by Keith F. Jensen

AIR POLLUTANTS AFFECT THE RELATIVE GROWTH RATE OF HARDWOOD SEEDLINGS

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370 REED ROAD, BROOMALL, PA 19008

The Author

KEITH F. JENSEN, plant physiologist, holds B.S. and Ph.D. degrees from Iowa State University. He joined the Northeastern Forest Experiment Station in 1963 and is now at the Station's research laboratory in Delaware, Ohio, conducting research on the effects of air pollutants on vegetation.

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Abstract

One-year-old seedlings of yellow-poplar (*Liriodendron tulipifera* L.), eastern cottonwood (*Populus deltoides* Bartr.), and white ash (*Fraxinus americana* L.) were divided into four groups. One group served as the control, and the other groups were fumigated for 12 hours per day with either 0.1 ppm O_3, 0.2 ppm SO_2, or 0.1 ppm O_3 plus 0.2 ppm SO_2. Two or three seedlings of each species were harvested twice a week for 6 weeks, and leaf area and new growth weight were determined. Data on leaf area and new growth weight were transformed to natural logarithms and fitted with a linear regression model. Relative growth rate was positive in all species-treatment combinations, but varied with fumigation treatment. Net assimilation rate was suppressed in cottonwood seedlings in all fumigation treatments, and in yellow-poplar seedlings in the SO_2 and O_3 fumigations. Relative leaf area growth rate of the cottonwood and yellow-poplar seedlings was reduced by all three fumigation treatments. White ash growth was not analyzed because statistically significant differences were not found.

DO AMBIENT CONCENTRATIONS of atmospheric contaminants affect the growth and development of plants? The answer to this critical question is needed to establish environment standards for air pollutant concentrations and to calculate economic gains or losses.

The question has been addressed (Ashenden 1978, Bleasdale 1973, Heagle et al. 1973, Heck 1973, Jensen and Masters 1975, Mandl et al. 1973), but as the concentration of pollutants being investigated is reduced nearer and nearer to ambient levels, the problem of detecting effects rapidly increases. To determine statistically valid effects of low pollutant doses, large numbers of plants and long periods of fumigation are required. This greatly increases the cost and complexity of the research.

One method that may help in avoiding these problems is classical growth analysis (Oshima et al. 1978). Growth analysis divides growth into component processes, and focuses attention on rates of growth instead of on final yield or growth. It utilizes dry weight and leaf area measurements collected from periodic harvests, and partitions growth among component characteristics. The parameters from growth analysis can be used to compare the effect of various treatments on plant growth (Ledig 1974).

In this study growth analysis techniques were used to analyze and compare growth parameters of hardwood seedlings fumigated at low pollutant concentrations.

MATERIALS AND METHODS

One-year-old seedlings of yellow-poplar (*Liriodendron tulipifera* L.), eastern cottonwood (*Populus deltoides* Bartr.), and white ash (*Fraxinus americana* L.) were weighed and potted in a 1:1 sand-soil mix in 15 cm pots. After 144 seedlings of a species had broken bud, they were randomly divided into four groups and assigned to fumigation treatments. The plants were watered as needed and fertilized with soluble fertilizer (20-20-20) every second week.

The treatments were control, 0.1 ppm O_3, 0.2 ppm SO_2, and 0.1 ppm O_3 plus 0.2 ppm SO_2. The treatments were applied 12 hours a day, 7 days a week, in four circular chambers similar to those described by Heck and others (1978). The chambers were 1.5 m in diameter and height. They were covered with Teflon[1] film, and had flow-through air systems. The pollutants were added to the charcoal-filtered air stream before it entered the chamber, and automatically sampled in each chamber every 20 minutes. The SO_2 concentration was measured with a Beckman 906A SO_2 monitor, and the O_3 concentration was measured with a Beckman 950 ozone monitor. The

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average temperature in the chambers was 29°C, and the relative humidity ranged between 35 and 75 percent. Because the chambers were small, only two species could be treated at one time. Yellow-poplar and white ash were treated in the first study, and eastern cottonwood was treated in the second study.

One week after the fumigation was initiated, three randomly preselected seedlings were harvested from each treatment on Monday and Thursday of each week. The height of each seedling was measured to the nearest mm, and leaf area was measured to the nearest square centimeter with an automatic area meter. The leaves were then combined with the new shoot (stem growth for the current season) and dried to constant weight at 100°C. Plants were harvested for 6 weeks. Near the end of the study some seedlings had died, and then only two seedlings were harvested from some treatments.

Data on the height, leaf area, and new growth dry weight were transformed to natural logarithms and fitted with a linear regression model as a function of days (Hughes and Freeman 1967). Growth analysis parameters were calculated from the modeled growth curves (Radford 1967).

RESULTS AND DISCUSSION

To test if the treatments affected the growth parameters I did an analysis of covariance. I found statistically significantly differences between treatments for the following variables: cottonwood height, leaf area, new growth dry weight, and yellow-poplar leaf area and new growth dry weight (Figs. 1 and 2). Relative growth rate (RGR), leaf area ratio (LAR), relative leaf area growth rate (RLAR), and net assimilation rate (NAR) were calculated for cottonwood and yellow-poplar (Table 1). White ash growth was not analyzed further because statistically significant differences were not found.

Figure 1.—Response of cottonwood seedlings to fumigation.

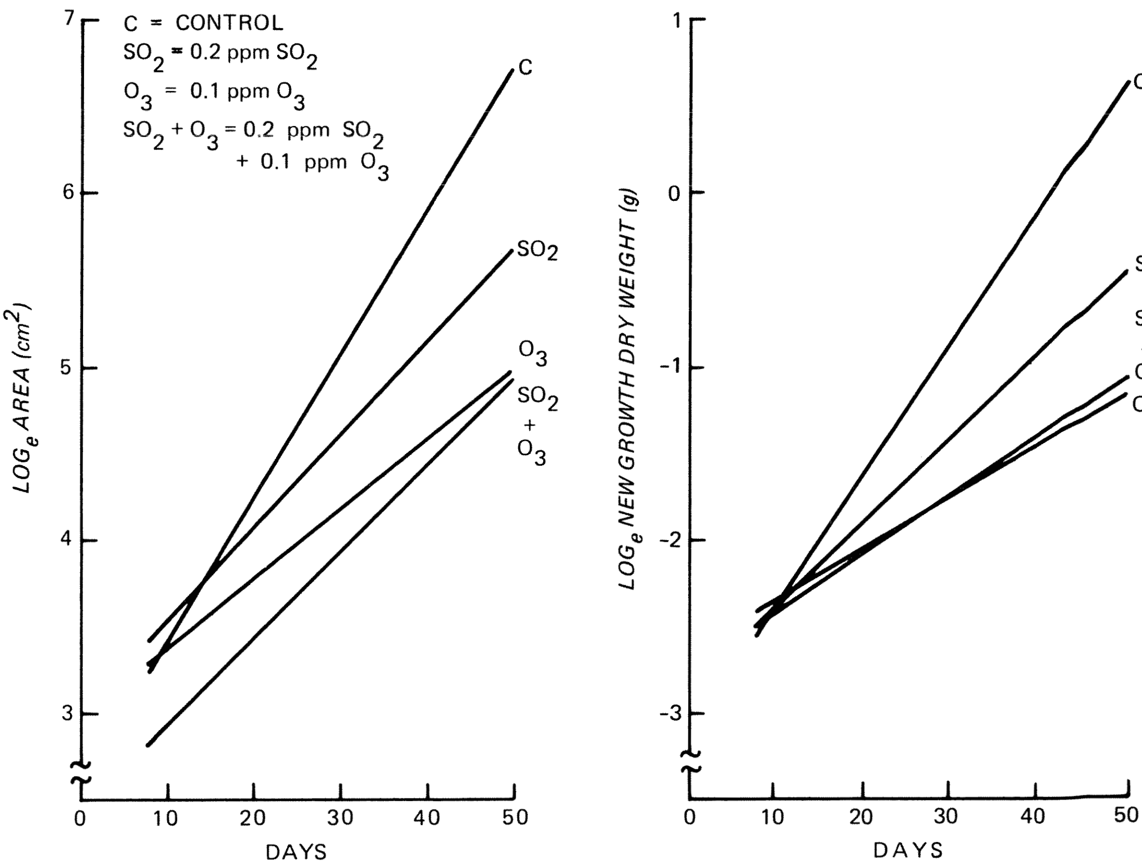

Figure 2.—Response of yellow-poplar seedlings to fumigation.

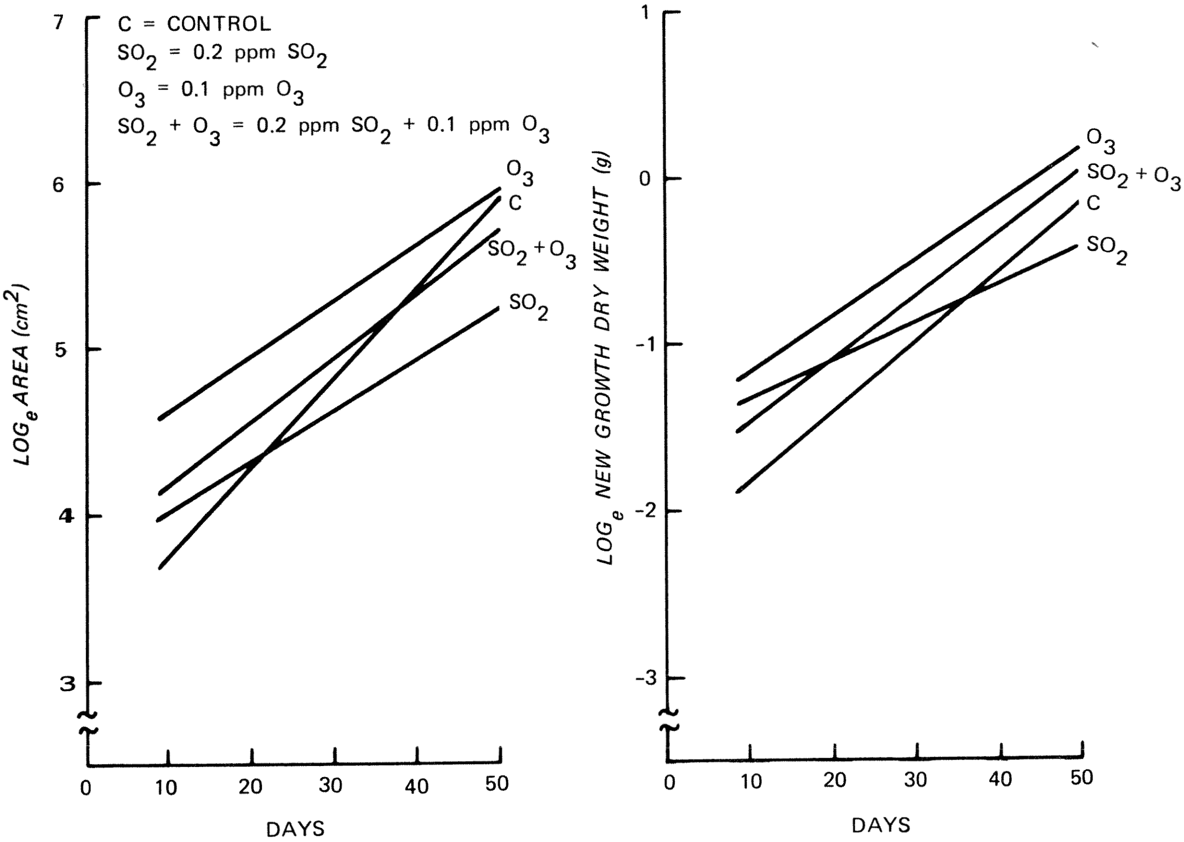

Table 1.—Growth parameters of hardwood species fumigated with air pollutants.

Species treatment	Relative growth rate	Leaf area ratio	Net assimilation rate	Relative leaf area growth rate
	g/(g· day)	*cm^2/g*	*g/(cm^2· day)*	*cm^2/(cm^2· day)*
Cottonwood:				
Control	0.0750	393	0.190	0.0838
SO_2	0.0482	424	0.113	0.0526
O_3	0.0304	377	0.080	0.0400
O_3 + SO_2	0.0335	296	0.113	0.0528
Yellow-poplar:				
Control	0.0419	342	0.122	0.0518
SO_2	0.0198	257	0.077	0.0307
O_3	0.0338	331	0.102	0.0328
O_3 + SO_2	0.0391	276	0.136	0.0400

Relative growth rate (RGR) is a measure of productivity, and expresses the growth rate relative to the amount of growing material present (Ledig 1974). RGR is equal to the slope of the linear regression model calculated for dry weight. RGR was positive in all treatment combinations, but varied with fumigation treatment. Compared to the control seedlings the RGR of the cottonwood seedlings fumigated with SO_2 was reduced by more than 30%, and the RGR of the yellow-poplar seedlings was reduced by more than 50%. The RGR of the cottonwood seedlings fumigated with O_3 was only 40% of that of the control seedlings, while the RGR of the yellow-poplar seedlings fumigated with ozone was only reduced by 20%. The RGR of the yellow-poplar seedlings fumigated with both gases was only slightly less than that of the controls, while the RGR of the cottonwood seedlings in the same treatment was reduced more than 50%.

RGR is a complex function and has been viewed as an efficiency index. In this study RGR was based only on the weight of the new stem and leaves produced during the study, and did not include the original stem and root weight. This approach was selected because the original stem and roots contribute little to the overall production process (Watson 1952).

The reduction in RGR after fumigation suggests that the dry weight needed to produce an additional unit of dry weight was increased by fumigation. This could be caused by a decrease in the photosynthetic rate, an increase in the respiration, or a change in the partitioning of photosynthate between the stem and the leaves. RGR can be examined further by dividing it into two additional growth parameters, leaf area ratio (LAR) and net assimilation rate (NAR); RGR is equal to NAR times LAR.

LAR (leaf area/plant dry weight) was calculated for the 30th day of the study and divided into RGR to calculate NAR for the same day. LAR is an index of leafiness and expresses the relationship of assimilatory surface to respiratory mass (Ledig 1974), and NAR is an index of physiological activity and a measure of the change in dry weight per unit area per unit time.

LAR of the cottonwood seedlings fumigated with O_3 + SO_2 and the yellow-poplar seedlings fumigated with SO_2 and O_3 + SO_2 was reduced markedly (Table 1). NAR was suppressed in all fumigated cottonwood seedlings and in yellow-poplar seedlings fumigated with SO_2 and O_3 alone (Table 1).

LAR declines with a decrease in leaf area or an increase in the respiration rate per unit leaf area (Watson 1952). The reduction in leaf area might be caused by early leaf senescence or early bud set. Air pollution causes early leaf senescence in hardwood and citrus trees (Jensen and Masters 1975, Thompson and Taylor 1969).

NAR is a measure of the photosynthate changed into plant structures or stored in the plant after respiration demands are met. It is a function not only of the rate of photosynthesis but also the respiration rate. It measures how efficiently photosynthate is used or stored in the plant. NAR might be reduced by pollutants inhibiting photosynthesis (Ormrod 1978) or causing an increase in the respiration rate (Mudd and Kozlowski 1975).

The final parameter that was calculated was RLAR, relative leaf area growth rate. It is equal to the slope of linear regression model calculated for leaf area. RLAR decreased in all fumigated cottonwood and yellow-poplar seedlings.

A decrease in RLAR means that a larger area is required to produce an additional unit of leaf area. Thus, it supports the conclusion suggested by RGR that the overall efficiency of the growth process declines after fumigation.

Growth analysis suggests that ozone and sulfur dioxide reduce the growth of some hardwood seedlings by reducing their growth efficiency. The analysis does not pinpoint the process or processes that are influenced, but it does suggest that growth is retarded. This is supported by RGR and RLAR that require more weight or area to produce each additional unit. It is also supported by NAR that decreased with fumigation in all but one case. The differences that were calculated might appear to be extremely small and thus unimportant. However, a reduction of only 0.01 g/(g· day) on a 100 gm plant would result in a reduction in dry weight of more than

8 gm in one week. A change of RGR of this magnitude, or even less, would probably have a significant effect on trees over an entire season or over several years.

Watson (1952) and Shibles and MacDonald (1962) stated that leaf area or leaf area growth rate was better correlated with the total plant growth rate than photosynthesis. To evaluate these relationships in this study, the coefficients of correlation between RGR and NAR and RLAR were calculated. The coefficient between RGR and NAR was 0.90 and between RGR and RLAR was 0.83. Both correlations were fairly good but were based on only a small sample, so no definite conclusion could be reached in this study.

In general, O_3 reduced growth in cottonwood more than SO_2, while SO_2 reduced growth in yellow-poplar more than O_3. When both gases were used, growth was not reduced as much as in the single gas fumigation. This suggests an antagonistic relationship between the two gases.

In this study only the initial, log-linear, portion of the growth curve was analyzed. More useful information could be obtained from regression models describing growth over entire seasons. The change in growth parameters over a longer period of time would allow a more thorough examination of the growth relations.

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