Response of Indicator Plants to Ozone Levels in Georgia

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ABSTRACT

Bel-W 3 tobacco and Snowstorm petunia, exposed to ambient air beneath antiozonant-treated cloth at seven Georgia locations, generally were taller and weighed more than companion plants under nontreated cloth chambers. Ratings of foliar injury on Bel-W 3 were less, but not always significantly, on plants in treated chambers than in nontreated chambers. Oxidant levels, monitored in Atlanta, the state's largest city, averaged 2.6 pphm hourly for April, May, June, and July, 1971; sixteen episodes of concns greater than 5 pphm for 5 h or longer occurred during these months. Injury, typical of fluoride, occurred regularly on Snow Princess gladiolus at one location only, irrespective of chamber or exposure period. Ozone is present at sufficient concns in both urban and rural Georgia to cause injury and retard growth of indicator plants.

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For over a decade, attention has been focused on concns of photochemically generated ozone (O_3), probably the most important air pollutant affecting vegetation in the U.S. (4, 6, 7, 12).

Ozone injury on tobacco in south Georgia has been suspected (S. Thompson, *personal communication*) but, cursory surveys by these authors for O_3 injury on other vegetation in various areas of the state have been inconclusive. With this in mind, a study was initiated to compare the relative sensitivity and growth of certain indicator plants (2) exposed only to naturally occurring concentrations of O_3 in widely scattered areas of Georgia. An abstract on certain aspects of this study has been published (16).

Most research on plant response to O_3 has employed the technique of exposing plants to O_3 in charcoal-filtered air. These systems may require a power supply to operate and charcoal may alter other pollutant levels. Cheesecloth chambers, impregnated with an antiozonant, were constructed to determine the effects of ambient ozone on indicator plants at diverse locations.

MATERIALS AND METHODS.—Ten different indicator species were grown in methyl bromide-treated greenhouse soil subsequently fertilized with Osmocote (14-14-14). Prior to exposure at the various sites, a systemic insecticide [2% Disyston® (disulfoton)] was applied to the soil surface of each pot. Potted plants were placed in plastic (55.8 × 27.9 × 6.9 cm) plant trays with drainage holes. A new group of plants, at approximately the same growth stage, was exposed each month of 1971 and at 3-wk intervals in 1972.

Portable knock-down 55.8 × 50.8 × 50.8 cm cubical frames, constructed of 1.27 cm diam polyvinyl chloride tubing held together at each corner by custom-made tri-corner fittings, and draped with one layer of cheesecloth, were used as plant chambers. The antiozonant compound (4, 4′-dioctyl diphenylamine, R. T. Vanderbilt Company, New York, N.Y.) was applied once to the outside surface of the cheesecloth in small droplets on 3-cm centers at the rate of 57 g/1.2 m^2 (2 oz/yd^2). Companion chambers were not treated with antiozonant.

The following locations with approximate 1970 populations were selected in Georgia for chamber placement: Atlanta (1,500,000), Augusta (60,000), Griffin (25,000), Lyons (3,800), Macon (122,000), Rossville (5,000), and Savannah (118,000). These represent large metropolitan centers, semi-urban, and rural areas scattered from the northern (Rossville), the central (Macon), to the southeastern (Savannah) part of the state. The annual mean and maximum temp differential between the north and southeast is approximately 7 C. Plants received natural rainfall, plus supplemental water to prevent wilting.

Three plants of most species were placed in each chamber during 1971, whereas six petunia (cultivar Snowstorm) and six tobacco (Bel-W 3) were used in each chamber during the 1972 season. The species utilized in 1971 were: bean (*Phaseolus vulgaris* L.), beet (*Beta vulgaris* L., 'Crosby's Egyptian'), begonia (*Begonia semperflorens* Link & Ott., 'Scandanavian Red', 'Carmen Red', 'White Comet'), gladiolus (*Gladiolus primulinus*, Baker, 'Snow Princess'), petunia (*Petunia hybrida* Vilm. 'Snowstorm', 'White Magic'), tobacco (*Nicotiana tabacum* L., 'Bel-W 3'), tomato (*Lycopersicon esculentum* L., 'Bonny Best').

After 1-mo exposures in 1971 and 3-wk exposures in 1972, all plants were returned to the Georgia Station in Experiment, Georgia. Photographs were taken and height and fresh top weight recorded. Plants were also rated on a 0-5 scale for abnormalities including flecking, chlorosis, general tissue necrosis, or other symptoms suggestive of ozone damage to plants; 0 indicated no macroscopic injury and 5 signified severe injury.

RESULTS.—*1971 exposures.*—The total oxidants recorded in the spring and early summer of 1971 in Atlanta with a Beckman Acralyser are presented in Table 1. Out of 2,147 h monitored during 4 mo, oxidant concns exceeded 5 pphm 10.8% of the time. However, an oxidant level of $\geq$ 5 pphm for 5 h or longer in duration occurred only 16 times. On a minimum 5-h basis, this would be approximately 4% of the monitored time. Although similar data were not obtained for any other sites in this

TABLE 1. Summary of total oxidants recorded in Atlanta by the Air Quality Control Section of Georgia Department of Natural Resources using a Beckman Acralyser

	MONTH (1971)			
	April	May	June	July
Number hours monitored	435	613	600	499
Number hours ≥ 5 pphm	59	98	74	1
% of time	13.6	16.0	12.3	0.2
Number of episodes ≥ 5 h ≥ 5 pphm	1	7	8	0
% of time	0.2	5.7	6.6	0
Average hourly conc. (pphm)	3.5	3.3	2.5	1.1
Average daily maximum (pphm)	7.2	5.1	4.8	3.0

study, the results from Atlanta are similar to those reported in the Chattanooga, Tennessee/Rossville, Georgia Interstate Air Quality Study 1967-1968 (5).

There was little difference in wt or ht among many of the plant species exposed under treated or nontreated chambers for 4-wk periods from May through October, 1971. However, seasonal average ht and fresh wt of Snow Princess gladiolus, Snowstorm petunia, and Bel-W 3 tobacco from the treated chambers regularly exceeded the averages of plants in the nontreated chambers. Presentation of tabulated data for 1971 is omitted for brevity.

The mean ht of tobacco from treated chambers was 9% greater than that from nontreated chambers when data over all locations and exposure periods were considered. Analysis of variance revealed this difference to be significant ($P = 0.05$). The difference in ht occurred at all locations except Augusta, where the average ht was the same for treated and nontreated chamber plants.

Except for October, the fresh wt of tobacco in treated chambers exceeded that of plants in nontreated chambers by an average of 18%. Tobacco fresh wt varied with the different monthly exposures ($P = 0.01$).

Ozone injury [weather fleck (3)] occurred regularly on tobacco in nontreated chambers at all locations. Some injury also appeared on tobacco leaves in treated chambers, but the incidence of injury was less than in nontreated chambers at all locations.

The mean fresh and dry wt of Snowstorm petunia from treated chambers exceeded those from nontreated chambers in four out of the six mo. Significant reduction in petunia ht was recorded at only three locations. Visible oxidant damage, as described on petunia (7), seldom was noted on this cultivar, however the begonia cultivar, White Comet, occasionally exhibited suspected O_3 damage (Fig. 1).

1972 exposures.—Beginning May 3, 1972 and at 3-wk intervals thereafter, 2-mo-old tobacco (Bel-W 3) and 6-wk-old petunia (Snowstorm) were exposed under diphenylamine-treated and nontreated cheesecloth chambers at each of the seven locations of the 1971 study. Additionally, six gladiolus (Snow Princess) were exposed during the same periods in each chamber at Savannah.

Following each exposure, ht and fresh wt of each plant were recorded. Data were collated and differences tested by analysis of variance and Duncan's multiple range test. The "f" values of these analyses are presented in Table 2.

Analysis of data over all locations and periods showed ht and wt of petunia and ht of tobacco in treated chambers were significantly greater than that of plants exposed in nontreated chambers (Table 3). Tobacco ht in treated chambers exceeded that in nontreated chambers by approximately 7% (9% in 1971).

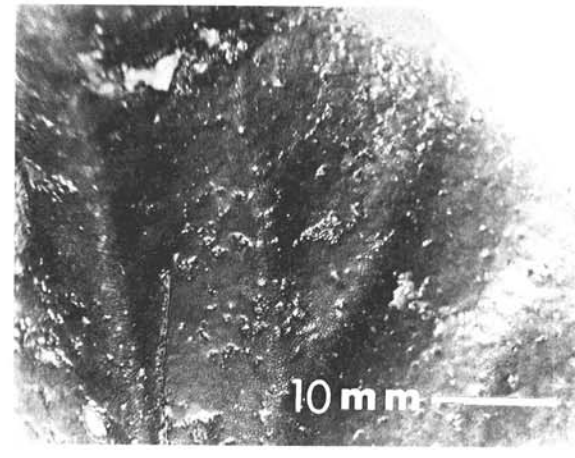

Fig. 1. Suspected O_3 damage to *Begonia semperflorens* (cultivar White Comet) exposed to ambient air in Georgia.

Responses of the two species, in terms of ht, at individual locations during specific exposure periods are shown in Fig. 2 and 3. The tobacco showed a significant ht response more often than did the petunia cultivar Snowstorm. If oxidant (O_3) concns influence plant ht, then the ht responses observed might be attributed not only to location, and time of exposure, but also to different oxidant levels at the various sites during the growing season. Greatest ht differences between tobacco in the two chambers occurred at Macon where there was a significant response 50% of the time; at Lyons, a rural area, there was a positive response 38% of the time, but in Atlanta and Savannah the response was positive only 12% of the time. At Savannah, mean ht in treated chambers was less than in nontreated chambers during six of eight exposure periods.

Although the fresh wt of tobacco over all nontreated chambers did not differ significantly from the wt of plants in treated chambers (Table 3), the mean fresh wt in treated chambers exceeded that in nontreated chambers 60% of the time (33 of 55 exposures). Greatest differences in tobacco wt occurred during 18 August to 8 September with the next greatest difference between the period 6 July to 27 July.

TABLE 2. Summary of analysis ("f" statistic) for mean ht and fresh wt of tobacco and petunia plants exposed under treated (4,4′-dioctyl diphenylamine) and nontreated cheesecloth chambers at seven Georgia locations during eight 3-wk periods in 1972

	"f" values for means			
	Tobacco		Petunia	
Effects:	Ht.	Wt.	Ht.	Wt.
Location (L)	79.21**[a]	80.05**	43.92**	30.50**
Exposure Periods (EP)	51.65**	26.77**	164.01**	106.48**
Chamber Treatment (T)	12.41**	5.54	14.82**	7.98**
L × T	3.08**	2.31	2.43*	0.88
EP × T	1.20	0.89	1.37	0.50
L × EP × T	1.61*[b]	2.22**	1.72**	1.31

[a]**Significant, $P = 0.01$.
[b]* Significant, $P = 0.05$.

Petunias generally were taller in treated than in nontreated chambers during the 1972 exposure periods, but differences were significant only at Macon, Augusta, and Griffin. The differences between means from treated and nontreated chambers for each location/exposure period treatment were subjected to the "*t*" test. Differences are presented graphically in Fig. 3, with areas above the baseline representing the ht which the plants in treated chambers exceeded that in nontreated chambers.

Ratings of foliar injury to tobacco and petunia also were subjected to analysis of variance. Most of the main effects (chamber treatment, location, and exposure period) were significant ($P = 0.01$), but few of the interactions were significant for both plants. One exception was the location-treatment interaction for tobacco (Table 4). Only significant differences between ratings of fleck injury in the two chambers occurred at Rossville, Augusta, and Griffin. Although the average ratings of general chlorosis and subsequent necrosis of lower tobacco leaves in the two type chambers were not statistically different, the average of these ratings from the treated chamber plants were generally less than ratings of nontreated chamber plants (data not presented).

Fluoride injury.—Injury, typical of fluoride, occurred on Snow Princess gladiolus at only one location (Savannah) in Georgia during every 1971 exposure period. Lack of sufficient replications at the 1971 locations did not justify statistical analysis of data, but the seasonal average ht in the treated chambers did exceed that of nontreated chambers at five of seven locations. Differences in gladiolus ht at Savannah in 1972 were not significant, although the mean ht was greater in treated chambers during five of the eight exposure periods. The injury rating during 1972, based on the extent of leaf-tip necrosis, varied little between the two types of chambers; plants in treated chambers had the same or a lower rating than plants in nontreated chambers. The highest rating (3.5 out of 5.0) occurred from 28 July to 17 August. Prewashed leaf samples from this period contained 70 ppm total fluoride (Analyzed by TRW Environmental Services, Redondo Beach, California), whereas control samples from the greenhouse contained 2.4 ppm. Samples for the period 24 May to 12 June contained 3.0 ppm; and those for 9 to 28 September contained 6.0 ppm.

TABLE 3. Mean ht and fresh wt of tobacco (cultivar Bel-W 3) and petunia (cultivar Snowstorm) under antiozonant-treated (4,4′-dioctyl diphenylamine) and nontreated cheesecloth chambers in ambient Georgia air during 1972 (data pooled for all periods and locations)

	Tobacco		Petunia	
Chamber	Ht. (cm)	Wt. (g)	Ht. (cm)	Wt. (g)
Nontreated	36.5	36.7	31.1	13.7
Treated	39.1**[a]	39.7	34.2**	15.2**

[a]** Difference significant, $P = 0.01$.

DISCUSSION.—Increased plant ht and wt in charcoal-filtered chambers is a common response (9, 15) that also was apparent with the O_3 sensitive plants under the antiozonant-treated chambers used in these studies. Although the mode of action of diphenylamine is not completely described, the patent states that this material, formulated in a butyl latex base, reacts with ozone passing through the shade cloth. Although this material is not meant for direct applications to plants, when we applied it directly to Bel-W 3 leaves or stems no effect on ht was observed.

Rich and Taylor (12, 13), who performed laboratory and field experiments with this antiozonant in the early 1960's found that weather fleck susceptible tobacco was protected for the greater part of the Connecticut growing season. C. R. Hibben used this or similar material on chambers adapted for woody plants, and suggested its possibility for these studies (C. R. Hibben, *personal communication*).

The effectiveness of 4, 4′-dioctyl diphenylamine to breakdown or react with ambient NO_x^- was not determined. Its antiozidant properties would suggest that it might be effective in eliminating oxides of nitrogen. We doubt that the elimination of NO_x^- in our chambers would explain our results because the ht of bean and tomato in treated chambers during 1971 was not always enhanced. Further, the average NO_2 concns monitored in Atlanta were 5-10 times less than the concns required to suppress growth of pinto bean and tomato under controlled NO_2 fumigations (13).

These portable inexpensive (estimated $7/chamber) chambers were modeled after the aluminum-framed chambers described by Emge, et al. (1). They were snapped to large eye-bolts in the ground to protect against high winds. After severe storms during the latter part of the season, some cloth replacements were necessary.

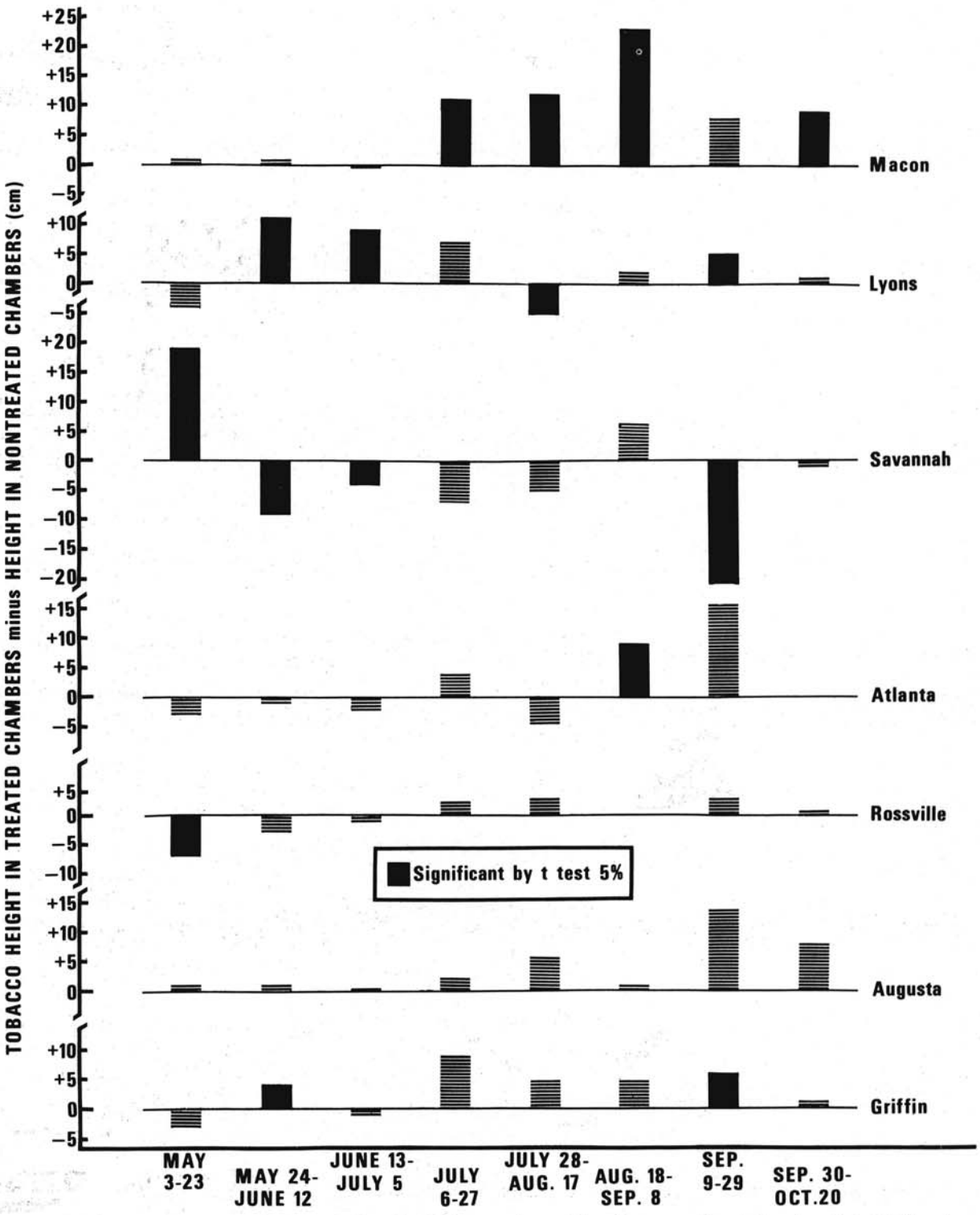

Fig. 2. Differences in mean ht of tobacco (cultivar Bel-W 3) exposed to ambient air at seven Georgia locations during 1972 under antiozonant-treated and nontreated chambers.

Shading due to antiozonant droplets on the cloth was considered miminal; light readings were only 6% lower in treated than in nontreated chambers. Temperature differences between the treated and nontreated chambers were minimal; the fabric coverings would decrease wind speeds below that over uncovered plants. These chambers

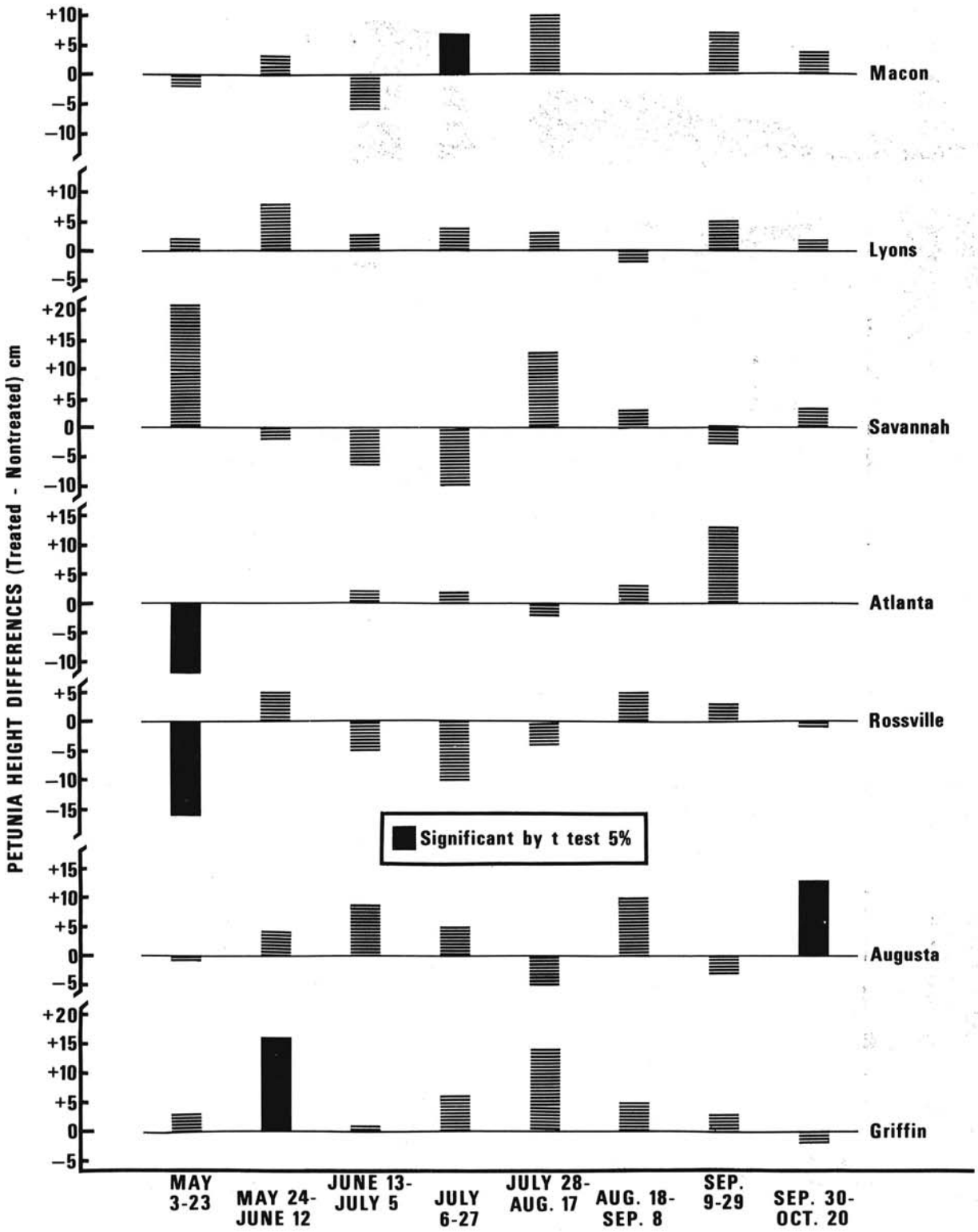

Fig. 3. Differences in mean ht of petunia (cultivar Snowstorm) exposed to ambient air at seven Georgia locations during 1972 under antiozonant-treated and nontreated chambers.

TABLE 4. Mean ratings of fleck injury to tobacco (cultivar Bel-W 3) leaves during 1972 under nontreated and treated (antiozonant, 4,4′-dioctyl diphenylamine) cheesecloth chambers at various locations in Georgia

Location	Fleck injury[a]	
	Nontreated	Treated
Macon	0.37	0.29
Lyons	0.38	0.50
Savannah	0.56	0.30
Atlanta	0.79	0.74
Rossville	0.90*[b]	0.60
Augusta	1.93*	1.27
Griffin	1.53*	1.10

[a]Rating based on 0 = none, 5 = severe.

[b]* = Difference between nontreated and treated significant, $P = 0.05$.

or similar type enclosures seem to merit further consideration for the investigation of air pollutant injury under ambient conditions in widely scattered areas. They are particularly useful where chemicals might be utilized to deactivate specific air pollutants. For example, if a compound could deactivate fluorides, the combined effect of other pollutants in the absence of fluorides could be ascertained.

We recognize that certain fungicides can reduce oxidant damage on plants (8, 10). To our knowledge, no information is available on the effect of insecticides such as phosphorodithioates (disulfoton), applied to soil surfaces, on subsequent oxidant damage. A differential effect of this systemic on plant growth in the two type chambers seems improbable.

In our opinion these field studies in rural and urban environments have provided realistic information on the effects of oxidants (O_3) on plants under varied climatic and weather conditions in Georgia. The variation in response of indicator plants emphasized the importance of statistical analysis of data in similarly designed investigations, thereby avoiding erroneous inferences or interpretations that could be ascribed to a specific pollutant rather than local environments.

During inversion periods over Georgia's population centers, O_3 levels probably are sufficient to cause injury greater than that observed during these investigations. Despite these possibilities, it seems that the overall injury to Bel-W 3 tobacco and Snowstorm petunia during these studies was less than that observed by investigators in other areas of the United States. This may be a reflection of the fewer number of vehicles in the state (2.3 million in 1970) than in other areas. However, it is cogent to recognize that injury attributable to O_3 did occur in rural environments.

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