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Effect of Acid Mist and Air Pollutants on Yellow-Poplar Seedling Height and Leaf Growth

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Abstract

One-year-old yellow-poplar seedlings were treated with acid mist at pH 2.5, 3.5, 4.5, and 5.5 either alone or in combination with 0.1 ppm O_3, SO_2, and NO_2, or NO_2 plus SO_2. After 4 and 8 weeks of treatment, height, leaf area, and leaf and new shoot weight were determined and growth analysis variables calculated. Height, leaf area, and dry weight decreased with increasing acidity in seedlings treated with acid mist alone. Similar, but smaller reductions occurred in seedlings treated with SO_2 and acid mist, but no differences were found in seedlings fumigated with NO_2, NO_2 plus SO_2, or ozone and acid mist. Further studies using different combinations of pollutants and acid mist must be conducted before their apparent interactions can be more accurately assessed.

The Eastern United States has experienced sublethal doses of atmospheric deposition over long periods of time as regional industrialization and urbanization have intensified. Forests are a dominant ecosystem throughout the Northeast and numerous environmental stresses, including air pollution, have determined species succession, establishment, and productivity. Documentation of these atmospheric impacts is limited since the consequences of pollution are usually chronic and subtle, but over time these simple changes are detrimental to forest growth (Dochinger and Calvert 1978).

Yellow-poplar (*Liriodendron tulipifera* L.) is a primary species in 4 forest cover types and a secondary component in 12 other forest communities throughout most of the Eastern United States (Vick 1973). This species is sensitive to photochemical oxidants (ozone) which can effect foliage mottling, premature leaf loss, and reduced growth (Dochinger 1974, Duchelle et al. 1982). Additional biomass responses can also result from ozone fumigation including decreases in leaf-area ratio, net assimilation rate, and shoot height growth rate (Jensen 1973, 1981).

Although no information is available on the interaction of acid rain and gaseous pollutants on yellow-poplar, limited study has yielded some research data on the gaseous precursors of acid precipitation, sulfur dioxide, and nitrogen oxides, in various combinations with ozone. SO_2 and ozone alone did not suppress total shoot elongation of yellow-poplar after a 5-week fumigation period, whereas the combinations of $O_3 + SO_2$, $SO_2 + NO_2$, or the three gases significantly inhibited total shoot height and dry weight. Of the pollutant combinations, $SO_2 + NO_2$ most severely curtailed the rate of height growth (Mahoney et al. 1983). Conversely, treatment with concentrations of O_3 stimulated growth of yellow-poplar seedlings, whereas treatment with ambient levels had no adverse effect (Kress and Skelly 1982). In areas around urban centers and in the vicinity of industrial sites, dominant or codominant yellow-poplar, growing in ambient air composed periodically of elevated concentrations of oxides of nitrogen and sulfur dioxide, produced less radial increment growth during periods of high pollutant concentrations (Stone and Skelly 1974).

This study was designed to quantify the nature and extent of ambient concentrations of NO_2, SO_2, and O_3 in conjunction with acid mist on shoot growth and leaf biomass of yellow-poplar seedlings.

Materials and Methods

Twenty combinations of acid mist and air pollutant treatments were used in this study. As only four treatment chambers were available, five separate experiments were required. In the first experiment, the seedlings were treated with acid mist alone with pH of either 2.5, 3.5, 4.5, or 5.5. In the second experiment, the seedlings were treated with acid mist solution plus 0.1 ppm SO_2; in the third experiment, acid mist solution and 0.1 ppm NO_2; in the fourth experiment, acid mist and 0.1 ppm O_3; and in the fifth experiment, acid mist and 0.1 ppm SO_2 plus 0.1 ppm NO_2.

The fumigation chambers were similar to those described by Heck and others (1968). The Mylar-covered[1] chambers had a single-pass air system and were located in an environmentally controlled room. The average daily temperature was 25°C, and average night temperature was 20°C. Light intensity during the 16-hour photoperiod was approximately 250 $\mu Em^{-2}sec^{-1}$ The air pollutants were added to the charcoal-filtered air stream and were sampled automatically in each chamber at 20-minute intervals. Ozone was sampled with a Dasibi Model 1003-AHO_3 monitor, SO_2 with a Beckman Model 90 A SO_2 monitor, and NO_2 with a Monitor Labs Nitrogen Oxides Analyzer Model 8840. The seedlings were fumigated 4 hours each morning for 5 days a week, and the monitors were calibrated each day the seedlings were fumigated.

The acidified mist solutions were prepared by adding sulfuric acid to distilled water. The final pH of the four solutions was 2.5, 3.5, 4.5, and 5.5. The solutions were applied to the chamber atmospheres with Northern cold water humidifiers (Model 77). Approximately 1,500 ml of solution were added to each chamber during the 4-hour afternoon treatment period, and mist was applied 7 days a week.

The 1-year-old yellow-poplar seedlings in each experiment were selected for uniformity and potted in 15-cm plastic pots in a bog soil-sand mixture. They were immediately placed on benches in the environmentally controlled room that contained the fumigation chambers. When 80 seedling had broken dormancy, 20 seedlings were randomly assigned to each treatment in

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

the experiment and treatments started. The seedlings were watered as required and fertilized every 2 weeks with 100 ml of a general purpose fertilizer (Peters soluble fertilizer 20-20-20).

Four weeks after the treatments were started, 10 randomly selected seedlings from each treatment were harvested. The height, number of leaves, midrib length, and new stem and leaf dry weight of each seedling were measured. Dry weight of the leaves and stems was determined by drying them to constant weight at 100°C. Leaf area was calculated from a quadratic equation relating midrib length to area. The remaining 10 seedlings in each treatment were harvested after 8 weeks of fumigation.

After the final harvest, all the data were averaged by harvest date, and the growth analysis variables calculated. The variables calculated were relative growth rate ($\ln(W_2/W_1)/(T_2-T_1)$), relative leaf-area growth rate ($\ln(A_2/A_1)/(T_2-T_1)$), specific leaf area (A/L), leaf-area ratio (A/W), and net assimilation rate $((W_2 - W_1)/(A_2 - A_1)) * (\ln(A_2/A_1)/(T_2 - T_1))$ where W = total new growth weight, A = leaf area, and L = leaf weight (Hunt 1982). The data from the 8-week harvest within each experiment were also analyzed using a one-way ANOVA. No statistical comparisons were made between experiments because the means and variances were nonhomogeneous.

Results and Discussion

When the seedlings were treated only with acid mist, height growth after 8 weeks significantly decreased with a lowering in pH from 5.5 to 2.5 (Table 1). Leaf weight and new stem weight of these seedlings did not significantly change in pH from 5.5 to 3.5 but decreased significantly when the pH decreased from 3.5 to 2.5. Leaf area was also significantly decreased with a reduction in pH from 3.5 to 2.5.

These differences are also reflected in the growth analysis variables (Table 2). Relative growth rate (RGR), net assimilation rate (NAR), and relative leaf-area growth rate (RLAGR) all decreased with an increase in acidity. A small drop in the variables was observed as the pH went from 5.5 to 3.5, but sharper decreases were found as the pH was lowered from 3.5 to 2.5.

The mechanism by which seedling growth was reduced by the acid mist cannot be explained from this experiment. But by examining the growth analysis variables, some possibilities are suggested. The first suggestion is that acid mist reduced leaf growth rate. As leaf area is one of the controlling factors that determines the amount of photosynthate available for growth, this physiological relationship may then be responsible for the diminished growth of plant dry weight. This supposition is supported by the RLAGR data, which show that the seedlings in the pH 2.5 treatment were only adding new leaf area at a rate of one-seventh that of the seedlings in the pH 5.5 or 4.5 treatment. Even through the RLAGR was considerably lower for the seedlings in the pH 2.5 treatment, the amount of dry-weight movement into the leaves was nearly constant in all four treatments. Leaf-weight ratio (L/W) ranged from 0.76 gm/gm for the seedlings treated with pH 2.5 and 4.5 mist to 0.81 gm/gm for the seedlings treated with pH 3.5 mist. The acid mist may have directly reduced the leaf expansion rate by interfering with the rate of cell enlargement during the growth process or cell division in the meristematic regions.

The acid mist apparently reduced the treatment growth rates by indirectly inhibiting the photosynthetic rate. NAR for the seedlings treated with pH 2.5 mist was less than zero. This response implies that more carbohydrate was being used in respiration or repair of injured tissue than was being produced.

This reduction in growth or dry weight production with a decrease in pH is partially supported by other researchers. Irving (1983) reviewed the current literature and concluded that the effects of acidified precipitation on crops seem to be minimal and responses may be either positive or negative. Wedding and others (1979) treated soybean plants with sulfuric-acid mist droplets. They found no visible toxicity symptoms on the plants, and tissue examined with the scanning electron microscope showed no apparent damage due to the mist.

When the seedlings were fumigated with SO_2 in the morning before being treated with acid mist in the afternoon, similar growth patterns to those obtained with acid mist alone were observed, but only leaf area was significantly affected. Height of the seedling decreased with an increase in acidity, while acidity had no affect on leaf dry weight and new stem dry weight until the pH dropped below 3.5. RGR, NAR, LAR, SLA, and RLAGR decreased with increasing acidity with losses in LAR and SLA being greater than those observed with mist alone.

Table 1.—Height, leaf dry weight, new stem dry weight, and leaf area of yellow-poplar seedlings treated with acid mist and/or air pollutants for 8 weeks (mean of 10 seedlings)

Pollutant	Mist	Height	Leaf Dry Wt	New Stem Dry Wt	Leaf Area
	pH	*mm*	*gm*	*gm*	*cm²*
None	5.5	112a	.62a	.13a	198a
	4.5	99a	.72a	.13a	215a
	3.5	87a	.67a	.14a	186a
	2.5	44b	.15b	.05b	50b
SO_2	5.5	104	.90	.20	274a
	4.5	119	.98	.21	293a
	3.5	87	.71	.19	202ab
	2.5	65	.35	.10	78b
NO_2	5.5	213	1.49	.49	608
	4.5	175	1.60	.45	553
	3.5	206	2.03	.52	656
	2.5	175	1.40	.41	513
SO_2 + NO_2	5.5	225	1.07	.40	521
	4.5	210	1.19	.43	493
	3.5	148	.78	.25	277
	2.5	171	1.01	.32	315
O_3	5.5	259	.67	.17	292
	4.5	221	.60	.15	231
	3.5	242	1.10	.24	416
	2.5	228	.84	.18	302

Values in the same column for each pollutant followed by the same letter are not significantly different at the 0.05 percent level. (Duncans Multiple Range Test)

Table 2.—Growth analysis variables of yellow-poplar seedlings treated with acid mist and air pollutants

Pollutant	Mist	RGR ($gm\ gm^{-1}\ wk^{-1}$)	NAR ($gm\ cm^{-2}\ wk^{-1}$)	LAR ($cm^2\ gm^{-1}$)	SLA ($cm^2\ gm^{-1}$)	RLAGR ($cm^2\ cm^{-1}\ wk^{-1}$)
	pH					
None	5.5	.371	.0013	280	369	.342
	4.5	.338	.0013	247	326	.350
	3.5	.294	.0012	243	300	.265
	2.5	<0	<0	225	299	.046
SO_2	5.5	.400	.0014	294	355	.323
	4.5	.378	.0015	243	302	.386
	3.5	.252	.0011	275	201	.249
	2.5	.243	.0013	180	232	.217
NO_2	5.5	.109	.0006	198	278	.051
	4.5	.124	.0005	244	333	.159
	3.5	.315	.0001	263	386	.388
	2.5	.359	.0001	297	375	.347
SO_2 + NO_2	5.5	.392	.0010	388	484	.348
	4.5	.270	.0008	309	436	.260
	3.5	.189	.0006	270	357	.186
	2.5	.362	.0005	130	308	.221
O_3	5.5	.220	.0005	414	502	.204
	4.5	.174	.0005	360	441	.164
	3.5	.250	.0007	336	395	.233
	2.5	.206	.0006	335	397	.193

When the seedlings were fumigated with NO_2 alone or with SO_2 before the acid mist treatments, no significant differences were observed in any of the four variables measured with a change in pH. Similar results were observed with ozone. The growth analysis variables calculated for the NO_2, $NO_2 + SO_2$, and O_3 treated plants were variable and showed no consistent trends. For example, whereas RGR and RLAGR tended to increase with acidity in the NO_2 treated seedlings, no distinct trends were observed on the NO_2 plus SO_2 or O_3 fumigated seedlings.

The process by which the air pollutants altered the impact of acid mist observed in the first study is uncertain but may have been partially due to their nutritional contributions. Although no statistical test can be made to compare the seedlings treated wth NO_2 or NO_2 plus SO_2 with the seedlings that did not receive any fumigation, an examination of the data in Table 1 indicates that the seedlings in these treatments had more than twice the leaf area, twice the new stem and leaf dry weight, and were twice as tall as the seedlings that were not fumigated. Even though soluble fertilizer treatment can improve the growth of healthy seedlings, the NO_2 treatment and related gaseous pollutants may have further stimulated growth that could mask the harmful effect of the acid mist.

The results of these studies suggest that yellow-poplar growth decreased with increasing acidity whereas the addition of one or more gaseous pollutants of ozone, nitrogen dioxide, and sulfur dioxide did not cause significant growth reductions with increasing acidity. In an experiment designed to determine if the inclusion of ozone modified the effects of acidity of simulated rain on yield of soybean, Troiano et al. (1983) concluded that soybean mass was only slightly curtailed with increasing acidity in filtered air. However, with unfiltered air (ozone), vegetative mass decreased with increasing acidity. These findings are not in total agreement with our data which indicate that yellow-poplar seedlings receiving ozone and acid mist were not affected whereas seedlings growth was reduced with increasing acidity. Although the procedure and methodology of applying acid rain may be primarily responsible for the experimental discrepancy in growth responses, other environmental and plant characteristics such as dose response, genetical tolerance of host, stages of physiological development, and plant/soil nutrient status may also contribute.

The conclusions of these studies are representative of a laboratory experiment using low gaseous pollutants and acidity dosages to observe their effects on yellow-poplar seedlings. Such extrapolation to forests may be questionable because of probable differences in responses of mature trees subject to variable environmental conditions. Nevertheless, our results indicate that yellow-poplar growth is affected and that the potential for change in forest structure and function may exist. Further study coupling acidity and gaseous pollutant dosages with soil chemistry under field conditions must be conducted to more accurately assess the consequences of atmospheric deposition on early and subsequent growth of forest trees.

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