VARIABILITY OF CULTIVAR RESPONSES TO OZONE

Final Report

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and yield losses caused by O_3. Therefore, it may be possible to classify the degree of susceptibility or tolerance of cultivars to O_3 based upon their rates of physiological activity, growth, or yield.

This hypothesis was tested by exposing four cultivars each of three summer crops (dry beans, cotton, and tomato) and three winter annuals (lettuce, broccoli, and onions) to three levels of O_3 in open-top chambers. All the plants were field-grown and cultural practices followed standard agricultural practices for these crops. The three levels of O_3 were: charcoal-filtered air (CF), nonfiltered (NF) representing ambient O_3 concentrations, and NF plus O_3 to equal 1.5 times ambient concentrations. Summer crops were exposed from July to September (beans), October (tomato) or November (cotton), 1987. Winter crops were exposed from February to March (lettuce), May (broccoli), or June (onion), 1988. Cultivars were selected in consultation with vegetable and field crop specialists and were chosen to represent the most widely-grown cultivars in the state, but also those that would differ significantly in morphology (beans, lettuce) or in rates of maturity (cotton, tomato, broccoli, onion). Rates of stomatal conductance were measured bi-weekly on all cultivars (except for lettuce and onion which could not be measured because of technical difficulties due to leaf morphology). Cultivars were ranked in order of increasing rates of stomatal conductance (gas exchange), growth, maturation, productivity, and susceptibility to O_3 to determine the basis for the observed differences in cultivar responses to O_3.

Results

Dry beans. The four bean cultivars differed significantly in yield responses to O_3 and these differences appeared to be related to rates of stomatal conductance. The higher the rate of stomatal conductance, the more susceptible was the cultivar to O_3. Therefore, measurement of stomatal conductance could potentially be used to classify bean cultivars to susceptibility to O_3. The two pink bean cultivars were significantly more susceptible to O_3 than the kidney bean cultivar. Therefore, use of a dose-response equation based on a kidney bean cultivar could underestimate bean yield losses to O_3.

PROJECT SUMMARY

Air pollution, particularly in the form of the photochemical oxidant ozone (O_3)[1] significantly affects the productivity of agricultural crops in California. Estimates of the economic losses to producers and consumers of agricultural commodities in the state due to crop damage from O_3 have ranged from $37 million to $300 million. Recent estimates of the benefits to the state from cleaner air have ranged from $50 million to $330 million, depending upon the degree of air quality degradation from estimated background O_3 levels.

Some of the uncertainties in these crop loss estimates are due to uncertainties in the biological data base of dose-response equations that link atmospheric concentrations of O_3 to yield losses in specific crops. Dose-response experiments with most crops have used only one or two cultivars. But does the dose-response equation generated for one cultivar of a crop truly represent the response of the species as a whole? If it does not, to what degree does this bias the estimate of crop loss for that crop? Since it is clearly impossible to establish O_3 dose-yield response functions for all cultivars of a crop, some other means must be found to classify cultivars according to level of susceptibility to O_3. Then cultivars can be weighted by potential yield acreage across the state and individual cultivar yield losses can be aggregated to produce crop loss estimates based on all the cultivars of a crop in use, and not just on the one or two used in the dose-response experiment.

The objectives of this research were to determine the variability of physiological, growth, and yield responses of widely used cultivars of field crops grown in California, and to determine the underlying basis for that variability. The specific hypothesis to be tested is that the more physiologically active the cultivar, the more susceptible to O_3 it is. That is, there is a close correlation between rates of stomatal conductance, transpiration, photosynthesis, and productivity (growth and yield)

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1. Throughout this report the term ozone is used to indicate both photochemical oxidant air pollution in general and O_3 in particular. Ozone comprises >95% of ambient oxidant air pollution, although on occasion other phytotoxic photochemical oxidants, such as peroxyacetyl nitrate (PAN) may be present in sufficient concentration to cause injury to plants.

Processing Tomatoes. The four tomato cultivars were less susceptible to O_3 and the cultivars were not as distinctive in their responses as were the bean cultivars. The more productive cultivars; i.e., greater fruit yield, appeared to be more susceptible to O_3 than lower yielding lines. However, the tomato cultivars tested in this study showed about the same response to O_3 as those previously tested, suggesting that, in general, cultivar differences may be minimal in tomato.

Cotton. The four cotton cultivars were moderately susceptible to O_3, and significant differences among the cultivars in response to O_3 appeared to be related to degree of determinism. That is, the greater the tendency for the cultivar to mature rapidly and to switch from vegetative to reproductive growth in a short period of time, the greater the yield loss due to O_3. The most resistant cultivar to O_3 was 'SJ2,' which was used to develop the current dose-response equation for cotton. This suggests that cotton yield losses to O_3 throughout the state may be underestimated when other commonly grown cultivars of cotton are taken into account.

Lettuce. The four cultivars of leaf lettuce showed significant O_3 injury on older leaves, but no growth reduction due to O_3. These results are similar to those reported for other lettuce cultivars and they suggest that lettuce production should not be affected by O_3, except when O_3 injury symptoms severely impact the visual appearance of the plant.

Broccoli. Yield data for broccoli cultivars were highly variable, and no statistically significant reductions in yield in response to O_3 were observed. Yield losses did not appear to be related either to rates of stomatal conductance or to rates of maturation of the cultivars.

Onion. Only one of the four cultivars of onion (Rio Bravo) showed significant yield losses attributable to O_3, and this yield loss did not appear to be related to rate of maturation of this cultivar.

In conclusion, this attempt to relate cultivar susceptibility to O_3 with physiological parameters such as stomatal conductance or rates of growth and maturation was successful for some species, but not for others. This comparative approach showed promise and it appeared to be one of the best techniques for increasing the predictive power of empirically-derived dose-response equations relating O_3 concentrations to crop losses in the field.

relative susceptibilities of three cultivars of winter wheat (Triticum sp.), four cultivars of soybean (Glycine max Merr.), and four hybrids of field corn (Zea mays L.) were assessed. Significant differences in cultivar responses to O_3 were observed in winter wheat (Kress and Miller, 1985b). The cultivar 'Roland' was significantly more susceptible to yield reductions than 'Abe' or 'Arthur.' Soybean cultivars differed in susceptibility to O_3-induced yield losses when classified by maturity groups. Cultivars in maturity group II were slightly more susceptible to O_3 than those in maturity group III (Kress et al., 1984). In contrast, field corn hybrids did not differ significantly in response to O_3 (Kress and Miller, 1985a). The relative susceptibilities of bean (Phaseolus vulgaris L.) cultivars to O_3 have been studied extensively (Davis and Kress, 1974; Hucl and Beversdorf, 1982); Meiners and Heggestad, 1979; Reinert et al., 1984; Heck et al., 1988). Cultivars of other major field crops have also been evaluated for susceptibility to O_3, particularly alfalfa (Medicago sativa L.) (Howell et al., 1981), tomato (Lycopersicon esculentum Mill.) (Oshima et al., 1977; Reinert et al., 1972; Clayberg, 1971), and cotton (Gossypium hirsutum L.) (Heggestad and Christiansen, 1982).

Since it is clearly impossible to establish firm O_3 dose-crop yield loss functions for all cultivars of all crops, what strategies can be devised to provide information on the susceptibilities of cultivars to O_3-induced yield losses? One possibility is to screen cultivars on the basis of some easily determined function of O_3, such as visible injury symptoms, and to correlate susceptibility to visible injury with yield losses. Experiments using this approach have shown that for species that exhibit large differences in cultivar responses to O_3, such as bush bean, using a visible injury screen can predict the relative yield responses of cultivars grown under field conditions (Heck et al., 1988). However, this screening approach was not successful in predicting yield losses in peanut (Arachis hypogaea L.) (Ensing et al., 1986) or tomato (Oshima et al., 1977; Henderson and Reinert, 1979). A second difficulty with this approach is that it has not been possible to establish a correspondence between amounts of foliar injury induced by O_3 and growth and yield reductions in plants (Heck et al., 1988). Therefore, while screening crop cultivars for foliar injury may in some cases predict which cultivars may

INTRODUCTION

A. Statement of the Problem

Recent evidence has confirmed that air pollution, principally in the form of the photochemical oxidant ozone (O_3), has significantly reduced yields of major agronomic crops throughout the U.S. Estimates of economic losses to agriculture induced by O_3 have varied widely, but the most reliable estimate of total aggregate damage is on the order of $3 billion (Adams et al., 1984). California, with the largest and most diverse agricultural economy of any state and also, unfortunately, with the most severe photochemical oxidant problem, is particularly susceptible to O_3-induced crop losses. Estimates of the economic impacts of air pollution on agriculture in California have varied widely (Adams et al., 1982; Howitt et al., 1984, 1985; Leung et al., 1982; Rowe and Chestnut, 1985). Loss estimates for the state have ranged from $37 million (Howitt et al., 1985) to $300 million (Leung et al., 1982). The California Air Resources Board (CARB) has estimated benefits to agriculture from cleaner air ranging from $330 million to $50 million, depending upon attainment of specific O_3 standards (CARB, 1987). The rationale for the CARB assessment, including the specific O_3 dose-crop yield loss equations upon which it is based, has recently been described by Olszyk et al. (1988).

Some of the uncertainty in estimates of economic losses from O_3 stems from uncertainties in the biological data base of O_3 dose-crop loss equations. The cultivar or cultivars selected for study in a dose-response experiment are normally chosen on the basis of their economic importance or ease of growth at a particular experimental site, and not on how accurately they reflect the range of O_3 responses expected in the crop species as a whole. Thus one of the major uncertainties in crop loss assessments is the degree to which cultivars differ in their responses to O_3 and the degree to which the crop loss assessment model is sensitive to these differences. Most dose-response experiments have been conducted on only one or two cultivars of the most widely grown crop plants. Plant cultivars vary widely in response to O_3 (NAS, 1976), so dose-response equations generated for a single cultivar may not adequately represent the response of the species as a whole. In a series of dose-response experiments conducted by the National Crop Loss Assessment Network (NCLAN) the conductance, transpiration, growth and productivity (potential yield) and O_3-induced yield losses.

The objectives of this research are:

1. To determine the variability of physiological, growth, and yield responses of widely grown cultivars of California field crops to O_3.

2. To determine the underlying physiological basis for the observed variability.

3. To associate rates of physiological processes with O_3-induced yield losses as the basis for a classification of cultivar responses to O_3.

MATERIALS AND METHODS

A. Selection of Crop Cultivars

The six field crop species selected for study included three summer annuals and three winter crops. The summer crops were tomato, beans and cotton. The winter crops were lettuce (*Lactuca sativa* L.), onion (*Allium cepa* L.) and broccoli (*Brassica oleracea* L.). Four cultivars of each of these crops were selected in consultation with field crop specialists and agricultural extension agents to represent cultivars that were widely grown, representative of major cultivar types, differed in major growth characteristics, and would perform well under Riverside growing conditions. The four cultivars selected for each crop are listed in Table 1.

Tomato cultivars were selected in consultation with W. L. Sims, Extension Vegetable Specialist, UC Davis. These processing tomato cultivars represent 20% (E6203), 10% (FM785), 6% (UC204C) and <5% (Hybrid 31) of the total processing tomato acreage in California. No other tomato cultivar is grown over a larger acreage. Hybrid 31 is a fast growing, early maturing line. FM785 is normally the largest in growth, followed by E6203, UC204C, and Hybrid 31. Certified seed of each of these cultivars was obtained from W. L. Sims and planted in a peat-vermiculite potting mix on May 20, 1987.

Dry bean cultivars were selected in consultation with W. H. Isom, Extension Agronomist, UC Riverside. The four cultivars represent, to some extent, the spectrum of bean types grown in California. 'Sal Small White' is a pea bean type; 'Linden Red Kidney' is a large red-type;

be susceptible to O_3, such screenings cannot provide quantitative data on the possible extent of crop yield reductions.

An alternative approach is to determine the underlying physiological mechanisms that relate cultivar susceptibility to O_3 with reductions in crop growth and yield. Since stomatal conductance is the rate-determining step in regulating O_3 entry into leaves, it is a logical area in which to conduct mechanistic studies. Stomata have been shown to play a major role in regulating plant responses to air pollutants (Heath, 1980; Mansfield, 1973; Unsworth and Black, 1981). Environmental factors that are conducive to high rates of stomatal conductance such as high relative humidity and adequate soil moisture, increase pollutant uptake and increase plant susceptibility to O_3 (Rich and Turner, 1972; Tingey et al., 1982; Tingey and Hogsett, 1985). Intrinsic factors that control maximum rates of stomatal conductance also determine relative susceptibility to O_3. Reich and Amundson (1985) established a significant relationship between rates of maximum stomatal conductance and susceptibility to O_3 for a number of tree and crop species. Harkov and Brennan (1982) also suggested that the susceptibilities of plants to O_3 are in direct proportion to intrinsic rates of metabolic functions. This relationship between rates of physiological processes, particularly stomatal conductance, and relative susceptibility to O_3 can be used to model variability in cultivar responses to O_3.

Once this link between cultivar physiology and susceptibility to O_3 has been established, cultivars can be classified according to level of responses to O_3. Widely-grown cultivars of field crops can then be weighted by both predicted susceptibility to O_3 and total acreage or annual production. These individual cultivar yield losses can be aggregated to produce an economic assessment of the costs of air pollution to agriculture that is based on all the cultivars of a crop in production, and not just on the one that was used in a crop loss experiment.

B. Hypothesis and Objectives

The specific hypothesis to be tested by this research is that the more physiologically active the cultivar, the more susceptible to O_3 it should be; that is, there is a close correlation between rates of stomatal

Valley. 'SS2086' is a new 'short-season' cotton line currently under development in Shafter. It is more determinate than other released cotton lines and thus may have potential uses in areas with shorter growing seasons. Certified seed of each of these cultivars was obtained from the USDA Cotton Research Station at Shafter.

Cultivars for the 1988 winter crops were selected in consultation with Hunter Johnson, Extension Vegetable Specialist, UC Riverside, and with agricultural extension agents and seed companies in Imperial County. These cultivars were the major cultivars used by growers in the Imperial Valley in 1988. Lettuce cultivars were 'Royal Green,' a loose-leaf lettuce with dark green leaves; 'Dark Green Boston,' a butterhead lettuce with loose heads and smooth, green outer leaves; 'Prizehead,' a loose-leaf lettuce with red-tinged leaves; and 'Parris Island Cos,' a romaine lettuce with loose leaves and a cylindrical head. The broccoli cultivars differed in rates of maturation, based upon number of heat units required for maturation. 'Green Duke' required 90 days from seedling emergence, 'Emperor' and 'Commander,' 100 days; and 'Green Belt,' 112 days to maturity. Onion cultivars included 'Colossal,' a short-day, late-maturing, yellow globe-type; 'NU-MEX BR-1,' a short-day early maturing, yellow, flat Grano; 'Rio Hondo,' a short-day, yellow, globe, hybrid modified Grano; and 'Rio Bravo,' a short-day, yellow, flat, hybrid Granex.

B. Site Description

Crops were grown in Riverside, California on Hanford coarse sandy loam (coarse-loamy, mixed, non-acid, thermic Typic Xerothents). A field 30 m by 45 m contained 30 plots, each 4.5 by 5.5 m. Ten plots each of beans, tomatoes, and cotton were grown in the summer of 1987 and 10 plots each of broccoli, lettuce, and onions were grown in the winter of 1988. Each plot contained four cultivars of each crop.

A barley cover crop was incorporated into the field on April 15, 1987. The field was disked again on June 17 and fertilized at 112 kg ha^{-1} of 16-20-0 (N-P-K). Six rows 75 cm apart were formed in cotton and bean plots; four rows 110 cm apart were formed in tomato plots. Cotton and bean seeds were planted July 1, and the tomato plants that were started May 20 in the greenhouse were transplanted on July 2 to July 3. All plants were watered with Riverside city water using drip tapes on the

Table 1. List of cultivars used in the study of variability of cultivar responses to ozone

A. Summer crops - 1987

Tomato:	E6203 UC204C HYBRID 31 FM785	Cotton:	SJ-2 GC510 C1 SS2086
Bean:	Sutter Pinks Yolano Pinks Sal Small White Linden Red Kidney		

B. Winter Crops - 1988

Broccoli:	Commander Green Belt Green Duke Emperor	Lettuce:	Royal Green Prizehead Dark Green Boston Paris Island Cos
Onion:	Rio Bravo Rio Hondo Colossal Nu-Mex BR-1		

'Sutter' and 'Yolano' are two pink bean types. Certified seed of each of these cultivars was obtained from B. Ray, California Seed Producers Board, UC Davis.

Cotton cultivars were chosen in consultation with Dr. Lee Urie, USDA Cotton Research Station, Shafter. The cultivar 'SJ-2' is the standard "acala" cotton type. It is widely grown in the southern San Joaquin Valley, covering about 40% of cotton acreage in the state. This cultivar is largely indeterminate; that is, it will continue to grow and produce bolls until frost, defoliation, drought, or other external factors prevent it from growing. 'GC510' is more widely grown in the northern part of the San Joaquin Valley because it is more determinate; that is, it shifts more rapidly from the vegetative to the reproductive stage, and so it has a more defined growing season which is shorter than 'SJ-2.' 'C1' is an older cotton cultivar that is still widely planted in the San Joaquin analyzer (Model 1003 AH; Dasibi Environmental Corp; Glendale, CA) were inputted to a proportional controller which modulated voltage to the O_3 generator. Thus, the concentration of O_3 produced by the generator and supplied to O_3-added chambers was proportional to ambient O_3 concentrations. Loss of O_3 through individual sample lines was determined at the beginning and at the end of each growing season. Sample lines with less than 90% efficiency were replaced. Other quality control/quality assurance protocols for the collection of O_3 air quality data were followed using standard protocols developed for the NCLAN program of EPA (Heck et al., 1984).

Stomatal conductance was measured bi-weekly in one plot from each O_3 treatment using a steady-state porometer (LI-1600; Li-Cor, Inc., Lincoln, NB). Conductance was measured on abaxial and adaxial leaf surfaces of the highest fully-expanded leaves of each crop. Replicate measurements were taken on three plants of each cultivar in each chamber or plot between 1100 to 1400, when stomatal conductance was expected to be at its maximum. The mean maximum seasonal rate of stomatal conductance for each cultivar in each treatment was calculated from the sum of abaxial plus adaxial conductance measurements averaged over the growing season. Conductance measurements were not taken on lettuce or onion cultivars because the surface morphology of these leaves did not permit an air-tight seal between the leaf surface and the steady-state porometer.

Visible O_3 injury symptoms on beans, cotton and tomato were evaluated on August 7 and September 8. For each crop, visible injury was subjectively evaluated by expressing the degree of O_3-induced chlorosis and necrosis on each cultivar in each chamber as none, trace, light, moderate, or severe. Evaluations from each chamber or plot were compared to derive a final assessment of the degree of foliar injury on each cultivar of each crop. Plant heights and internode lengths were measured in all treatments on three plants in each of the four cotton cultivars on October 5.

Bean plants were harvested on September 21 and 22. All fresh and dry bean pods were removed from the plants. Fresh and dry weights were obtained for pods, leaves, an stems. The roots were excavated and fresh and dry weights were obtained for bean roots. Tomatoes were harvested on October 1. Red and green tomatoes were picked separately and graded for center of each row. The drip tapes had been calibrated for uniformity of delivery. Pressure within the drip tapes was controlled by individual water pressure regulators located at each plot.

Twenty-seven cylindrical open-top chambers 3 m in diameter by 2.4 m high were placed on the plots on July 16. The chambers were positioned on the plots so that equal areas of each of the four cultivars were covered. The remaining single plots of tomato, beans, and cotton were used as ambient air (AA) controls. One-third of the chambers were equipped with charcoal filters (CF) so that plants received essentially O_3-free air; one-third had dust filters only (NF), so that plants were exposed to ambient O_3 concentrations; and one-third had O_3 added in proportion to ambient O_3 so that O_3 levels were 1.5 times greater than ambient (NF150). Each O_3 treatment was replicated three times.

Ozone dispensing began July 30, 1987. Ozone was produced using a Griffin O_3 generator (Model GTC-1A; Griffin Technics Corp, Lodi, NJ). Tests of the O_3 generation system determined that the concentration of trace contaminant nitrogen oxides co-generated with O_3 were approximately 1% of the total O_3 output of the generator (A. Bytnerowicz, unpublished). Chamber blowers were programmed to start at 0600 and to stop at 2100; O_3 was added from 0600 to 2000, whenever ambient O_3 exceeded 0.03 ppm. Sample air from chambers or open plots was collected 0.5 m above canopy height through continuously-aspirated dust-filtered Teflon® lines 46 m long. The lines merged at two 12-port rotary sampling valves (Scanivalve Corp., San Diego, CA) that rotated to the next position every two minutes so that every line was sampled five times per hour. Because only 24 positions were available on the sample valves, not all chambers and plots could be sampled. Seven CF, seven NF, nine NF150, and one AA plot were continuously sampled.

Fewer numbers of CF and NF chambers were sampled than NF150 chambers because previous research using an identical sampling system had shown that O_3 concentrations inside CF and NF chambers were more uniform among chambers than O_3 concentrations in NF150 chambers. Similarly, only one AA plot was sampled because previous research had shown that O_3 concentrations were relatively uniform from plot to plot.

Ambient O_3 was sampled continuously through a separate line and O_3 analyzer from a height 5 m above the field. Signals from the ambient O_3

C. Summarization and Analysis of Data

Data on O_3 concentrations in chambers and ambient air were summarized for the growing seasons of each crop. Seasonal mean 12-hour O_3 concentrations were computed from hourly average O_3 readings from 0800 to 2000, averaged across the growing season. Other measures of plant exposure to O_3, including seasonal 24-hour mean, highest and second highest hourly concentrations, and highest 12 and 24-hour daily concentrations were also summarized for each crop.

Data on yields of harvested plant parts were analyzed by regression of mean seasonal 12-hour O_3 concentration for each chamber as the independent variable and yield for each cultivar in each chamber as the dependent variable. Data from open (AA) plots were not included in the regression analysis, nor were harvest data from two bean plots (A4 and A7), where herbivore damage had substantially reduced yields. In those crops for which regression analysis indicated statistically significant reductions in yields in response to increasing O_3 exposures, the regression equations were used to predict the percent reduction in yield at ambient O_3 concentrations relative to yield at a theoretical background O_3 level of 0.03 ppm. The magnitude of these yield reductions was used to assess the relative susceptibility of the cultivars to O_3, and the cultivars were ranked in order of decreasing yield losses. Cultivars whose predicted yield losses differed by less than 10% were ranked equally susceptible to O_3. Because of the low number of treatment levels and replications, the statistical significance of these cultivar rankings cannot be determined by this experiment.

Linear, quadratic, and higher order terms for seasonal O_3 concentration were used in the analysis in a step-wise multiple regression format. In most cases only the linear O_3 term was statistically significant, but in those cases in which a higher order O_3 term was also statistically significant, the term was also added to the regression equation.

Since the objective of this study was to associate differences in cultivar susceptibility to O_3 with specific physiological processes, primarily gas exchange, cultivars were ranked in order of rates of seasonal mean stomatal conductance in CF chambers. These rankings were compared with those of cultivar susceptibility to yield losses to deterquality. All undersized or damaged fruit were discarded. Fresh and dry weights were obtained for tomato stems and leaves and tomato roots were excavated, washed, and fresh weight and root lengths were measured. Cotton was harvested December 4 to 9. Numbers of bolls and number of open bolls were counted and lint and seed were separated using a portable cotton gin. Leaves and stems were weighed and roots excavated, washed, and weighed. Lint and seed weights were determined after air drying for seven days; other plant parts were oven-dried at 60°C before weighing.

Following the cotton harvest the field was disked, leveled, and fertilized with 140 kg ha^{-1} of 16:16:16 (N:P:K). Broccoli seeds were planted on January 13, 1988 in 12 rows spaced 30 cm apart, with 15 cm spacing between plants. Lettuce seeds were planted with the same spacing as broccoli on January 15. Onion seeds were planted on January 20 in 28 rows spaced 10 cm apart, with 6 cm spacing between plants. All plots were watered with drip tapes located on the center of each row.

Open-top chambers were placed on 27 of the plots on Feb. 23 and O_3 dispensing began on Feb. 27. Ozone dispensing and monitoring systems and O_3 treatments were the same as those previously described.

Visible injury symptoms were evaluated on lettuce on March 28, broccoli, April 22; and onion May 23, using the system described previously.

The four lettuce cultivars were harvested on April 1, 60 days after seedling emergence. Plants were harvested from two 1 meter row segments in the center of the chambers or AA plot. Each broccoli cultivar was harvested when 10% of the heads were over-mature. 'Green Duke' was harvested on April 25, 'Emperor' and 'Commander' on May 5, and 'Green Belt' on May 17. Plants were divided into heads and stalks and heads were graded for size and quality before weighing. All the onion cultivars were harvested on June 13, when top growth had become senescent. Plants were harvested from five 1 meter rows for each cultivar in each chamber or plot. Roots of these winter annuals were all fibrous and too fine to permit excavation.

Stomatal conductance was measured on broccoli plants bi-weekly beginning March 16. The foliage of both lettuce and onion was not flat enough to permit use of the porometer in these crops.

mine if an association existed between the two sets of rankings. Since O_3 is known to reduce stomatal conductance primarily through its effects on photosynthesis (Reich and Amundson, 1985; Unsworth and Black, 1981), the percent reduction in stomatal conductance in NF150 chambers relative to CF chambers was used as a measure of cultivar susceptibility to O_3, and the cultivars were ranked in order of increasing susceptibility to O_3-induced reductions in stomatal conductance. As with the yield loss rankings, the statistical significance of these stomatal conductance rankings could not be determined. Other measures of plant growth, such as rate of maturation, degree of determinism, rate of senescence, and yield potentials (i.e., yield in CF chambers), and other measures of plant response to O_3, such as foliar injury symptoms, or reductions in root or shoot growth were used heuristically to explain the observed cultivar responses to O_3.

Table 2. Seed dry weight and percent change from control (CF) of four dry bean cultivars exposed to ozone in Riverside, CA in 1987. Data are in g per meter-row[a], means of three replicate plots per ozone level

Treat-ment	Sutter Pink		Yolano Pink		S.S. White		L.R. Kidney	
	Seed wt	%	Seed wt	%	Seed wt	%	Seed wt	%
CF	147	-	149	-	148	-	52	-
NF	47	-68.2	42	-71.7	74	-50	77	+47.6
NF150	13	-91.3	12	-91.9	51	-65.9	27	-49.1

[a]G per m-row x 11.89 = lbs $acre^{-1}$ x 1.12 = kg ha^{-1}.

responded similarly to seed yield. These data and yields from AA plots are given in Appendix B.

The increase in seed yield observed in Linden Red Kidney in the NF treatment was anomalous, reflecting one unusually low-yielding plot in the CF treatment and one very high-yielding plot in the NF treatment. The ranking of the four cultivars by susceptibility to O_3-induced yield losses, with the two pinks most susceptible, followed by Sal Small White, then Linden Red Kidney, was the same as their ranking by amount of foliar injury. This suggested that foliar injury could be used as a surrogate to screen bean cultivars for potential crop losses. This suggestion was supported by the work of Heck et al. (1988) who also reported that susceptibility to visible O_3 injury was correlated with growth and yield reductions in four bean cultivars.

Measurements of maximum rates of stomatal conductance indicated that the four bean cultivars had the same ranking in rates of stomatal conductance as in amount of foliar injury and yield reductions (Table 3). Sutter Pink had the highest stomatal conductance, followed by Yolano Pink, Sal Small White, and Linden Red Kidney. Ozone markedly reduced stomatal conductance in these bean cultivars, but the two susceptible pink cultivars maintained higher rates of gas exchange than the more resistant small white and red cultivars, even when they were severely injured by

RESULTS AND DISCUSSION

A. Air Quality

Ozone concentrations were typical of those encountered in the South Coast Air Quality Basin for 1987 and 1988. Ambient O_3 concentrations for the 12-hour daylight period from 0800 to 2000 ranged from 0.082 ppm during the exposure period for beans to 0.064 ppm for the cotton exposure period in 1987. During the exposure period for winter crops in 1988 ambient O_3 ranged from 0.044 ppm for lettuce to 0.053 ppm for the longer growing season of onion. Concentrations in nonfiltered (NF) chambers averaged about 10% lower than ambient, indicating that the dust filters and blower boxes had removed a small amount of ambient O_3. Concentrations in O_3-added chambers ranged from 1.6 to 1.9 times higher than NF.

Other measures of crop exposure to O_3, such as seasonal 24-hour mean, peak hour, second highest hour, highest 12-hour day, and highest 24-hour day are given in Appendix A.

B. Cultivar Responses to O_3

1. Beans

The four bean cultivars differed significantly in their responses to O_3, but all four were susceptible to O_3 injury and yield losses. Visible injury symptoms appeared in AA, NF, and NF150 chambers and consisted of dark bronzing or brownish stippling on upper leaf surfaces. Plants in NF150 chambers had the most severe injury and many plants showed symptoms of premature senescence by August 7, the date of the first injury evaluations. Based upon the time required for injury symptoms to develop and upon the amount of foliar injury and senescence, the four cultivars were ranked in order of decreasing susceptibility to O_3 as follows: Sutter Pinks = Yolano Pinks > Sal Small White > Linden Red Kidney.

Bean seed dry weights for the four cultivars are shown in Table 2. With the exception of Linden Red Kidney, plants exposed to O_3 had seed yields severely reduced in both chambers and open plots, compared with CF controls. Yield losses in O_3-added chambers were up to 91% for the two pink bean cultivars, 66% for Sal Small White, and 49% for Linden Red Kidney. Other measures of plant growth and yield in response to O_3, including stem, leaf, and root fresh and dry weights and bean pod weight

O_3. This close association among rates of gas exchange, degree of foliar injury, and growth and yield reductions in bean cultivars suggested that measurements of rates of stomatal conductance in bean cultivars could be used to develop a ranking of bean cultivar susceptibilities to O_3.

2. Tomato

Total fresh fruit weight for the four tomato cultivars is shown in Table 4. Fruit weights were generally greater in NF chambers relative to CF, but in O_3-added chambers yields were from 52% lower for Hybrid 31 to 17% lower for UC204C. However, only E6203 and Hybrid 31 showed statistically significant responses of decreased fruit yield with increased concentrations of O_3 (Table 14). These data show that processing tomato was not as susceptible to O_3 as was bean, nor were differences in susceptibility as pronounced as dry bean cultivars. The four tomato cultivars were ranked Hybrid 31 = E6203 > FM785 = UC204C in order of decreasing susceptibility to O_3-induced yield losses. While visible foliar symptoms of O_3 injury developed on plants in the field, differences among the cultivars were not apparent and did not appear to be correlated with subsequent yield losses.

Table 4. Fresh fruit weight and percent change from control (CF) of four cultivars of processing tomato exposed to ozone in Riverside, CA in 1987. Data are grams per m-row[a]; means of three replicate plots per ozone level

Treatment	FM785		HYB31		UC204C		E6203	
	g	%	g	%	g	%	g	%
CF	6650	-	7819	-	4470	-	6706	-
NF	7842	+17.9	8587	+9.8	5477	+22.5	6606	-1.5
NF150	4994	-24.9	3742	-52.1	3722	-16.7	3675	-45.2

[a]G per m-row x 8.11 = lbs $acre^{-1}$ x 1.12 = kg ha^{-1}.

Table 3. Mean seasonal rates of maximum stomatal conductance (C) and percent change from control (CF) for four dry bean cultivars exposed to ozone in Riverside, CA in 1987. Data are in cm s^{-1}; mean of 45 measurements per ozone level (± 1 s.d.)

Treat-ment	Sutter Pink		Yolano Pink		S. S. White		L. R. Kidney	
	C	%	C	%	C	%	C	%
CF	2.48 (0.49)	-	2.33 (0.42)	-	1.69 (0.77)	-	1.44 (0.59)	-
NF	1.96 (0.68)	-21.0	1.95 (1.01)	-16.3	1.76 (0.47)	+4.1	1.11 (0.38)	-22.9
NF150	1.56 (0.79)	-37.1	1.24 (0.69)	-46.8	1.18 (0.47)	-30.2	1.18 (0.65)	-18.1

Table 6. Lateral root dry weights and percent change from control (CF) of four cultivars of processing tomato exposed to ozone in Riverside, CA in 1987. Data are in g per m-row[a]; means of three replicate plots per ozone level

Treat-ment	FM785		HYB31		UC204C		E6203	
	g	%	g	%	g	%	g	%
CF	4.32	-	1.88	-	2.41	-	4.82	-
NF	3.75	-13.2	1.57	-16.5	3.12	+29.5	6.46	+34.0
NF150	2.39	-44.7	1.26	-33.0	2.47	+2.5	3.50	-27.4

[a]G per m-row x 8.11 = lbs $acre^{-1}$ x 1.12 = kg ha^{-1}.

The most useful predictor was fruit yield itself. The cultivar with the greatest yield under Riverside growing conditions, Hybrid 31, also had the greatest yield reduction in the high O_3 treatment. UC204C, the lowest yielding cultivar, showed the least response to added O_3. It might be possible, then, to rank tomato cultivars according to potential yield, and to use this ranking to predict which cultivars might be most susceptible to O_3.

3. Cotton

Typical O_3-induced foliar injury symptoms were observed on all the cotton cultivars as early as August 7, four weeks after germination. Injury symptoms were observed on all treatments, except for CF. No apparent differences in degree or expression of foliar O_3 injury were observed among the four cultivars.

Lint yields of the four cotton cultivars are shown in Table 8. These data show that the four cultivars differed significantly in their responses to O_3. The most determinate, short-season cultivar, SS2086, had over 70% reduction in yield in NF150 chambers, compared with CF controls. The next most determinate, GC510, also had high yield losses (66%) when exposed to high levels of O_3. The cultivar C1 had a lint yield loss of nearly 60%, while the most widely-planted cultivar in the southern San Joaquin Valley, SJ-2, had nearly 40% yield loss. At ambient O_3 concentrations in NF chambers, SJ-2 showed no yield loss, while SS2086 and GC510

The effects of O_3 on stem and leaf dry weight of tomato paralleled those of fruit yield; that is, plants were larger in NF chambers, but were reduced in growth in NF150 chambers, compared with CF controls (Table 5). In contrast, root growth was more susceptible to O_3 than top growth, and two of the cultivars showed reduced root growth at ambient O_3 concentrations (Table 6). Reasons for the apparent stimulation in growth of tomato in NF chambers are not clear. Previous research has shown that 'Murrieta', a cultivar of processing tomato grown in California showed relatively little response to ambient O_3 in the northern San Joaquin Valley. However, the reduction in root growth of these tomato cultivars in response to ambient O_3 (Table 6) suggests that under more adverse growing conditions; e.g., drought stress or reduced nutrient availability, O_3 would have a greater effect on growth of processing tomato cultivars. Other measures of tomato response to O_3, including data from AA plots are given in Appendix B.

Seasonal rates of maximum stomatal conductance are shown in Table 7. Neither the control rate of conductance (in CF chambers) nor the reduction in rates of conductance caused by exposure to O_3 were correlated with yield reductions in these tomato cultivars. Thus, unlike beans, gas exchange was not a useful measurement for predicting tomato cultivar responses to O_3.

Table 5. Stem and leaf dry weight and percent change from control (CF) of four cultivars of processing tomato exposed to ozone in Riverside, CA in 1987. Data are in g per m-row[a]; means of three replicate plots per ozone level

Treatment	FM785		HYB 31		UC204C		E6203	
	g	%	g	%	g	%	g	%
CF	507	-	390	-	456	-	588	-
NF	548	+8.0	475	+21.8	570	+25.1	515	-12.5
NF150	487	-4.1	268	-31.2	421	-7.7	349	-40.7

[a]G per m-row x 8.11 = lbs $acre^{-1}$ x 1.12 = kg ha^{-1}.

Table 8. Lint weights and percent change from controls (CF) of four cultivars of cotton exposed to ozone in Riverside, CA in 1987. Data are in g per m-row[a]; means of three replicates per ozone level

Treat-ment	SJ-2		SS2086		C1		GC510	
	g	%	g	%	g	%	g	%
CF	33.14	-	35.11	-	27.82	-	33.69	-
NF	42.30	+27.6	32.48	-7.5	26.79	-3.7	29.71	-11.8
NF150	20.02	-39.6	10.27	-70.7	11.28	-59.5	11.35	-66.3

[a]G per m-row x 11.84 = lbs $acre^{-1}$ x 1.12 = kg ha^{-1}.

had 8 to 12% losses. Except for SJ2, regression analyses of yield data showed statistically significant reductions in lint yield of each cotton cultivar with increasing concentrations of O_3 (Table 14). The increase in yield of SJ2 at low O_3 levels relative to CF control plots was likely due to plot to plot variations in plant growth, because previous studies have shown that yields of SJ2 cotton were reduced 15 to 20% by ambient O_3 concentrations (Temple et al., 1985).

Vegetative growth of cotton was also reduced by exposure to high seasonal concentrations of O_3, but not to the degree that lint yields were reduced. Lint yields of GC510 were reduced 66% by the NF150 treatment (Table 3), but plant weights were reduced only 18% (Appendix B, Table 17). Reductions for cultivar 2086 in the high O_3 treatment were: lint 71%, plant 37% (Table B18); for SJ-2, lint 40%, plant 21% (Table B19); and for C1, lint 59%, plant 34% (Table B20). The greater effect of O_3 on lint yields relative to vegetative growth may reflect the shrubby, perennial nature of cotton as a species. Under O_3 stress, which reduces the photosynthetic energy available for metabolic functions, the plant may

Table 7. Seasonal rates of maximum stomatal conductance (C) and percent change from control for four cultivars of processing tomato exposed to ozone in Riverside, CA in 1987. Data are in cm s^{-1}; means of 45 measurements per ozone level (± 1 s.d.)

Treatment	FM785		HYB31		UC204C		E6203	
	C	%	C	%	C	%	C	%
CF	1.90 (0.94)	-	1.80 (0.88)	-	1.91 (0.73)	-	1.60 (0.79)	-
NF	1.37 (0.71)	-27.9	1.70 (0.81)	-5.6	1.57 (0.57)	-17.8	1.44 (0.51)	-10.0
NF150	0.95 (0.58)	-50.0	1.18 (0.58)	-34.4	1.29 (0.61)	-32.5	1.28 (0.50)	-20.0

4. Lettuce

Visible O_3 injury symptoms developed on all outer leaves of lettuce cultivars, and all except 'Prizehead' also developed symptoms of peroxyacetyl nitrate (PAN) injury following a PAN episode that occurred from March 4 to 6, 1988. However, despite the appearance of severe O_3 injury symptoms on lettuce leaves, none of the cultivars showed consistent effects of O_3 on yield (Table 10). Other measures of lettuce response to O_3, including data form AA plots, are given in Appendix B.

These results are consistent with those of previous field studies on a cultivar of head lettuce ('Empire') which also reported severe foliar injury symptoms on outer leaves of lettuce, but no reductions in lettuce yield (head weight) except at O_3 concentrations higher than those expected in lettuce-growing regions of the state (Temple et al., 1985). The lack of significant effects of O_3 on yield of these four cultivars (Table 14), coupled with no significant effects of O_3 on other cultivars of lettuce in previous studies indicates that lettuce yields should not be significantly affected by O_3, and that cultivars appear to be relatively homogeneous in their lack of yield responses to O_3.

5. Broccoli

No O_3 injury symptoms were observed on any of the four broccoli cultivars. A summary of the harvest data for the four cultivars of broccoli is given in Table 11. Yield data for AA plots is given in Appendix B. The harvest data showed a trend of reduced growth and yield in plants exposed to O_3, compared with growth in CF chambers, but none of the cultivars showed a statistically significant decrease in yield with increasing O_3 concentrations (Table 14). The cultivar 'Green Belt' showed a statistically significant ($p = 0.03$) increase in growth in response to O_3, but the biological significance of this is difficult to evaluate because of large plot-to-plot variations in cultivar yield. These among-plot variations account for the lack of statistical significance in the O_3 dose-yield relationship.

Data on rates of stomatal conductance (Table 12) also did not reveal any consistent pattern among the broccoli cultivars. Plants exposed to O_3 had lower stomatal conductance than plants in CF (control) chambers, but rates of stomatal conductance did not appear to be associated either with yield or with susceptibility to O_3. These data indicated that measurement reduce reproductive effort to maintain vegetative, primarily foliar, growth. Other measures of cotton response to O_3, including data from AA plots, are given in Appendix B.

These results confirm previous reports of the susceptibility of cotton to O_3 (Temple et al., 1985), and they also suggest that crop loss equations based upon responses of SJ-2 cotton to O_3 (Temple et al., 1985) may underestimate overall losses to O_3, based upon all the cultivars of cotton grown in the state. However, this conclusion must be viewed with caution because of the preliminary nature of these results. In particular, the growing season in 1987 was an atypical one for cotton. The crop was planted in July and most of the bolls were set and matured during the cooler, short-day season of fall. Bolls were harvested in December. Although plants grew well in open (AA) plots, boll yields were very poor and two of the cultivars matured no bolls in AA plots (Appendix B). Plants inside chambers had better yields, aided perhaps by the slightly higher temperatures inside chambers. However, boll set inside chambers may also have been influenced by the atypical growing season.

Seasonal mean rates of stomatal conductance for the four cotton cultivars are shown in Table 9. The cultivar SJ-2 had the highest rate of stomatal conductance and also the greatest reduction in conductance in plants exposed to O_3. Since this cultivar had the least yield reduction in response to O_3, this suggests that stomatal conductance was not a good predictor of cultivar responses to O_3. Rates of conductance and the effect of O_3 upon those rates appeared to be about the same in the other three cultivars, again indicating that conductance measurements were not useful in predicting cotton cultivar responses to O_3. However, the cultivar having the shortest growing season (SS2086) was the most susceptible to O_3 and the one with the longest growing season (SJ2) was the most resistant. This suggests that the more determinate the cultivar; that is, the more rapidly it shifts from the vegetative to the reproductive stage and the more compressed the reproductive stage, the more susceptible to O_3 it may be. Thus, degree of determinism in a cotton cultivar could possibly be used to rank cotton cultivars to susceptibility to O_3-induced yield reductions.

Table 10. Head fresh weight and percent change from control (CF) of four cultivars of lettuce exposed to ozone in Riverside, CA, February-March 1988. Data are in g per m-row[a]; means of six replicates per ozone level

Treat-ment	Royal Green		Prizehead		Dark Green		P.I. Cos	
	g	%	g	%	g	%	g	%
CF	1642	-	749	-	1005	-	809	-
NF	1595	-2.8	607	-19.0	1108	+10.2	954	+17.9
NF150	1502	-8.5	871	+16.3	1019	+1.4	948	+17.2

[a]G per $m\text{-row}^{-1}$ x 29.74 = lbs $acre^{-1}$ x 1.12 = kg ha^{-1}.

of stomatal conductance in broccoli was useful in showing that ambient concentrations of O_3 could reduce rates of stomatal conductance, but these measurements were not useful in predicting the responses of individual cultivars of broccoli to O_3.

6. Onion

Ozone injury symptoms had developed on onion leaves by late April, and plants in NF150 chambers showed severe O_3 injury symptoms by mid-May. Ozone also increased the rate of senescence in onion so that by June 1, plants in NF150 plots showed advanced senescence (tops had fallen and leaves were brown). In comparison, plants in CF chambers had no fallen top leaves and foliage remained green. Plants in NF chambers and those exposed to ambient air also had advanced senescence of tops, relative to plants in CF chambers, although the response was not as pronounced as in the NF150 treatment. Senescence rates were evaluated on 23 May, and the cultivars ranked: 'Rio Hondo' > 'Rio Bravo' > 'Nu-Mex' > 'Colossal' in rate of maturation, with 'Rio Hondo' the fastest to mature.

Bulb fresh weights for each cultivar are shown in Table 13. Other harvest data, and yields from AA plots, are given in Appendix B. The large amount of visible foliar injury observed in NF150 treatments translated into reduced yields at this level of O_3, but yield reductions appeared to be less than expected relative to the amount of foliar injury. In addition, only the cultivar 'Rio Bravo' showed a statistically

Table 9. Seasonal mean maximum rates of stomatal conductance (C) and percent change from control (CF) for four cultivars of cotton exposed to ozone in Riverside, CA in 1987. Data are in cm s^{-1}; means of 45 measurements per ozone level (± 1 s.d.)

Treat-ment	SJ2		SS2086		C1		GC510	
	C	%	C	%	C	%	C	%
CF	2.47 (0.40)	-	2.34 (0.77)	-	2.05 (0.72)	-	1.98 (0.50)	-
NF	2.35 (0.57)	-4.9	2.07 (0.47)	-11.5	2.01 (0.52)	-2.0	2.01 (0.48)	+1.5
NF150	1.39 (0.69)	-43.7	1.51 (0.60)	-35.5	1.47 (0.52)	-28.3	1.49 (0.76)	-24.7

Table 12. Mean seasonal rates of maximum stomatal conductance (C) and percent change from control (CF) of four cultivars of broccoli exposed to ozone in Riverside, CA, February-April 1988. Data are in cm s^{-1}; means of 18 measurements per cultivar per level of ozone (± 1 s.d.)

Treatment	Green Duke		Emperor		Commander		Green Belt	
	C	%	C	%	C	%	C	%
CF	0.96 (0.48)	-	1.32 (0.16)	-	1.22 (0.19)	-	0.99 (0.39)	-
NF	0.95 (0.65)	-1.0	0.78 (0.08)	-40.9	0.98 (0.13)	-19.7	0.96 (0.35)	-3.0
NF150	0.74 (0.42)	-22.9	0.81 (0.34)	-38.6	0.82 (0.27)	-32.8	0.79 (0.50)	-20.2

Table 11. Head fresh weight and percent change from control (CF) of four cultivars of broccoli exposed to ozone in Riverside, CA, February-April 1988. Data are in g per m-row[a]; means of three replicates per ozone level. Harvest dates are in parentheses

Treatment	Green Duke (4/25)		Emperor (5/5)		Commander (5/5)		Green Belt (5/17)	
	g	%	g	%	g	%	g	%
CF	1420	-	2211	-	2554	-	2778	-
NF	1056	-25.6	1579	-28.6	2073	-18.8	2530	-8.9
NF150	1195	-15.8	2073	-6.2	1881	-26.4	3996	+43.8

[a]G per m-row x 14.87 = lbs $acre^{-1}$ x 1.12 = kg ha^{-1}.

significant linear regression between reduction in yield and increased O_3 concentrations (Table 14). Reductions in yield caused by O_3 did not appear to be related to rates of maturation of these onion cultivars because the cultivar with the fastest growth rate, 'Rio Hondo,' also had the least response to O_3. The other cultivars also showed no relationship between rate of maturity and susceptibility to O_3.

Table 14. Regression equations for yield (Y, g m-row^{-1}) and seasonal 12-hour ozone concentrations [O_3, ppm] for four cultivars of field crops grown in Riverside, CA (1987-1988). Numbers in parentheses are standard errors of the parameter estimates; s = standard deviation of residual mean square error = MSE. Each level of O_3 was replicated three times.

Beans (Y = Seed Weight, x 13.3 = kg ha^{-1})

Linden Red Kidney

$Y = 25.2 + 2014.7\,[O_3] - 18011\,[O_3]^2$ $p = 0.07$ $R^2 = 0.65$; $s = 20.45$
(±20.1) (±875.3) (±6633)

Sal Small White

$Y = 163.6 - 978.7\,[O_3]$ $p = 0.002$, $R^2 = 0.83$; $s = 22.24$
(±14.4) (±179.9)

Sutter Pinks

$Y = 165.8 - 1357.3\,[O_3]$ $p = 0.003$, $R^2 = 0.79$; $s = 34.99$
(±22.7) (±283.1)

Yolano Pinks

$Y = 167.6 - 1397.7\,[O_3]$ $p = 0.06$, $R^2 = 0.46$; $s = 75.75$
(±49.2) (±612.8)

Cotton (Y = Lint Weight, x 13.3 = kg ha^{-1})

C1

$Y = 32.3 - 202.5\,[O_3]$ $p = 0.03$, $R^2 = 0.51$; $s = 7.38$
(±4.6) (±75.4)

GC510

$Y = 38.6 - 266.3\,[O_3]$ $p = 0.05$, $R^2 = 0.44$; $s = 11.12$
(±6.9) (±113.7)

SJ2

$Y = 25.4 + 883.3\,[O_3] - 10528\,[O_3]^2$ $p = 0.02$, $R^2 = 0.71$; $s = 7.29$
(±6.3) (±328.1) (±3256)

SS2086

$Y = 41.6 + 306.1\,[O_3]$ $p = 0.01$, $R^2 = 0.62$; $s = 8.80$
(±5.5) (±89.9)

Table 13. Bulb fresh weights and percent change from control (CF) of four cultivars of onion exposed to ozone in Riverside, CA, February-June, 1988. Data are in g m^{-2} [a]; means of three replicates per level of ozone

Treat-ment	Rio Hondo		Rio Bravo		Nu-Mex		Colossal	
	g	%	g	%	g	%	g	%
CF	4404	-	4775	-	5011	-	4183	-
NF	4712	+7.0	4592	-3.8	5246	+4.7	4333	+3.6
NF150	4310	-2.1	3912	-18.1	4670	-6.8	3647	-12.8

[a]G m^{-2} x 8.921 = lbs $acre^{-1}$ x 1.12 = kg ha^{-1}.

Table 14 (continued) - 3

<u>Onion (Y = Total Bulb Fresh Weight, x 10 = kg ha^{-1})</u>

<u>Colossal</u>

$Y = 4442 - 6977\ [O_3]$; $p = 0.25,\ R^2 = 0.18;\ s = 554.7$
(±363) (±5616)

<u>Nu-Mex</u>

$Y = 5238 - 4716\ [O_3]$; $p = 0.55,\ R^2 = 0.05;\ s - 746.8$
(±488) (±7562)

<u>Rio Bravo</u>

$Y = 5034 - 10941\ [O_3]$; $p = 0.04,\ R^2 = 0.48;\ s = 420.4$
(±275) (±4256)

<u>Rio Hondo</u>

$Y = 4570 - 1710\ [O_3]$; $p = 0.78,\ R^2 = 0.01;\ s = 596.8$
(±390) (±6042)

<u>Broccoli (Y = Head Fresh Weight, x 16.65 = kg ha^{-1})</u>

<u>Green Duke</u>

$Y = 1360 - 2827\ [O_3]$; $p = 0.39,\ R^2 = 0.11;\ s = 259.4$
(±173) (±3103)

<u>Green Belt</u>

$Y = 2199 + 18758\ [O_3]$; $p = 0.03,\ R^2 = 0.52;\ s = 571.4$
(±380) (±6836)

<u>Commander</u>

$Y = 2641 - 9811\ [O_3]$; $p = 0.17,\ R^2 = 0.26;\ s = 529.5$
(±352) (±6334)

<u>Emperor</u>

$Y = 2016 - 1273\ [O_3]$; $p = 0.83,\ R^2 = 0.01;\ s = 466.2$
(±310) (±5577)

Table 14 (continued) - 2

<u>Tomato (Y = Fruit Fresh Weight, x 9.08 = kg ha^{-1})</u>

<u>FM785</u>

$Y = 9055 - 32367 [O_3]$ $p = 0.12$, $R^2 = 0.35$, $s = 1875.7$
(±1410) (±17913)

<u>HYBRID31</u>

$Y = 9504 - 42832 [O_3]$ - $p = 0.05$; $R^2 = 0.51$; $s = 1795$
(±1350) (±17139)

<u>UC204C</u>

$Y = 6315 - 21070 [O_3]$ $p = 0.28$, $R^2 = 0.19$; $s = 1862.6$
(±1401) (±17789)

<u>E6203</u>

$Y = 8590 - 41277 [O_3]$ $p = 0.01$, $R^2 = 0.70$; $s = 1158.8$
(±871) (±11067)

<u>Lettuce (Y = Head Fresh Weight, x 33.31 = kg ha^{-1})</u>

<u>Dark Green</u>

$Y = 2167 - 3086 [O_3]$ $p = 0.48$; $R^2 = 0.07$; $s = 299.1$
(±209) (±4175)

<u>Parris Island Cos</u>

$Y = 1672 + 2011 [O_3]$ $p = 0.64$; $R^2 = 0.03$; $s = 295.2$
(±207) (±4121)

<u>Prizehead</u>

$Y = 1337 + 2310 [O_3]$ $p = 0.78$; $R^2 = 0.02$; $s = 512.8$
(±429) (±7908)

<u>Royal Green</u>

$Y = 3267 - 4784 [O_3]$ $p = 0.41$; $R^2 = 0.10$; $s = 395.8$
(±277) (±5526)

related to rate of growth or other physiological responses measured in this study.

- Differences in relative responses to O_3 between summer crops and winter annuals may be attributable to lower ambient O_3 concentrations during the winter and perhaps to the lower rates of stomatal conductance of winter crops.

In conclusion, this study showed promising results in relating susceptibility to O_3 yield reductions caused by exposure to O_3 and physiological traits in four cultivars of beans, tomato, and cotton, but not in cultivars of onion, lettuce, or broccoli. Further research is needed to determine if the responses observed in this study have wider applicability to other cultivars and other field crops in California.

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CONCLUSIONS

The hypothesis to be tested by this research project was that susceptibility to O_3 of cultivars of crop plants was related to rates of physiological processes of these cultivars, so that the faster the process, such as gas exchange, as measured by stomatal conductance, or rate of maturation, as measured by growth per unit time, the more susceptible to O_3 the cultivar should be. Therefore, measurement of these physiological traits could predict responses of cultivars to O_3. This hypothesis was tested by exposing four cultivars of three summer and three winter crops to three levels of O_3 throughout the life of the crop. Results showed that the hypothesis was true for some crop species, but not for others:

- Beans - Susceptibility to O_3 of four bean cultivars was related to rates of stomatal conductance.

- Tomato - Cultivar susceptibility was related to cultivar productivity; that is, the most productive cultivars (highest yields) were the most susceptible to O_3.

- Cotton - Cultivar susceptibility appeared to be related to rate of maturation because the short-season, faster-growing cultivars were more susceptible to O_3 than the longer-season, less deterministic (more indefinite growing season) cultivars.

- Lettuce - Yields of the cultivars used in this study did not appear to be significantly affected by O_3.

- Broccoli - Yield reductions in broccoli cultivars did not appear to be related either to rates of stomatal conductance or to rates of maturation of these cultivars.

- Onion - Only one onion cultivar showed significant reductions in yield in response to O_3, and this response did not appear to be

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APPENDIX A

Summary of Ozone Exposure Statistics for Summer and Winter Crops
Used in Cultivars Study, Riverside, CA
(1987-1988)

All data are in ppm

Table A2. Summary of ozone exposure statistics - individual plot means for seasonal 12-hour (0800-2000) ozone concentrations (ppm)

Beans		Tomato		Cotton	
Plot No.	O_3	Plot No.	O_3	Plot No.	O_3
A4	0.019	B1	0.012	A3	0.111
A6	0.013	B5	0.013	D5	0.007
C5	0.014	D3	0.015	E3	0.012
A7	0.071	B6	0.064	C7	0.053
C6	0.072	C3	0.069	D6	0.055
D1	0.072	E5	0.067	E2	0.054
C4	0.116	A5	0.108	A2	0.090
D2	0.116	C2	0.111	B3	0.089
E1	0.116	E4	0.109	B4	0.090

Lettuce		Onion		Broccoli	
Plot No.	O_3	Plot No.	O_3	Plot No.	O_3
B4	0.017	B2	0.018	C4	0.017
B5	0.016	C6	0.017	C5	0.015
E4	0.015	E1	0.017	D5	0.015
A2	0.042	A7	0.051	C7	0.045
A4	0.042	B3	0.052	D1	0.044
B1	0.042	D6	0.052	D4	0.046
A5	0.074	A3	0.099	A6	0.082
D3	0.073	C3	0.098	C2	0.084
E2	0.076	D2	0.096	E5	0.085

Table A1. Summary of ozone exposure statistics - treatment means (ppm)

Treatment	Highest Hour		Highest Day		Seasonal Means	
	1st	2nd	12[a]	24	12[a]	24
			Bean (7/31/87 - 9/21/87)			
CF	0.053	0.051	0.030	0.018	0.015	0.007
NF	0.198	0.196	0.114	0.067	0.072	0.030
NF150	0.339	0.334	0.188	0.105	0.116	0.048
AA	0.210	0.208	0.124	0.071	0.082	0.037
			Tomato (7/31/87 - 10/13/87)			
CF	0.060	0.044	0.029	0.019	0.013	0.008
NF	0.244	0.201	0.112	0.066	0.067	0.036
NF150	0.377	0.369	0.189	0.105	0.109	0.058
AA	0.256	0.217	0.124	0.071	0.077	0.043
			Cotton (7/31/87 - 11/9/87)			
CF	0.069	0.059	0.031	0.018	0.010	0.010
NF	0.228	0.201	0.109	0.063	0.054	0.039
NF150	0.382	0.368	0.193	0.107	0.090	0.062
AA	0.256	0.217	0.124	0.074	0.064	0.046
			Lettuce (2/29/88 - 4/1/88)			
CF	0.048	0.046	0.028	0.024	0.018	0.014
NF	0.118	0.118	0.084	0.047	0.042	0.027
NF150	0.219	0.208	0.141	0.077	0.074	0.044
AA	0.149	0.145	0.091	0.052	0.044	0.029
			Onion (2/29/88 - 5/5/88)			
CF	0.065	0.062	0.033	0.024	0.017	0.014
NF	0.176	0.175	0.094	0.050	0.052	0.032
NF150	0.286	0.281	0.173	0.091	0.098	0.055
AA	0.197	0.195	0.109	0.059	0.060	0.059
			Broccoli (2/29/88 - 5/27/88)			
CF	0.078	0.074	0.033	0.027	0.016	0.013
NF	0.230	0.214	0.117	0.060	0.045	0.029
NF150	0.311	0.297	0.211	0.116	0.084	0.049
AA	0.247	0.211	0.129	0.071	0.053	0.033

[a]0800-2000 PST.

APPENDIX B

Individual Plot Data for All Cultivars of
All Crops Harvested in 1987 and 1988

Table B2. Harvest weights of dry beans, cv. Sal Small White, in grams

	Number				Fresh Weight			Dry weight				Wt./
			Pods									100
Plot	Plant	Beans	Green	Total	Plant	Pod	Root	Plant	Pod	Root	Beans	Seeds
					Charcoal Filtered (CF)							
A4	12	928	17	208	409.8	179.9	40.4	82.0	137.5	8.0	107.9	11.6
A6	12	1148	50	262	656.0	305.7	39.5	125.6	192.6	8.6	158.0	13.8
C5	8	1139	38	263	502.2	296.7	39.6	105.6	214.4	8.0	177.7	15.6
					Nonfiltered (NF)							
A7	6	416	75	133	257.3	122.7	11.7	59.1	47.6	2.5	33.5	8.1
C6	13	893	17	242	347.7	159.5	23.3	74.2	127.4	13.8	104.4	11.7
D1	12	771	72	217	449.6	211.2	28.5	98.1	105.9	1.4	82.8	10.7
					Nonfiltered x 1.5 (NF150)							
C4	12	445	32	148	248.5	76.7	17.5	54.9	52.0	3.9	41.8	9.4
D2	11	380	1	132	158.1	56.6	11.6	39.7	48.7	2.6	40.5	10.7
E1	13	653	43	193	619.5	139.7	24.9	147.1	86.1	6.0	69.4	10.6
					Ambient Air (AA)							
A1	10	178	3	59	39.7	25.7	9.4	7.9	19.7	2.0	14.5	8.1

Table B1. Harvest weights of dry bean, cv. Sutter pink, in grams

	Number				Fresh Weight			Dry weight				Wt./
			Pods									100
Plot	Plant	Beans	Green	Total	Plant	Pod	Root	Plant	Pod	Root	Beans	Seeds
					Charcoal Filtered							
A4	10	396	16	111	346.6	181.8	64.2	72.7	123.0	10.7	99.1	25.0
A6	15	798	46	213	677.5	493.0	53.0	123.0	261.1	10.4	217.0	27.2
C5	9	445	19	107	353.2	225.3	46.0	75.9	147.7	2.5	124.0	27.9
					Nonfiltered							
A7	10	149	10	51	100.0	44.5	17.8	28.1	26.6	3.4	21.3	14.3
C6	11	281	8	92	107.5	80.4	16.1	48.0	63.9	3.3	50.2	17.7
D1	13	416	27	125	256.6	156.2	32.0	82.4	87.5	8.0	68.2	16.4
					Nonfiltered x 1.5							
C4	12	78	10	35	77.4	21.0	13.7	18.5	12.2	3.2	9.1	11.7
D2	5	107	4	44	46.2	19.1	21.5	15.9	14.8	1.2	11.2	10.5
E1	15	125	15	51	136.0	36.0	17.5	40.9	22.3	3.3	17.7	14.2
					Ambient Air							
A1	13	159	2	72	143.6	71.9	23.4	41.2	55.7	4.4	45.0	28.3

Plant weight is without pods.
Dry bean count and weight is after culls removed.

Table B4. Harvest weights of dry beans, cv. Yolano Pink, in grams

	Number				Fresh Weight			Dry weight				Wt./
			Pods									100
Plot	Plant	Beans	Green	Total	Plant	Pod	Root	Plant	Pod	Root	Beans	Seeds
					Charcoal Filtered							
A4	9	195	2	63	145.6	73.9	38.3	29.3	58.7	7.0	47.9	24.6
A6	12	395	35	136	395.6	293.9	53.8	75.9	128.5	8.9	100.0	25.3
C5	13	960	87	297	839.0	637.1	39.6	174.0	357.6	8.0	298.4	31.1
					Nonfiltered							
A7	11	140	11	59	109.5	38.1	19.2	27.6	25.2	3.0	19.6	14.0
C6	11	343	3	123	91.1	93.7	12.4	47.2	78.1	3.0	61.0	17.8
D1	10	262	27	125	57.8	156.2	12.5	32.1	58.3	3.2	45.7	17.4
					Nonfiltered x 1.5							
C4	16	86	12	50	88.6	20.9	18.5	21.4	11.5	3.7	8.5	9.9
D2	10	77	21	48	129.6	25.5	11.1	29.3	10.5	2.6	8.0	10.4
E1	10	152	5	85	96.7	35.2	12.5	42.0	28.9	3.1	19.6	12.9
					Ambient Air							
A1	16	293	1	116	63.1	71.0	15.7	26.2	59.1	4.1	44.7	15.3

Table B3. Harvest weights of dry beans, cv. Linden Red Kidney, in grams

	Number				Fresh Weight			Dry weight				Wt./
			Pods									100
Plot	Plant	Beans	Green	Total	Plant	Pod	Root	Plant	Pod	Root	Beans	Seeds
					Charcoal Filtered							
A4	11	101	11	41	179.6	97.1	62.1	40.7	49.7	13.5	30.9	30.6
A6	10	154	16	72	261.7	161.6	41.4	68.9	78.2	9.4	49.3	32.0
C5	11	183	33	84	441.6	240.3	55.1	108.1	115.8	13.6	75.5	41.3
					Nonfiltered							
A7	10	178	44	99	326.6	235.5	40.6	75.8	100.9	10.2	57.7	32.4
C6	11	195	31	94	268.0	234.7	46.1	64.7	112.0	10.5	69.7	35.7
D1	10	314	71	154	574.3	502.5	63.3	140.8	190.3	17.5	102.3	32.6
					Nonfiltered x 1.5							
C4	11	108	17	83	228.3	90.2	39.0	44.4	47.5	9.0	30.0	27.8
D2	10	53	12	55	177.9	54.4	4.4	32.4	33.0	5.3	15.7	29.6
E1	10	121	47	100	322.5	165.6	51.0	64.7	56.7	11.3	33.6	27.8
					Ambient Air							
A1	10	83	17	39	88.2	92.8	38.6	17.8	36.3	17.8	23.3	28.1

Table B6. Harvest weights of tomato fruit, cv. Hybrid 31, in grams

Plot	Total		Red		Green		Red Market		Green Market	
	No.	g	No.	g	No.	g	No.	g	No.	g
					Charcoal Filtered					
B1	266	8226.7	150	6400.9	116	1825.8	139	6323.6	71	1680.4
B5	247	7976.6	216	7610.3	31	366.3	183	7204.9	13	295.8
D3	204	7991.6	123	6136.8	81	1854.8	123	6136.8	70	1784.7
					Nonfiltered					
B6	226	8579.9	126	6039.9	100	2539.9	115	5947.2	87	2470.0
C3	264	9099.9	231	8643.9	33	455.9	195	8171.9	20	414.9
E5	196	8081.2	159	7726.2	37	355.1	140	7143.1	13	274.2
					Nonfiltered x 1.5					
A5	122	3526.9	75	3083.1	47	443.8	67	2998.9	23	367.3
C2	224	4181.3	140	3585.1	84	596.2	116	3452.3	28	468.3
E4	141	3517.4	101	3274.1	40	243.2	78	2716.8	8	136.2
					Ambient Air					
D4	134	5828.0	106	5631.0	28	197.1	92	5008.6	6	83.5

Table B5. Harvest weights of tomato fruit, cv. FM785, in grams

Plot	Total		Red		Green		Red Market		Green Market	
	No.	g	No.	g	No.	g	No.	g	No.	g
					Charcoal Filtered					
B1	187	4013.4	72	2187.5	115	1825.9	58	2119.9	74	1608.1
B5	238	7944.0	126	5322.8	112	2621.2	113	5129.2	93	2478.1
D3	204	7991.6	123	6136.8	81	1854.8	123	6136.8	70	1784.7
					Nonfiltered					
B6	222	6622.6	95	4080.2	127	2542.4	82	3952.9	97	2350.1
C3	162	6416.6	118	5480.6	44	935.9	114	5451.1	36	894.7
E5	255	10486.1	130	7753.3	125	2732.8	123	7409.9	94	2550.7
					Nonfiltered x 1.5					
A5	122	4110.8	68	3285.8	54	825.0	68	3285.8	46	804.9
C2	144	3831.4	93	3055.6	51	775.8	88	3015.7	32	714.3
E4	222	7040.1	49	2693.7	173	4346.4	49	2693.7	137	4118.0
					Ambient Air					
D4	112	5934.2	92	5424.9	20	509.3	87	5273.8	14	369.1

Tomatoes not in the market count and weight were under 3 cm or rotten.
All plots had three plants.

Table B8. Harvest weights of tomato fruit, cv. E6203, in grams

Plot	Total		Red		Green		Red Market		Green Market	
	No.	g	No.	g	No.	g	No.	g	No.	g
					Charcoal Filtered					
B1	229	5192.9	101	2467.9	128	2725.0	71	2708.0	90	2453.5
B5	199	7296.5	128	5709.7	71	1586.7	113	5545.5	60	1514.4
D3	243	7629.7	166	6479.6	77	1150.1	158	6365.7	47	981.1
					Nonfiltered					
B6	178	7554.7	155	6967.3	23	587.4	153	6941.0	22	576.7
C3	148	4793.6	88	3408.5	60	1385.1	83	3359.7	52	1342.6
E5	247	7468.3	122	5837.4	125	1631.0	115	5737.2	95	1436.1
					Nonfiltered x 1.5					
A5	85	4366.1	66	4094.6	19	271.5	66	4094.6	14	246.8
C2	98	3505.0	58	2677.6	40	827.5	58	2677.6	32	763.0
E4	105	3153.9	52	2369.7	53	784.3	48	2347.7	30	650.1
					Ambient Air					
D4	237	10476.0	197	9540.3	40	935.7	185	9313.8	27	780.0

Table B7. Harvest weights of tomato fruit, cv. UC204C, in grams

Plot	Total No.	Total g	Red No.	Red g	Green No.	Green g	Red Market No.	Red Market g	Green Market No.	Green Market g
					Charcoal Filtered					
B1	79	2196.0	21	844.3	58	1351.7	19	773.6	33	1207.3
B5	171	5905.9	73	3547.1	98	2358.8	70	3437.8	83	2228.5
D3	124	5306.8	84	4306.5	40	1000.4	79	4167.9	35	984.0
					Nonfiltered					
B6	160	5905.3	76	3866.0	84	2039.2	74	3857.7	76	1957.4
C3	129	3504.2	37	1656.5	92	1847.7	34	1639.1	76	1762.0
E5	199	7022.1	101	5388.4	98	1633.8	98	5309.5	58	1360.2
					Nonfiltered x 1.5					
A5	64	2127.2	14	1147.7	50	979.5	13	1131.2	42	928.8
C2	51	2387.8	45	2286.4	6	101.4	44	2285.7	5	96.9
E4	169	6650.4	63	4119.9	106	2530.5	63	4119.9	94	2454.8
					Ambient Air					
D4	162	8548.9	123	7460.6	39	1088.3	122	7289.7	27	978.2

Table B10. Harvest weights of tomato plants, cv. Hybrid 31, in grams

Plot	Total Root Fresh	Total Root Dry	Lateral Root Fresh	Lateral Root Dry	Vertical Root Fresh	Vertical Root Dry	Plant Fresh	Plant Dry	Soluble Solids g/100 g
				Charcoal Filtered					
B1	123.8	29.3	1.58	1.54	30.60	27.73	2672.7	489.0	4.7
B5	105.1	27.5	3.26	2.60	80.18	24.89	1996.2	382.3	4.6
D3	111.3	17.0	2.61	1.51	73.59	15.48	1165.4	298.1	4.1
				Nonfiltered					
B6	225.4	36.4	7.55	6.75	99.34	29.60	5014.0	763.7	6.4
C3	132.4	21.1	2.14	1.97	55.76	19.08	1588.5	383.0	3.4
E5	82.0	12.9	1.40	1.16	14.59	11.75	1519.3	277.5	4.0
				Nonfiltered x 1.5					
A5	15.3	6.8	0.76	0.43	6.82	6.37	1007.4	194.9	3.6
C2	124.9	21.6	3.05	2.69	64.30	18.88	1623.9	345.6	5.6
E4	49.6	9.7	0.70	0.66	12.94	9.05	916.5	263.8	3.1
				Ambient Air					
D4	21.7	8.2	0.89	0.83	8.13	7.37	486.4	116.2	5.4

Table B9. Harvest weights of tomato plants, cv. FM785, in grams

Plot	Total Root		Lateral Root		Vertical Root		Plant		Soluble Solids
	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry	g/100 g
				Charcoal Filtered					
B1	118.9	28.0	8.18	5.96	65.60	22.06	2432.3	464.7	7.4
B5	144.0	25.3	6.08	4.90	77.68	30.36	2309.9	560.8	6.2
D3	165.9	27.2	2.35	2.09	93.98	25.12	2465.1	496.5	6.6
				Nonfiltered					
B6	179.9	30.0	5.55	4.03	101.58	25.97	3477.7	612.6	6.6
C3	173.5	27.9	6.28	4.37	111.00	23.57	2215.4	481.9	5.5
E5	137.5	21.5	2.97	2.85	22.26	18.61	2778.4	548.5	3.6
				Nonfiltered x 1.5					
A5	65.6	16.0	1.03	0.90	32.69	15.11	1755.5	292.4	4.6
C2	158.6	27.4	3.17	2.34	96.08	25.10	1906.7	420.3	6.9
E4	131.4	22.0	4.40	3.94	56.40	18.04	4524.2	747.2	4.9
				Ambient Air					
D4	11.6	8.2	1.13	1.11	7.66	7.07	531.9	132.7	5.0

Weights are the total of three plants.
Plant weights are without fruit.

Table B12. Harvest weights of tomato plants, cv. UC204C, in grams

Plot	Total Root		Lateral Root		Vertical Root		Plant		Soluble Solids
	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry	g/100 g
					Charcoal Filtered				
B1	168.5	38.2	8.35	6.05	107.66	32.10	3082.9	477.8	6.9
B5	213.0	46.2	3.95	3.03	161.54	43.19	3067.8	561.4	5.9
D3	196.8	34.7	2.18	1.79	131.68	32.94	1281.5	328.4	5.6
					Nonfiltered				
B6	278.9	44.4	3.34	2.16	208.08	42.28	3813.6	627.5	6.2
C3	206.9	35.4	3.27	2.59	109.27	32.85	2284.4	518.6	6.1
E5	281.8	45.0	3.89	3.65	190.63	41.32	2518.8	564.7	4.9
					Nonfiltered x 1.5				
A5	46.8	14.6	1.14	1.05	20.43	13.58	1659.7	273.2	3.7
C2	126.8	21.3	4.25	3.56	46.58	17.70	1493.0	327.2	6.3
E4	224.5	35.5	2.95	2.79	69.02	32.66	3232.0	661.8	4.8
					Ambient Air				
D4	38.8	15.0	0.61	0.56	15.93	14.48	770.2	168.4	4.0

Table B11. Harvest weights of tomato plants, cv. E6203, in grams

Plot	Total Root		Lateral Root		Vertical Root		Plant		Soluble Solids
	Fresh	Dry	Fresh	Dry	Fresh	Dry	Fresh	Dry	g/100 g
					Charcoal Filtered				
B1	252.2	56.7	6.99	5.01	166.41	51.64	4133.8	755.5	5.7
B5	178.8	41.8	5.52	4.88	97.76	36.90	2309.9	509.3	5.1
D3	217.7	32.5	6.15	4.58	123.80	27.89	2150.6	500.2	5.5
					Nonfiltered				
B6	209.4	31.5	6.50	5.87	71.13	25.64	2499.7	416.9	4.7
C3	228.3	33.5	6.69	6.34	55.43	27.11	2026.9	515.3	5.3
E5	237.8	32.1	7.65	7.18	45.03	24.95	2895.7	611.2	4.5
					Nonfiltered x 1.5				
A5	60.8	15.6	3.30	2.90	21.73	12.66	1471.9	298.3	3.4
C2	172.7	26.2	7.62	4.15	100.66	22.01	1588.4	393.5	6.0
E4	133.9	18.1	3.67	3.45	24.91	14.68	1504.3	355.3	5.4
					Ambient Air				
D4	43.4	17.6	1.17	1.12	20.71	16.47	1084.2	244.8	4.9

Table B14. Harvest numbers of cotton plants, cv. C1

Plot	Number					
	Plant	Bolls Total	Bolls Unopened	Bolls Open	Seed	Roots
			Charcoal Filtered			
A3	12	26	9	17	548	12
D5	9	46	34	12	479	9
E3	13	51	36	15	496	13
			Nonfiltered			
C7	10	26	16	10	379	9
D6	10	36	14	22	506	9
E2	9	37	16	21	632	9
			Nonfiltered x 1.5			
A2	11	19	11	8	155	11
B3	10	29	12	17	382	10
B4	11	20	16	4	100	11
			Ambient Air			
B2	9	24	24	0	0	9

Table B13. Harvest numbers of cotton plants, cv. SJ2

Plot	Number					
	Plant	Bolls Total	Bolls Unopened	Bolls Open	Seed	Roots
			Charcoal Filtered			
A3	10	42	19	23	710	10
D5	8	40	21	19	598	8
E3	14	64	48	16	535	13
			Nonfiltered			
C7	11	49	25	24	784	11
D6	9	45	22	23	594	9
E2	9	43	18	25	722	9
			Nonfiltered x 1.5			
A2	11	39	12	27	626	10
B3	10	33	15	18	371	11
B4	10	30	23	13	170	10
			Ambient Air			
B2	8	32	29	3	94	7

Seed count is from the open bolls only.

Table B16. Harvest numbers of cotton plants, cv. GC510

Plot	Number					
	Plant	Bolls Total	Bolls Unopened	Bolls Open	Seed	Roots
			Charcoal Filtered			
A3	13	35	10	25	756	13
D5	10	39	29	10	280	10
E3	11	36	14	22	654	11
			Nonfiltered			
C7	11	36	15	21	539	12
D6	10	29	13	16	505	10
E2	9	45	32	13	392	9
			Nonfiltered x 1.5			
A2	12	16	11	5	88	11
B3	11	25	11	14	337	11
B4	10	24	14	10	228	10
			Ambient Air			
B2	10	43	43	0	0	10

Table B15. Harvest numbers of cotton plants, cv. SS2086

Plot	Number					
	Plant	Bolls Total	Bolls Unopened	Bolls Open	Seed	Roots
			Charcoal Filtered			
A3	13	31	7	24	648	13
D5	10	33	14	19	562	10
E3	10	25	8	17	452	10
			Nonfiltered			
C7	9	33	5	28	729	9
D6	11	27	12	15	382	11
E2	10	53	27	26	634	9
			Nonfiltered x 1.5			
A2	10	18	3	15	246	10
B3	10	23	13	10	239	10
B4	9	15	4	11	205	8
			Ambient Air			
B2	10	38	37	1	60	10

Table B18. Harvest weights of cotton plants, cv. SS2086, in grams

Plot	Fresh Weight: Plant	Fresh Weight: Root	Fresh Weight: Bolls Unopened	Fresh Weight: Cotton Seed	Dry Weight: Plant	Dry Weight: Root	Dry Weight: Cotton	Dry Weight: Seed	Grams/ 100 Seeds
				Charcoal Filtered					
A3	304.1	60.0	132.8	124.1	113.1	26.2	39.7	60.4	9.3
D5	343.6	81.4	288.2	112.5	115.1	29.5	38.4	58.6	10.4
E3	192.6	58.2	136.1	74.9	69.8	18.3	27.2	37.4	8.3
				Nonfiltered					
C7	362.7	75.4	69.4	128.9	133.2	28.8	42.1	70.9	9.7
D6	271.6	67.2	216.4	62.9	89.2	23.0	21.2	34.9	9.1
E2	554.3	96.9	435.2	116.2	180.0	30.3	34.1	53.9	8.5
				Nonfiltered x 1.5					
A2	233.4	22.5	34.3	26.5	55.4	9.8	10.5	11.2	4.6
B3	282.4	30.1	122.1	36.6	74.9	15.1	11.7	18.5	7.8
B4	206.8	36.2	60.9	28.4	58.5	10.6	8.6	14.4	7.1
				Ambient Air					
B2	327.9	109.7	755.5	12.6	108.9	32.5	3.4	7.1	11.8

Table B17. Harvest weights of cotton plants, cv. GC510, in grams

Plot	Fresh Weight Plant	Fresh Weight Root	Fresh Weight Bolls Unopened	Fresh Weight Cotton Seed	Dry Weight Plant	Dry Weight Root	Dry Weight Cotton	Dry Weight Seed	Grams/ 100 Seeds
				Charcoal Filtered					
A3	329.0	91.5	170.3	130.4	121.5	35.9	48.4	63.0	8.3
D5	543.5	87.1	607.3	52.9	156.7	28.9	16.6	25.3	9.0
E3	391.4	108.7	205.5	101.3	137.4	31.0	36.0	47.2	7.2
				Nonfiltered					
C7	493.2	99.5	285.0	104.8	164.6	36.1	36.4	50.1	9.3
D6	375.2	91.9	231.9	84.1	127.7	27.8	30.1	46.0	9.1
E2	725.6	121.3	611.4	67.8	223.2	36.9	22.7	36.6	9.3
				Nonfiltered x 1.5					
A2	329.7	36.8	144.5	11.2	79.5	15.9	4.2	5.5	6.3
B3	426.1	58.4	182.3	54.8	128.5	23.7	16.9	22.3	6.6
B4	402.6	66.7	265.1	40.5	113.2	18.7	12.9	17.3	7.6
				Ambient Air					
B2	782.0	167.9	1137.5	0.0	240.6	55.9	0.0	0.0	0.0

Plant weight is without bolls.
Cotton and seed weight is from open bolls only and no hulls.

Table B20. Harvest weights of cotton plants, cv. C1, in grams

Plot	Fresh Weight				Dry Weight				Grams/ 100 Seeds
	Plant	Root	Bolls Unopened	Cotton Seed	Plant	Root	Cotton	Seed	
				Charcoal Filtered					
A3	302.9	72.7	173.6	99.4	98.4	27.4	30.1	43.4	7.9
D5	740.6	115.1	701.6	101.3	218.8	37.9	30.8	48.7	10.2
E3	677.9	149.9	744.8	91.5	210.2	45.6	22.5	39.3	7.9
				Nonfiltered					
C7	361.5	68.9	294.8	78.2	112.6	21.5	23.7	36.5	9.6
D6	480.2	86.5	304.5	71.3	156.6	28.3	24.7	37.9	7.5
E2	651.9	106.7	319.1	101.9	224.7	33.8	32.0	48.9	7.7
				Nonfiltered x 1.5					
A2	422.9	48.3	136.2	18.3	115.1	21.7	6.9	9.5	6.1
B3	433.6	63.4	176.2	61.6	135.4	25.6	22.1	32.5	8.5
B4	353.6	72.8	274.6	13.5	96.9	23.2	4.9	6.9	6.9
				Ambient Air					
B2	579.4	116.1	571.7	0.0	178.1	39.9	0.0	0.0	0.0

Table B19. Harvest weights of cotton plants, cv. SJ2, in grams

Plot	Fresh Weight				Dry Weight				Grams/
	Plant	Root	Bolls Unopened	Cotton Seed	Plant	Root	Cotton	Seed	100 Seeds
				Charcoal Filtered					
A3	488.2	73.4	381.8	122.0	159.2	26.5	34.1	57.3	8.1
D5	494.3	101.5	397.4	124.1	175.3	32.4	30.0	63.6	10.6
E3	837.1	175.5	895.8	119.6	273.0	48.3	35.4	54.2	10.1
				Nonfiltered					
C7	643.2	116.0	466.3	153.6	233.2	38.6	50.3	85.2	10.9
D6	612.4	109.2	389.0	114.3	208.1	37.0	39.5	62.9	10.6
E2	629.9	100.0	287.0	134.5	215.0	31.2	37.1	56.3	7.8
				Nonfiltered x 1.5					
A2	602.7	68.1	122.7	92.3	186.1	28.8	30.5	46.5	7.4
B3	568.8	76.1	242.5	69.7	169.0	30.6	20.2	30.9	8.3
B4	435.1	85.5	371.4	30.7	124.2	23.9	9.4	16.2	9.5
				Ambient Air					
B2	443.8	98.0	777.8	12.0	142.1	29.0	3.2	7.3	7.7

Table B22. Plant height and leaf node data for cotton, cv. GC510

Plot	Height (cm)			Number: Nodes			Number: Leaf Scars			Node length (cm)		
				Charcoal Filtered								
A3	67.2	58.3	73.5	16	14	16	8	7	8	6.5	5.7	6.9
D5	74.0	81.0	66.0	15	13	16	7	8	9	6.2	10.3	6.1
E3	75.5	78.0	69.5	15	15	15	9	9	9	8.3	6.5	5.2
				Nonfiltered								
C7	75.0	89.0	71.0	17	16	15	10	9	10	5.2	7.8	6.9
D6	73.0	70.5	85.0	16	16	17	10	11	11	5.3	6.1	5.4
E2	92.0	102.0	96.5	18	19	20	12	11	11	6.0	7.6	6.9
				Nonfiltered x 1.5								
A2	80.5	76.3	78.7	19	18	19	14	14	15	4.3	3.4	3.8
B3	85.0	93.7	94.0	17	19	19	15	14	13	6.0	6.5	6.7
B4	85.0	94.0	77.5	19	17	16	14	13	13	6.4	4.7	6.6
				Ambient Air								
B2	83.0	80.0	83.5	16	17	17	9	9	9	7.8	5.2	4.7

Table B21. Plant height and leaf node data for cotton plants, cv. C1

Plot	Height (cm)			Number						Node length (cm)		
				Nodes			Leaf Scars					
				Charcoal Filtered								
A3	56.5	57.0	64.3	14	14	15	6	7	7	6.2	5.4	4.9
D5	89.0	93.5	81.5	15	18	18	8	9	9	7.9	7.7	7.0
E3	121.0	99.8	89.5	20	18	17	11	10	10	8.4	7.2	5.6
				Nonfiltered								
C7	80.0	76.5	63.5	17	17	15	10	9	10	5.3	5.5	6.3
D6	97.5	79.5	69.0	18	16	15	11	10	8	5.0	4.8	6.3
E2	108.0	93.0	92.0	17	18	17	8	12	9	8.9	5.9	6.5
				Nonfiltered x 1.5								
A2	71.5	84.0	77.0	19	19	19	14	14	14	3.5	3.7	4.3
B3	87.0	81.3	83.0	18	18	18	13	14	12	6.2	6.0	5.5
B4	80.5	77.5	92.0	18	18	19	14	15	14	5.7	4.0	4.2
				Ambient Air								
B2	88.0	68.0	80.5	19	16	17	10	10	10	5.0	5.9	5.0

Measurements are from three selected plants in the row. Node length is the average of the three node lengths from the middle of the plant.

Table B24. Plant height and leaf node data for cotton, cv. SS2086

Plot	Height (cm)			Number: Nodes			Number: Leaf Scars			Node length (cm)		
						Charcoal Filtered						
A3	68.0	75.0	61.0	16	15	17	9	8	10	6.2	6.0	3.7
D5	63.0	63.5	73.0	15	13	16	9	6	8	5.2	6.0	6.2
E3	53.0	62.5	63.5	15	16	14	9	9	9	5.2	5.3	6.7
						Nonfiltered						
C7	68.0	84.5	77.0	17	20	17	13	13	12	4.3	6.3	5.3
D6	65.0	63.0	62.0	16	16	16	10	11	10	5.4	5.0	4.6
E2	89.5	94.0	94.0	18	19	20	13	13	14	5.3	7.2	6.1
						Nonfiltered x 1.5						
A2	71.5	83.5	70.0	18	21	18	17	17	16	4.9	4.5	4.1
B3	87.5	81.0	73.5	19	20	20	16	17	13	5.3	4.3	5.5
B4	76.0	70.0	73.5	19	20	19	14	16	16	5.2	5.0	5.3
						Ambient Air						
B2	81.0	62.5	63.0	16	18	17	10	9	11	4.7	5.7	4.0

Table B23. Plant height and leaf node data for cotton, cv. SJ2

Plot	Height (cm)			Number: Nodes			Number: Leaf Scars			Node length (cm)		
				Charcoal Filtered								
A3	81.0	73.2	80.4	15	14	16	5	6	7	6.2	5.8	5.0
D5	88.0	73.5	78.0	15	15	15	9	6	9	5.8	6.8	7.8
E3	106.0	106.5	111.5	18	16	17	8	8	7	6.8	9.1	10.2
				Nonfiltered								
C7	82.5	82.5	81.0	16	15	15	7	7	7	6.4	6.7	6.8
D6	87.0	95.0	92.0	17	16	16	9	10	8	7.2	7.0	6.6
E2	103.5	102.5	101.5	18	17	18	10	9	11	6.2	6.5	6.3
				Nonfiltered x 1.5								
A2	93.3	90.8	92.0	18	18	15	12	12	10	4.9	5.3	7.6
B3	107.0	108.0	99.0	19	19	19	13	12	14	6.3	4.8	4.3
B4	90.0	94.0	93.0	16	16	17	11	9	12	6.8	4.4	5.2
				Ambient Air								
B2	86.0	78.5	77.0	18	13	15	11	5	9	6.0	6.7	6.2

Table B26. Number and weight, in grams, of broccoli, cv. Emperor

Plot	Number			Fresh Weight			Dry Weight		
	Plants	Heads	Commercial Heads	Heads	Plants No. Heads	Total Plants	Heads	Plants No. Heads	Total Plants
				Charcoal Filtered					
C4	12	10	6	1722	3897	5619	159.2	372.5	531.7
C5	13	12	7	2358	5046	7404	201.5	445.1	646.6
D5	11	10	7	2553	5106	7659	192.8	422.2	615.0
				Nonfiltered					
C7	13	13	4	1608	2876	4484	148.4	291.4	439.8
D1	13	7	4	1317	3859	5176	116.0	375.0	491.0
D4	12	10	6	1813	4003	5816	163.7	369.8	533.5
				Nonfiltered x 1.5					
A6	13	13	5	1761	3748	5509	148.1	344.9	493.0
C2	14	11	7	2563	4765	7328	207.6	419.2	626.8
E5	13	12	5	1894	3219	5113	181.2	321.8	503.0
				Ambient Air					
A1	14	11	5	2080	4473	6553	176.0	419.0	595.0

Table B25. Number of plants and harvested weights, in grams, of four cultivars of lettuce

	Royal Green			Prizehead			Dark Green Boston			Parris Island Cos		
Plot	Plants	Fresh Weight	Dry Weight	Plants	Fresh Weight	Dry Weight	Plants	Fresh Weight	Dry Weight	Plants	Fresh Weight	Dry Weight
Charcoal Filtered												
B4	13	2938	145.8	13	1268	69.1	13	1629	99.1	12	1255	85.0
B5	12	3151	144.6	6	613	33.9	13	2003	106.5	13	1745	104.4
E4	13	3764	175.2	14	1726	88.3	12	2405	117.4	14	1852	118.3
Nonfiltered Air												
A2	14	3106	148.2	7	333	18.4	14	2206	114.4	13	1702	101.8
A4	13	2936	148.1	13	1196	63.1	14	2323	114.8	14	2186	122.2
B1	11	2600	117.1	12	1230	59.4	14	2116	102.8	12	1836	96.7
Nonfiltered Air x 1.5												
A5	14	2607	149.5	13	731	48.8	14	1598	95.3	14	1421	90.5
D3	14	3534	159.6	14	1975	99.5	14	2171	106.0	14	1982	102.5
E2	14	2869	148.5	14	2018	96.9	12	1825	98.5	13	1871	103.3
Ambient Air												
E3	13	1451	86.9	13	1314	75.1	15	1884	107.8	11	1149	71.9

Table B28. Number and weight, in grams, of broccoli, cv. Green Belt

Plot	Number			Fresh Weight			Dry Weight		
	Plants	Heads	Commer-cial Heads	Heads	Plants No. Heads	Total Plants	Heads	Plants No. Heads	Total Plants
				Charcoal Filtered					
C4	12	10	8	2705	4435	7140	247.5	465.6	713.1
C5	14	12	7	2935	4483	7418	270.6	526.1	796.7
D5	14	9	7	2694	4671	7365	241.5	538.1	779.6
				Nonfiltered					
C7	11	8	5	1907	2998	4905	185.7	353.6	539.3
D1	14	12	7	3303	6329	9632	253.1	608.9	862.0
D4	14	10	8	2379	4244	6623	230.1	502.8	732.9
				Nonfiltered x 1.5					
A6	13	13	9	4037	4362	8399	312.7	452.1	764.8
C2	13	11	7	3979	5502	9481	332.1	576.9	909.0
E5	14	12	9	3973	5080	9053	343.3	595.1	938.4
				Ambient Air					
A1	14	11	2	1338	3126	4464	140.8	387.5	528.3

Table B27. Number and weight, in grams, of broccoli, cv. Green Duke

Plot	Number			Fresh Weight			Dry Weight		
	Plants	Heads	Commercial Heads	Heads	Plants No. Heads	Total Plants	Heads	Plants No. Heads	Total Plants
				Charcoal Filtered					
C4	12	10	7	1546	3114	4660	114.3	276.4	390.7
C5	11	9	3	1182	3501	4683	84.9	298.3	383.2
D5	12	9	4	1532	3674	5206	120.4	307.9	428.3
				Nonfiltered					
C7	12	12	1	850	2372	3222	73.4	238.0	311.4
D1	11	8	2	1088	3274	4362	81.0	289.7	370.7
D4	12	11	2	1231	3176	4407	103.7	290.8	394.5
				Nonfiltered x 1.5					
A6	12	12	4	930	2658	3588	71.5	262.7	334.2
C2	11	10	4	1501	3355	4856	102.0	279.0	381.0
E5	14	11	4	1153	2784	3937	92.6	262.3	354.9
				Ambient Air					
A1	14	9	2	771	2126	2897	69.6	229.9	299.5

Table B30. Number and weight, in grams, of onion, cv. BR-1

Plot	Total		Commercial		Culls	
	Number	Weight	Number	Weight	Number	Weight
			Charcoal Filtered			
B2	60	4080	55	4037	5	43
C6	47	5556	45	5543	2	13
E1	48	5398	48	5398	0	00
			Nonfiltered			
A7	54	4150	51	4101	3	49
B3	63	5437	60	5402	3	36
D6	50	6151	50	6151	0	00
			Nonfiltered x 1.5			
A3	62	4836	55	4709	7	127
C3	53	4266	50	4237	3	29
D2	53	4908	51	4891	2	17
			Ambient Air			
B6	66	5577	61	5528	5	49

Table B29. Number and weight, in grams, of broccoli, cv. Commander

	Number			Fresh Weight			Dry Weight		
Plot	Plants	Heads	Commer-cial Heads	Heads	Plants No. Heads	Total Plants	Heads	Plants No. Heads	Total Plants
				Charcoal Filtered					
C4	11	9	5	1870	3610	5480	144.7	323.9	468.6
C5	13	13	8	2450	4192	6642	185.2	380.3	565.5
D5	13	11	5	3341	5045	8386	237.4	437.9	675.3
				Nonfiltered					
C7	12	12	4	1534	2570	4104	123.6	277.2	400.8
D1	13	10	5	1970	3692	5662	159.7	335.1	494.8
D4	14	11	7	2716	4499	7215	203.0	404.3	607.3
				Nonfiltered x 1.5					
A6	11	9	5	2081	2835	4916	168.5	290.0	458.5
C2	14	11	5	1925	3744	5669	148.3	323.1	471.4
E5	14	10	5	1636	2610	4246	147.0	280.0	427.0
				Ambient Air					
A1	12	10	4	1527	3103	4630	137.0	340.8	477.8

Table B32. Number and weight, in grams, of onion, cv. Rio Hondo

Plot	Total		Commercial		Culls	
	Number	Weight	Number	Weight	Number	Weight
			Charcoal Filtered			
B2	52	4846	52	4846	0	00
C6	60	3978	58	3954	2	24
E1	63	4389	59	4366	4	24
			Nonfiltered			
A7	60	4119	58	4083	2	36
B3	59	4801	56	4755	3	46
D6	50	6151	50	6151	0	00
			Nonfiltered x 1.5			
A3	67	3418	60	3304	7	114
C3	61	4563	61	4563	0	00
D2	55	4948	55	4948	0	00
			Ambient Air			
B6	72	5020	68	4960	4	61

Table B33. Number and weight, in grams, of onion, cv. Rio Bravo

Plot	Total		Commercial		Culls	
	Number	Weight	Number	Weight	Number	Weight
			Charcoal Filtered			
B2	46	4476	45	4460	1	16
C6	64	4849	59	4809	5	40
E1	54	4999	49	4967	5	33
			Nonfiltered			
A7	60	4285	57	4236	3	50
B3	53	4089	50	4040	3	50
D6	55	5403	52	5366	3	37
			Nonfiltered x 1.5			
A3	55	4005	54	4001	1	4
C3	64	3858	59	3787	5	71
D2	52	3872	50	3852	2	20
			Ambient Air			
B6	57	6177	55	6156	2	21