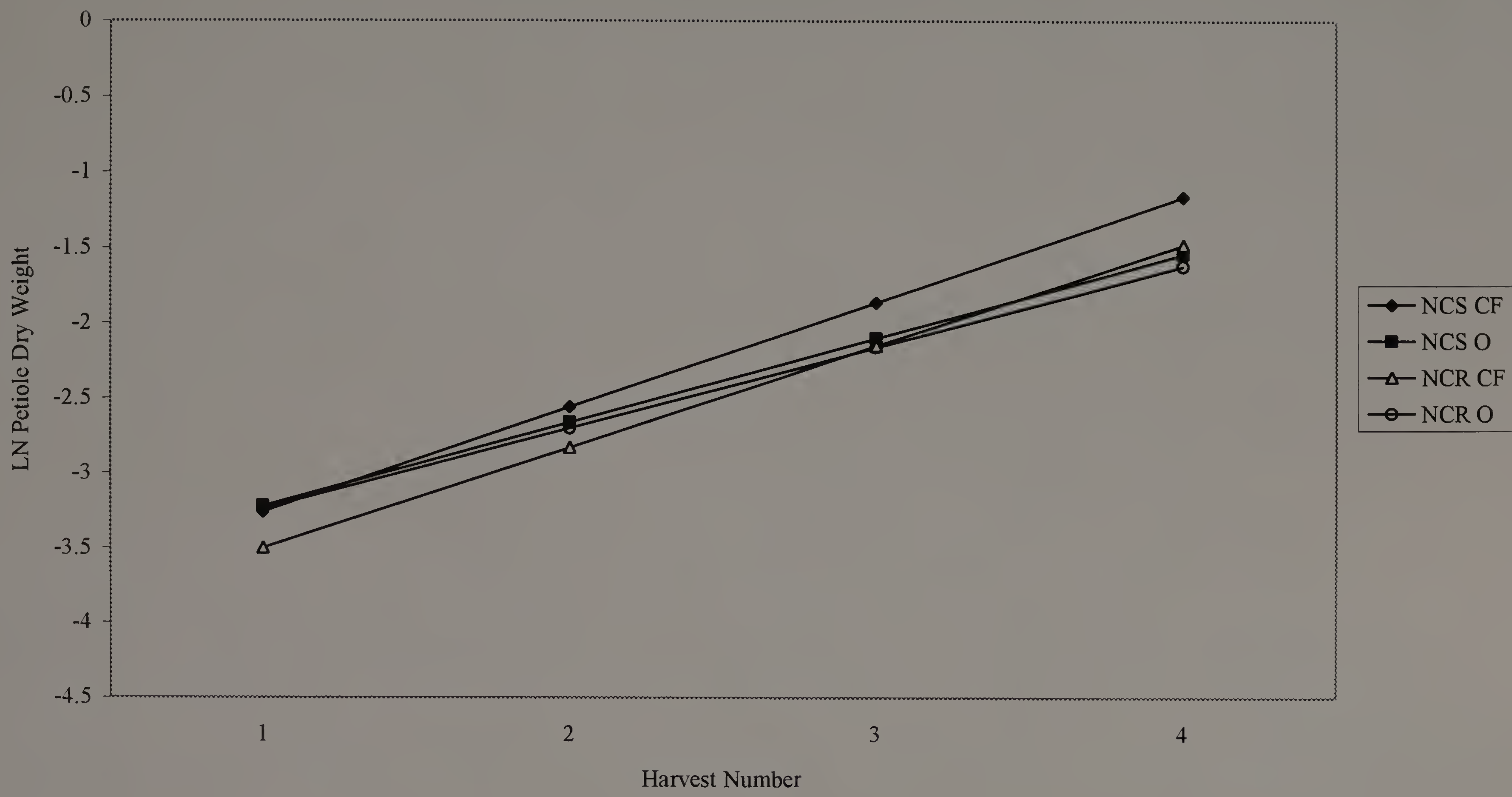

Figure 41: Petiole total dry weight (grams) from NCS and NCR grown in carbon filtered air (CF) or carbon filtered air plus ozone (O) as a function of harvests.

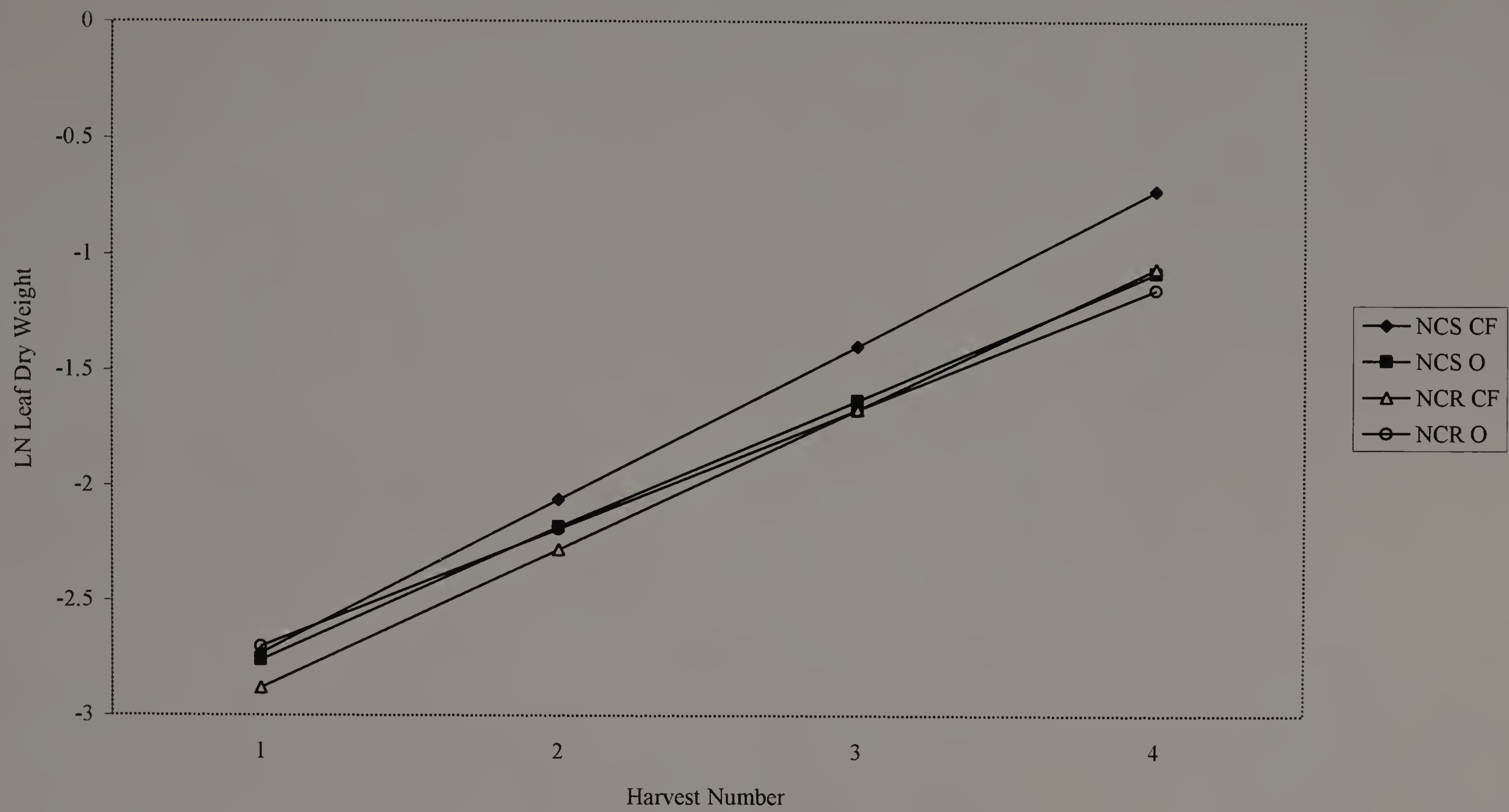

Figure 42: Leaf total dry weight (grams) from NCS and NCR grown in carbon filtered air (CF) or carbon filtered air plus ozone (O) as a function of harvests.

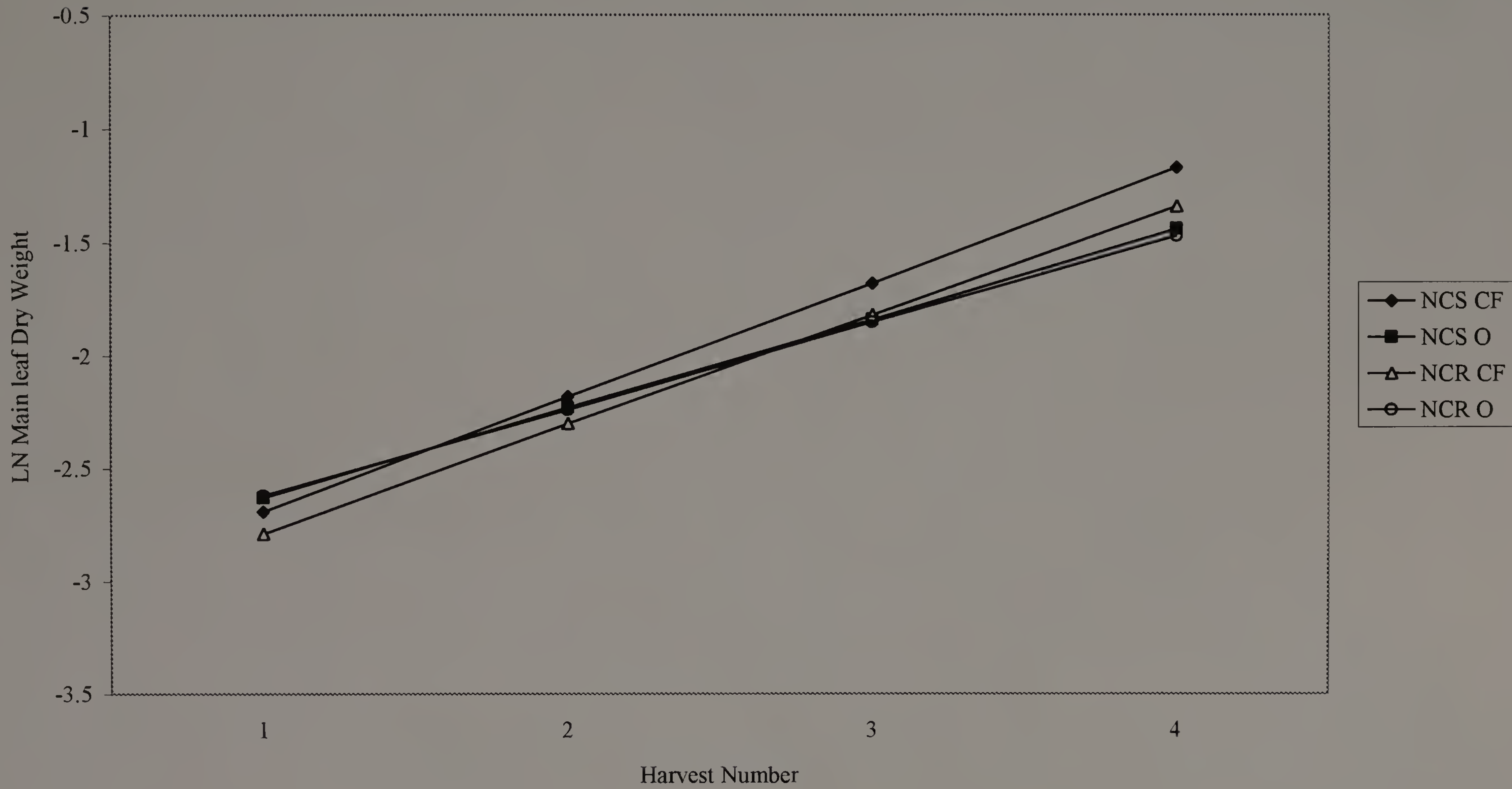

Figure 43: Main leaf total dry weight (grams) from NCS and NCR grown in carbon filtered air (CF) or carbon filtered air plus ozone (O) as a function of harvests.

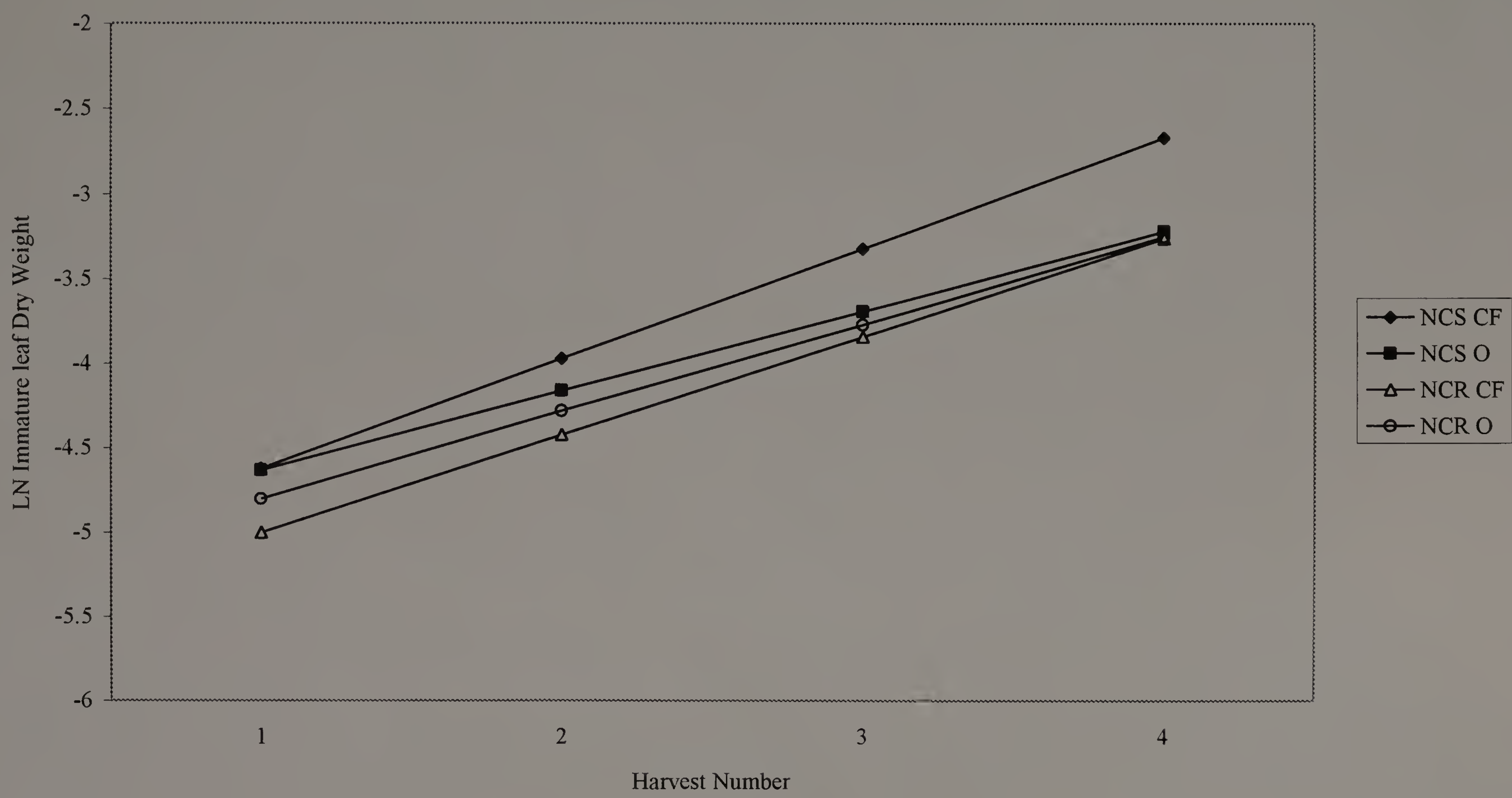

Figure 44: Immature leaf total dry weight (grams) from NCS and NCR grown in carbon filtered air (CF) or carbon filtered air plus ozone (O) as a function of harvests.

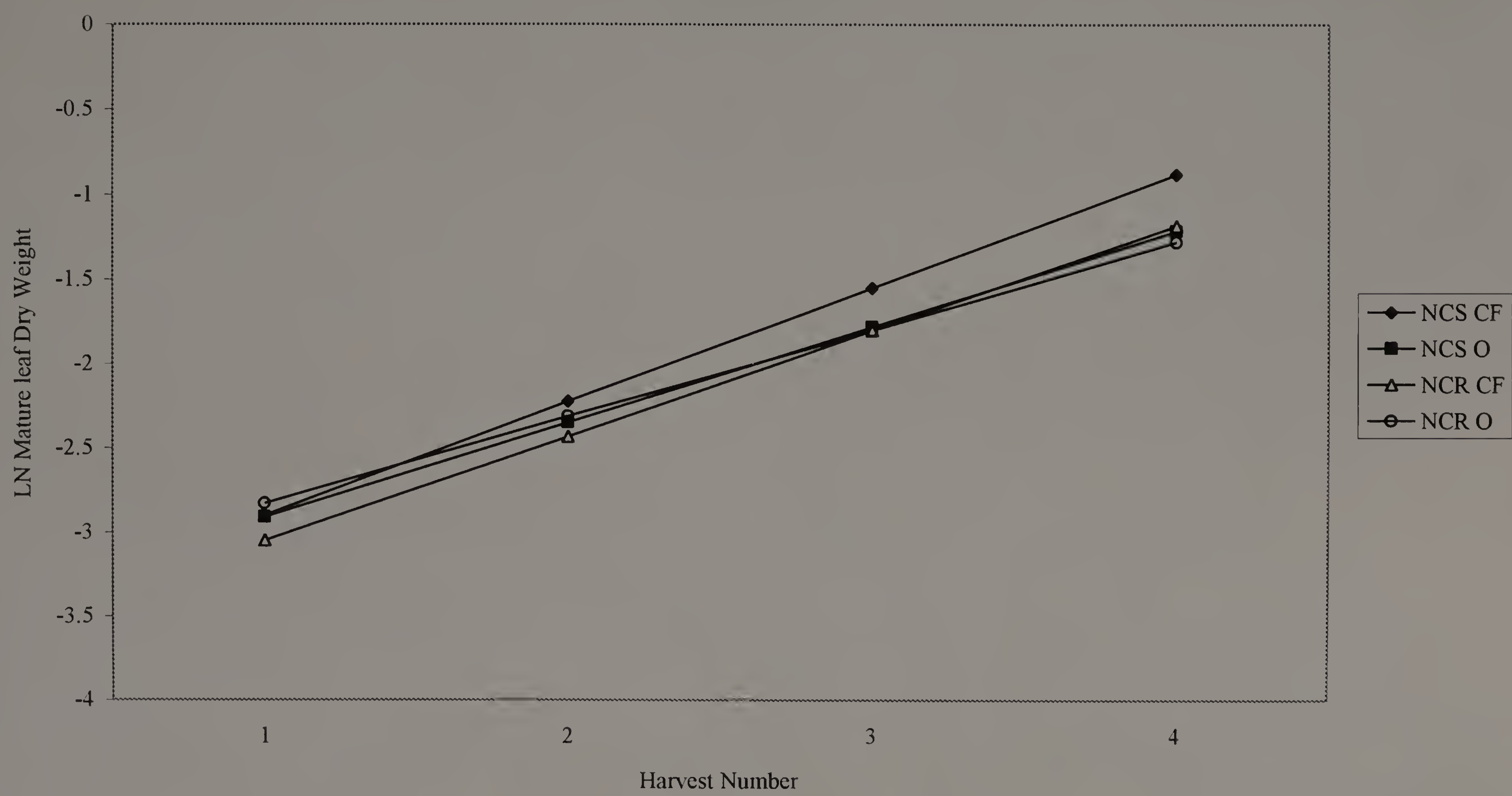

Figure 45: Mature leaf total dry weight (grams) from NCS and NCR grown in carbon filtered air (CF) or carbon filtered air plus ozone (O) as a function of harvests.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

There have been numerous investigations on the effect of ozone on the NCR and NCS clones of white clover. Most of these studies have focused on the influence of ozone on production of foliage (30, 33), survival in mixed species populations (35, 63), and interaction with disease (29). In this study, the effect of ozone on the individual organs was observed. The effect of ozone on the growth of NCR and NCS has not been examined in detail until now. Long term exposure to ozone led to reductions in growth of both clones. All organs were affected by ozone. Stolon length, petiole length, leaf area, and all organ dry weights were, generally, reduced by exposure to ozone. The impact of ozone on the organs followed a domino effect. Leaves are the first organs injured by ozone. This results in a reduction in the production of assimilates in that leaf. These assimilates were to be used by the petiole and the stolon to increase size and by the apical meristem in the development and expansion of new leaves (9, 13, 14). The lower availability of assimilates leads to decreased stolon and petiole lengths and decreased surface area of new leaves. When these new leaves are damaged, the supply of assimilates is further reduced. This results in even greater reductions in organ growth. This decrease can be best explained by looking at how ozone influences the growth of NCS and NCR. The impact of ozone on the two clones can be separated into two responses, 1) changes in growth to compensate for reduction of photosynthesis and 2) changes in biomass partitioning.

Both clones followed two stages of vegetative growth when exposed to growth. The first was a stimulation of growth indicated by an increase in main leaf number and individual leaf area. The clones may have changed their physiology to better adapt to ozone. Mehlhorn (1991) found that *Pisum sativum* adapted to high concentrations of ozone by reducing the rate of ethylene formation. These plants had a higher yield in the nonfiltered air treatment than those growing in the carbon filtered air treatment. In another study, *Phaseolus vulgaris* L. cv nerina developed more leaves when exposed to ozone (54). While ozone increased main leaf numbers in both clones, the mean number of immature and mature main leaves per plant differed between the clones. NCS had more immature and less mature main leaves when exposed to ozone. This suggests that photoassimilate was not being translocated to aid in the development of the younger leaves. Similar results were found with alfalfa (17). Alfalfa plants exposed to ozone retained photosynthate in older established leaves and was not used in the development of new leaves. NCR plants, however, had greater numbers of both mature and immature main leaves when exposed to ozone. NCR is less sensitive to ozone. The extra assimilate produced when plants were exposed to ozone was used for the production and expansion of new leaves.

The stimulation in growth ended by the second week. The main leaf number of NCR was the same for both treatments. NCS, however, had a reduced main leaf number in the ozone treatment compared to plants grown in the carbon filtered air treatment. Individual leaf area was still greatest for NCR in the ozone treatment, but NCS experienced reductions in individual leaf area when exposed to ozone. The ratio of immature to mature main leaves also changed for both clones in the ozone treatment. NCS now had more mature and less immature leaves. Under constant exposure to ozone, leaves would be injured just as they are reaching the rate of maximum expansion and ultimately die. In order to keep this loss to a minimum, NCS increased the rate of development of main leaves, but decreased the time allotted for expansion. This would also explain the reduction in leaf size. Immediate opening of folded leaves probably leads to reduced area per leaf. Since final lamina area is largely a product of the time over which the leaf is able to expand while unfolding (Brougham 1958). The premature loss of photosynthesizing surfaces due to ozone injury and subsequent reduction in the area of future leaves is similar to studies done by Carlson (21). Carlson found that continuous removal of white clover leaves at stage 0.9 led to an increased production rate of subsequent leaves, but these leaves had lower areas. The continuous injury by ozone and smaller leaf areas led NCS to have a lower main leaf number by the end of the fourth week. NCR also modified the production of main leaves when exposed to ozone. By the second week, ozonated plants had fewer mature and more immature main leaves compared to plants grown in the carbon filtered air treatment. This suggests that NCR was slowing down leaf development and increasing the period of leaf development and expansion. This would explain the increased individual main leaf area detected in plants grown in the ozone treatment. Cooley (17) found that alfalfa plants exposed to ozone had fewer main leaves, but with larger areas. Photosynthate produce by these leaves was not being translocated to new leaves, thus reducing the rate of leaf development. By the end of the fourth week, experiments two and three differed in the ratio of immature to mature leaf numbers.

In experiment three, the number of immature and mature main leaves were equal in both air treatments. In experiment two, there were less immature and mature main leaves in the ozone treatment. In experiment two, main leaves in the ozone treatment had larger leaf areas, while in experiment three, ozone reduce main leaf area. The only difference between the experiments was that plants in experiment two produced flowers and had less secondary stolons. Secondary stolons can translocate assimilate from the source leaves at any time, even when the leaves on the secondary stolons are mature. The translocation of assimilates from the main leaves would result in less energy for leaf expansion. Flowers translocate assimilate from the main leaves during flower development and seed set (26). After flower development and before fertilization, translocation of assimilate is minimum. The lack of demand allowed more assimilate to remain in the leaf, thus allowing for more expansion. This would explain the decreased leaf production rate in experiment two. Photosynthesis is driven by sink demand. In experiment two, main leaves are larger in the ozone treatment. The extra leaf area and reduced number of secondary stolons would mean that the plant would not have to produce as much assimilate to satisfy demand, thus leaf production would slow down.

In addition to changes in growth, the pattern of biomass partitioning was also altered by ozone in both clone. The major source of assimilate for white clover is the fully mature leaves (7). Sinks for the assimilate increase with plant growth. Initially, the only sinks were the apical meristem of the main stolon and the roots. As the plants grew, additional sinks appear in the form of secondary stolons and flowers. The destination of assimilate from the source leaf is generally to the nearest sink (15). The further away from the source, the less assimilate a sink will receive. Ozone reduces the translocation of photosynthesis from leaves to sinks in two ways, 1) direct damage to the tissue resulting in a reduced production of photosynthesis (50) and 2) increased use of photosynthates within the leaf to repair damage caused by ozone (24).

Initially, the sinks, unexpanded leaves and roots, of NCS had an increase in the percent of dry matter allotted to them when exposed to ozone. NCR also showed an increase in the percentage of dry matter partitioned to the roots, but instead of an increase in dry matter to the unexpanded leaves, there was an increase to the mature leaves. In NCS, the percent difference in dry matter allotted to mature leaves, thirty five percent was much greater than the difference found in the roots, five percent. This is similar to young bean plants, which have been shown to allocate more assimilate to the newly expanded leaves when exposed to ozone. In NCR, the percent increases in dry matter allocation to the roots and main leaves was about the same, five percent. In this case, the mature leaves may have been holding photosynthate and not translocating it to the younger leaves. This could be indicated in the decrease in percent dry matter allocated to the immature leaves. While more immature leaves were present in the ozone treatment, they had lower dry weights than those found in the carbon filtered air treatment. Both clones also showed differences in the amount of dry matter partitioned to the stolons between air treatments. In the ozone treatment, the percentage of dry matter allocated to the stolon of NCR increased by five percent. The percentage of dry matter allocated to the stolon of NCS decreased by five percent in the ozone treatment. This also suggests that differences between clones in the translocation of assimilates occurs. In NCS, the decrease in stolon dry matter and increase in dry matter in unexpanded leaves suggests that the clone is favoring new leaf production over carbohydrate storage. In NCR, the increase in percentage of dry matter to the stolon and mature leaves and the decrease to unexpanded leaves would indicate allocation of biomass was favored for established leaves and stolons.

After this initial stimulation, the root to shoot ratio showed a declining trend when either clone was exposed to ozone. Roots are the most sensitive organs to ozone. They are not directly damaged by ozone (8). However, ozone can reduce the amount of assimilate received by the roots via the leaves. The lower leaves supply the roots with most of its assimilates. The premature senescence of these leaves may explain the decrease in root dry weight. The development of secondary stolons and increased distances from the roots to active sources would also affect the translocation of assimilate to the roots. All experiments, except experiment one showed a lower root to shoot ratio at the end of twenty eight days when either clone was exposed to ozone. Both clones in experiment one had higher root to shoot ratios in the ozone treatment. The plants of both clones, in the carbon filtered air treatment, became potbound before the end of the experiment. This would inhibit root growth and hence result in lower root to shoot ratios.

In the upper part of the plant of both clones, response to ozone manifested as a trend to increase the dry weight of the leaves and to decrease dry weight allotted to the stolons and secondary stolons. This is similar to the results found by Heagle (34). Ozone causes a reduction in photosynthesis. Plants compensate for this loss by producing more leaves. Chapman (1990) found that reductions in the photosynthesis of white clover due to shading or defoliation led to similar results. Carbon was exported acropetally from the source leaf to younger leaves at the expense of the young elongating stolon tissue immediately behind the leaf. These results are evident in experiment three, but differences did occur in experiments one and two. In experiment one, biomass allocation to the leaves of NCS in the ozone treatment was reduced compared to plants grown in the carbon filtered air treatment. As was stated before, the plants in the carbon filtered air treatment were pot bound. White clover translocates carbohydrates via a system based on sink demand. The lower demand by the roots means more assimilate stays in the leaves. In experiment two, NCR showed an increase in the stolon dry weight to total plant dry weight ratio, while total leaf dry weight to total plant dry weight was reduced by ozone. This may have been caused by the increased allocation of dry matter to the flowers in the ozone treatment. The increased number of flowers means less secondary stolons. Flowers take up less assimilates than secondary stolons. Assimilate from the leaves could then be held by the stolon. The reduction in the number of secondary leaves would also lead to lower total leaf dry weights. The reductions in dry matter allocated to the secondary stolons can be attributed to the reduced number of secondary stolons in the ozone treatment. In experiment two, ozone induced both clones to favor production of flowers over secondary stolons. Turkington (1983) found that *Trifolium repens* produced more inflorenscences in increasingly harsh environments. The growth of secondary stolons is dependent on the adjoining main leaf as a source of carbohydrate (15). These leaves are the first to be injured by ozone. This greatly reduces the amount of carbon available for secondary stolon initiation. This may have been a major factor in experiment three, as flower production was not an important influence on secondary stolon production. This would account for differences in secondary stolon dry weight for NCS, but NCR showed an increase in branching in the ozone treatment. Okano (1984) found that plants of *Cicer ariatinum* exhibited a slight enhancement of branching when exposed to ozone.

These experiments determined that ozone altered the rate of leaf development and distribution of photosynthates between source and sink regions. Initial exposure of ozone appeared to have a stimulatory effect on growth of both clones, but at longer periods of exposure the effects were negative. The lower availability of assimilate resulted in smaller leaves, petioles, and stolon and decreased number of secondary stolons. These results of the negative impact of ozone on photosynthesis and biomass partitioning can contribute significantly to reduced harvest yield.

Conclusions

1) Both clones exhibit reductions in the dry weight of all organs when exposed to ozone. These reductions resulted in the dwarfing of the plants. NCS was more severely affected by ozone than NCR

2) Ozone influenced the rate of leaf development of both clones. Each clone had a different strategy to cope with ozone exposure. NCS increased leaf maturity rate. The increased number of mature leaves would produce more assimilate to repair injury and maintain growth over the short term. NCR reduced leaf maturity rate. These leaves would be over the long term be able to produce more dry matter because senescence would be delayed.

3) Ozone induced biomass allocation favored the leaves over the storage organs, main stolon and secondary stolons and the roots. Investment in the photosynthetic organs

would allow the clones to compensate for the reduction of photosynthesis induced by ozone.

LITERATURE CITED

1. Adams, M. W. (1967). Basis of yield component compensation in crop plants with special reference to the field bean, *Phaseolus vulgaris*. Crop Science. 7, 505 - 510.

2. Amundson, R. G., Raba, R. M., Schoettle, A. W., and Reich, P. B. (1986). Response of soybean to low concentrations of ozone: II. Effects on growth, Biomass allocation, and flowering. J. Environ. Qual. 2, 161 - 167.

3. Ashenden, T. W., Bell, S. A., and Rafarel, C. R. (1995). Responses of white clover to gaseous pollutants and acid mist : Implications for setting critical levels and loads. New Phytol. 130, 89 - 96.

4. Bambridge, L., Macleod, R., and Harmer, R. (1995). Plant growth and cell division in *Pisum sativum* L. and *Picea sitchensis* (Bong.) Carr. exposed to ozone. New Phytol. 130, 75 - 80.

5. Bender, J., Weigel, N. J., and Jager H, J, (1991). Response of nitrogen metabolism in beans (*Phaseolus vulgaris* L.) after exposure to ozone and nitrogen dioxide, alone and in sequence. New Phytol. 119, 261 - 267.

6. Blum, V., Heagle, A. S., Burns, J. C., and Linthurst, R. A. (1983). The effects of ozone on fescue - clover forage: Regrowth, yield, and quality. Environ and Expt. Bot. 23, 121 -132.

7. Blum, U., Mrozek, E., and Johnson, E. (1983). Investigation of ozone (O3) effects on 14 C distribution in Ladino clover, Environ and Expt. Bot. 23, 369 - 378.

8. Blum, U. and Tingey, D. T. (1977). A study of the potential ways in which ozone could reduce root growth and nodulation of soybean. Atmos. Environ., 11, 737 - 739.

9. Boller, B. C. and Nosberger, J. (1985). Photosynthesis of white clover leaves as influenced by canopy position, leaf age, and temperature. Ann. Bot. 56, 19 -27.

10. Brougham, R. W. (1958). Leaf development in swards of white clover (*Trifolium repens* L.). New Zealand J. Agric. Res. 1, 707 - 718.

11. Carlson, G. E. (1966). Growth of white clover leaves after leaf removal. Proc. 10th Int. Grassland Congr. 134 - 136.

12. Chapman, D. F., Robson, M. J., and Snaydon, R. W. (1990). The carbon economy of developing leaves of white clover (*Trifolium repens*). Ann. Bot. 66, 623 -628.

13. Chapman, D. F., Robson, M. J., and Snaydon, R. W. (1990). Short - term effects of manipulating the source : sink ratio of white clover (*Trifolium* repens) plants on export of carbon form, and morphology of, developing leaves. Phys. Plant 80, 262 -266.

14. Chapman, D. F., Robson, M. J., and Snaydon, R. W. (1991). The influence of leaf position and defoliation on the assimilation and translocation of carbon in white clover (*Trifolium repens* L.) 1. Carbon distribution patterns. Ann. Bot. 67, 295 - 302.

15. Chapman, D. F., Robson, M. J., and Snaydon, R. W. (1991). The influence of leaf position on the assimilation and translocation of carbon in white clover (*Trifolium repens* L.) 2. Qualitative carbon movement. Ann. Bot. 67, 303 -308.

16. Cooley, D. R. and Manning, W. J. (1987). The impact of ozone on assimilate partitioning in plants: A review. Environ. Poll., 95 - 114.

17. Cooley, D. R. and Manning, W. J. (1988). Ozone effects on growth and assimilate partitioning in alfalfa, *Medicago sativa* L. Environ. Poll. 49, 19 -36.

18. Cralle, H. T., and Heichel, G. H. (1985). Interorgan photosynthate partitioning in alfalfa. Plant Phys., 79, 381 - 385.

19. Danckwerts, J. E. and Gorden, A. J. (1989). Long-term partitioning, storage, remobilization of 14C assimilated by *Trifolium repens* (cv. Blanca). Ann. Bot. 64, 533 - 544.

20. Endress, A. G. and Grunwald, C. (1985). Impact of chronic ozone on soybean growth and biomass partitioning. Agric. Ecosys. and Environ. 13, 9 - 23.

21. Engle, R. L. and Gabelman, W. H. (1967). The effects of low levels of ozone on pinto beans, *Phaseolus vulgaris* L. Amer. Soc. Hort. Sci. Proc., 91, 304 - 309.

22. Evans, D. R., Hill, J., Williams, T. A., Rhodes, I. (1985). Effects of coexistence on the performance of white clover/ perennial ryegrass mixtures. Oceolgia, 66, 536 - 539.

23. Gordon, A. J., Ryle, G. J. A., Mitchell, D. F., Lowry, K. H., and Powell, C. E. (1986). The effect of defoliation on carbohydrate, protein, and Leghaemoglobin content of white clover nodules. Ann. Bot. 58, 141 -154.

24. Guzy, M. R. and Heath, R. L. (1993). Responses to ozone of varieties of common bean (*Phaseolus vulgaris* L.). New Phytol. 124, 617 - 625.

25. Hart, A. L. (1987). Physiology. pp. 125 - 151. In M. J. Baker and W. M. Williams (eds). White clover. CAB international, Wallingford Oxon, U.K.

26. Harvey, H. J. (1969). Patterns of assimilate translocation in *Trifolium repens.* In J. Lowe (ed). White Clover Research.

27. Heagle, A. S. (1973). Interactions between air pollutants and plant parasites. Ann. Rev. Phytopath., 11, 365 - 388.

28. Heagle, A. S. and Letchworth, M. B. (1982). Relationships among injury, growth, and yield responses of soybean cultivars exposed to ozone at different light intensities. J. Environ. Qual. 11, 690 -694.

29. Heagle, A. S., McLaughlin, M. R., Miller, J. E., and Joyner, R. L. (1992). Response of two white clones to peanut stunt virus and ozone. Phytopath. 82, 254 - 258.

30. Heagle, A, S., McLaughlin, M. R., Miller, J. E., Joyner, R. L., and Sprull, S. E. (1991). Adaptation of a white clover population to ozone stress. New Phytol. 119, 61 - 68.

31. Heagle, A. S. and Miller, J. E. (1996). Effects of rooting medium and fertilizer rate of response of white clover to tropospheric ozone. Environ. Poll. 91, 113 - 119.

32. Heagle, A. S., Miller, J. E., Rawlings, J. O., and Vozzos, F. (1991). Plant and environment interactions. Effect of growth stage on soybean response to chronic ozone exposure. J. Environ. Qual. 20, 562 - 570.

33. Heagle, A. S., Miller, J. E., and Sherrill, D. E. (1994). A white clover system to estimate effects of tropospheric ozone on plants. J. Environ. Qual. 23, 613 - 621.

34. Heagle, A. S., Miller, J. E., Sherrill, D. E., and Rawlings, J. O. (1993). Effects of ozone and carbon dioxide mixtures on two clones of white clover. New Phytol. 123, 751 - 762.

35. Heagle, A. S., Rebbeck, J., Shafer, S. R., Lesser, U. M., Blum, U., and Heck, W. W. (1989). Effects of long term ozone exposure and soil moisture deficit on growth of a ladino clover - tall fescue pasture. Phytopath., 79, 128 - 136.

36. Heath, R. L. (1975). Ozone. Responses of plants to air pollution. pp. 23 - 56. In J. B. Mudd and T. T. Kozlowski (eds). Physiological ecology. academic press.

37. Howell, R. K., Rose, L. P., and Leffel, R. C. (1980). Field testing soybeans for residual effects of air pollution and seed size on crop yield. J. Environ. Qual. 9, 66 - 68.

38. Kangaasjarvi, J., Talvinen, J., Utriainen, M., and Karjalainen, R. (1994). Plant defense systems induced by ozone. Plant, Cell and Environ., 17, 783 - 794.

39. Karlsson, G., Sellen, G., Skarby, L., and Pleijel, H. (1995). Clover as an indicator plant for phototoxic ozone concentrations: Visible injury in relation to species, leaf age, and exposure dynamics. New Phytol. 129, 355 - 365.

40. Kasana, M. S. (1991). Sensitivity of three leguminous crops to O3 as influenced by different stages of growth and development. Environ. Poll. 69, 131 - 149.

41. Krupa, S. A. and Manning, W. J. (1988). Atmospheric ozone: Formation and effects on vegetation. Environ. Poll. 50, 101 - 137.

42. Kudoh, H., Ishiguri, Y., and Kawano, S. (1995). Phenotypic plasticity in *Cardamine fleuosa*: variation among populations in plastic response to chilling treatments and photoperiods. Oecologia. 103, 148 - 156.

43. Melhorn, H. and Wellburn, A. R. (1987). Stress ethylene formation determines plant sensitivity to ozone. Nature. 327, 417 - 418.

44. Miller, J. E., Pursley, W. A., Vozzo, S. F., and Heagle, A. S. (1991). Response of net carbon exchange rate of soybean to ozone at different stages of growth and its relation to yield. J. Environ. Qual. 20, 571 - 575.

45. Modney, H. A., Fichnner, K., and Schulze, E. D. (1995). Growth, Photosynthesis, and storage of carbohydrates and nitrogen in *Phaseolus lunatus* in relation to resource availability. Oceologia. 104, 17 -23.

46. Mulchi, C. L., Tuthill, E. L. K., and Olinick, E. V. (1988). Influence of ozone stress on growth processes, yields, and grain quality characteristics among soybean cultivars. Environ. Pol. 53, 151 - 169.

47. Okano, K., Ito, O., Takeba, G., Shimizu, A., and Totsuka, T. (1984). Alteration of 13 C assimilate partitioning in plants of *Phaseolus vulgaris* exposed to ozone. New Phytol. 97, 153 -163.

48. Olszyk, D. M., Maas, E. V., Kats, G., and Francois, L. E. (1988). Soil salinity and ambient ozone: Lack of stress interaction for field grown clover. J. Environ. Qual. 17, 299 - 304.

49. Pell, E. J., Temple, P. J., Friend, A. L., Mooney, H. A., and Winner, W. E. (1994). Compensation as a plant response to ozone and associated stresses: an analysis of ROPIS experiments. J. Environ. Qual. 23, 429 -436.

50. Reich, P. B., Schoettle, A. Q., Raba, R. M., and Amunson, R. G. (1986). Response of soybean to low concentrations of ozone: I. Reductions of leaf and whole plant net photosynthesis and leaf chlorophyll content. J. Environ. Qual. !5, 31 -36.

51. Reilling, K. and Davison, A. W. (1992). The response of native, herbaceous species to ozone: Growth and fluorescence screening. New Phytol. 120, 29 - 37.

52. Reinert, R. A. and Ho, M. C. (1995). Vegetative growth of soybean as affected by elevated carbon dioxide and ozone. Environ. Poll. 89, 89 -96.

53. Ryle, G. J. A., Powell, C. E., and Gordon, A. J. (1986). Defoliation in white clover: Nodule metabolism, nodule growth, and maintenance, and nitrogenase functioning during growth and regrowth. Ann. Bot. 57, 263 -271.

54. Sanders, G. E., Robinson, A. D., Geissler, P. A., and Culls, J. J. (1992). Yield stimulation of a commonly grown cultivar of *Phaseolus vulgaris* L. at near ambient ozone concentrations. New Phytol. 122, 63 - 70.

55. Schenone, G., Botteschi, G., Fumagalli, I., and Montinaro, F. (1992). Effects of ambient air pollution in open top chambers on bean (*Phaseolus vulgaris* L.) I. Effects on growth and yield. New Phytol. 122, 689 - 697.

56. Schenone, G., Fumagalli, I., Mignanego, L., Montinaro, F., and Soldatina, G. F. (1994). Effects of ambient air pollution in open air chambers on bean (*Phaseolus vulgaris* L.) II. Effects on photosynthesis and stomatal conductance. New Phytol. 126, 309 - 315.

57. Sheng, W. S., Chevone, B. I., and Hess, J. L. (1993). Photosynthetic inhibition and superoxide dimutase activity in soybean cultivars exposed to short-term ozone fumigations. Environ. Poll. 80, 45 - 52.

58. Tingey, D. T. and Blum, U. (1973). Effects of ozone on soybean nodules. J. Environ. Qual. 12, 341 - 342.

59. Tingey, D. T., Reinert, R. A., Vickliff, C., and Heck, W. W. (1973). Chronic ozone and sulfur dioxide exposures, or both, affect the early vegetative growth of soybean. Can. J. Plant Sci. 53, 875 - 879.

60. Turkington, R. (1983). Plasticity in growth and patterns of dry matter distribution of two genotypes of *Trifolium repens* grown in different environments of neighbors. Can. J. Bot. 61, 2186 - 2194.

61. Turkington, R. and Burdon, J. J. (1983). Biology of Canadian weeds. 57. *Trifolium repens*. Can. J. Plant Sci., 63, 243 - 266.

62. Weaver, G. M. and Jackson, H. O. (1968). Relationship between bronzing in white beans and phototoxic levels of atmospheric ozone in Ontario. Can. J. Plant Sci. 48, 561 - 568.

63. Wilbourn, S., Davison, A. W., and Ollerenshaw, J. H. (1995). The use of an unenclosed field fumigation system to determine the effects of elevated ozone on a grass-clover mixture. New Phytol. 129, 23 - 32.

64. Younglove, T., McCool, P. M., Musselman, R. C., and Kahl, M. E. (1994). Growth stage dependent crop yield response to ozone exposure. Environ. Poll. 86, 287 - 295.