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Ozone fumigation of Norway spruce at timberline

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Introduction

Ozone is thought to be involved in forest decline (Bucher, 1986; Krause *et al.*, 1986), especially at high altitudes, where increased O_3 levels together with a fast increase in forest damage has been observed (Berichte Tiroler Landtag, 1985–1988). Many investigations on the impact of O_3 on trees have been carried out under laboratory conditions, mainly with seedlings, but few in the field (Smidt, 1978; Pye, 1988). Experimental data of effects of O_3 on adult trees under field conditions are rare (Coyne and Bingham, 1982) or lacking altogether as for instance for the timberline region. Therefore it seemed to be of interest to fumigate an adult spruce tree with various O_3 concentrations and to examine the effects of O_3 on gas exchange and chlorophyll fluorescence, both known to be indicators of latent or hidden O_3 injury.

Materials and Methods

For this study, a 60 yr old spruce tree (*Picea abies* (L.) Karst.) near the Klimahaus research station on Mt. Patscherkofel (1920 m a.s.l.) near Innsbruck was selected. For each treatment, 6 similar twigs were enclosed in plexiglass chambers, where the air was exchanged 3–4 times per minute. O_3 treatments were as follows: control (charcoal-filtered air), ambient air, ambient air + 38 ppb O_3 (1987) and 120 ppb O_3 (1986), respectively. The twigs were left in the fumigation chambers for one full growing season (July to September). Monthly means of

Table I. Monthly means of O_3 concentration, air temperature, relative humidity and sums of precipitation at the research site on Mt. Patscherkofel.

	1986				*1987*			
	O_3 (ppb)	*Temp. (°C)*	*R.H. (%)*	*P (mm)*	*O_3 (ppb)*	*Temp. (°C)*	*R.H. (%)*	*P (mm)*
July	72	8.3	68	85	74	10.2	92	189
Aug.	66	8.8	68	199	62	7.5	80	129
Sept.	48	6.9	61	52	57	9.8	71	75

Table II. Stomatal conductance (mmol $H_2O \cdot m^{-2} \cdot s^{-1}$) of current and last year's needles in 1986 and 1987.

Treatment	*Fumigation*	*Fumigation 12 wk*	*Needles*
1986	*4 wk*		
control	27.5 ± 5.1	37.3 ± 7.9	current
ambient air	29.9 ± 8.1	46.9 ± 9.6	
120 ppb O_3	39.7 ± 10.7[a]	42.1 ± 12.7	
1987	*8 wk*		
control	45.9 ± 7.7	54.6 ± 8.0	current
ambient air	52.9 ± 13.1	54.0 ± 3.8	
ambient + 38 ppb	49.1 ± 10.2	55.3 ± 9.3	
control	–	34.3 ± 7.0	last yr's
ambient air	–	42.0 ± 19.9	
ambient + 38 ppb	–	38.2 ± 10.1	

[a] Statistically different from control: $P < 0.05$.

O_3, air temperature, relative humidity and sums of precipitation for 1986 and 1987 are given in Table I.

O_3 was produced with a UV-lamp (Osram HNS-UOZ) and O_3 concentrations in the chambers were checked daily with an ozone meter (Monitor Labs Mod. 8810). All gas exchange measurements were made in ambient air with a thermoelectrically controlled Minicuvette System (Walz, Effeltrich, FRG). Measurements were taken at light saturation, leaf temperatures of 21°C (1986) or 18°C (1987) and at a relative vapor pressure deficit of 10.6 Pa/kPa.

Chlorophyll fluorescence of small twigs from all cuvettes (*i.e.*, 6 replicates per treatment) was also measured *in situ* after predarkening with light tight bags in 1987 (23 September, during daylight hours). A pulse-modulation fluorometer (Pam 103, Walz, Effeltrich, FRG) was used, as described by Schreiber *et al.* (1986).

Results and Discussion

At the end of the fumigation period, all twigs looked healthy and there was no visible needle damage. However, O_3 concentrations were high enough to alter gas exchange parameters.

Stomatal conductance

In no case investigated did O_3 treatments reduce stomatal conductance to values lower than those of control twigs. On the contrary, low doses of O_3 seemed to increase conductance at least temporarily. In 1986, a 4 wk fumigation with 120 ppb led to a statistically significant increase of conductance of 45% compared to O_3-free controls, which disappeared after 12 wk of fumigation (Table II). Under the 1987 conditions, all treatments resulted in similar stomatal conductance. A stomatal behavior similar to that observed in 1986 was found by Keller and Häsler (1984) in spruce seedlings, where conductance was also higher and stomata reacted more sluggishly than in controls.

Chlorophyll fluorescence and net photosynthesis

After 8 wk of fumigation in 1987, all samples exhibited normal fluorescence transients. There were no significant differ-

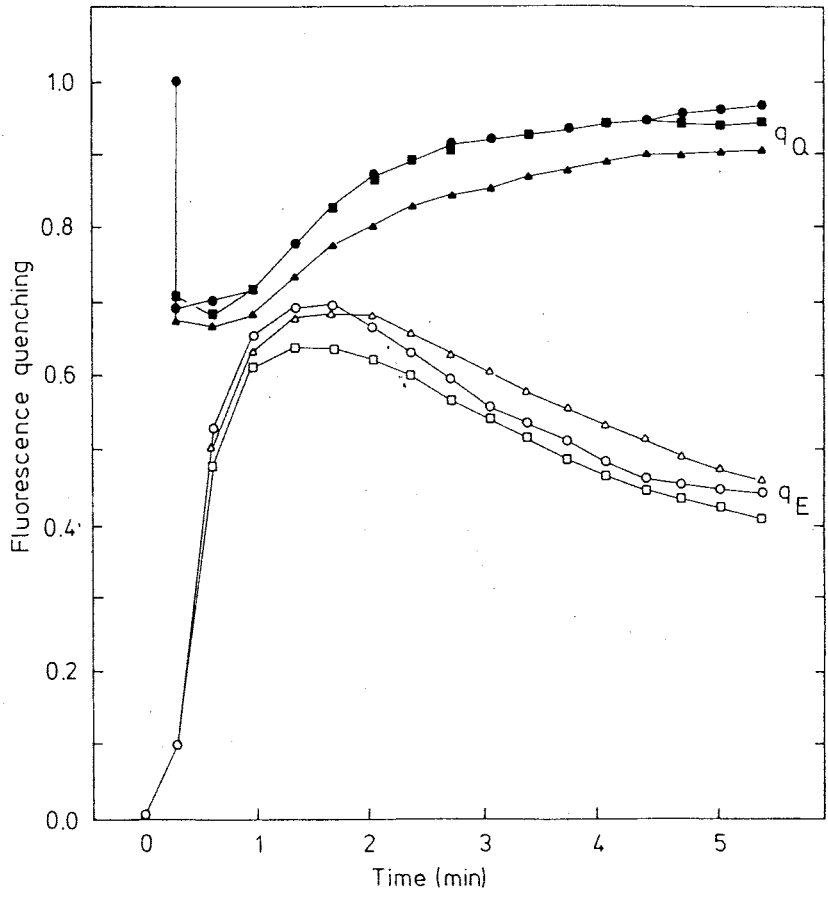

Fig. 1. Mean photochemical (q_Q) and non-photochemical (q_E) quenching coefficients of current needles of Norway spruce after 10 wk of fumigation with 0 ppb O_3 (○), ambient air (mean = 64 ppb, □), or ambient air + 38 ppb = 102 ppb O_3 (△). ($n = 6$).

ences between the quenching coefficients (Fig. 1). The quotient $(F_{max} - F_0)/F_{max}$, which is a quantitative measure of the photochemical efficiency of photosystem II, was between 0.81 and 0.82 for all 3 treatments which is within the normal range for C_3 plants (Björkman and Demmig, 1987).

At the same time, net photosynthesis was slightly but not significantly reduced in O_3-treated twigs. 12 wk of fumigation with ambient air also did not alter photosynthesis significantly compared to controls (Fig. 2). Elevated O_3 levels, however, led to a significant decline in photosynthesis. Current year's needles fumigated with ambient air + 38 ppb O_3 during daylight hours showed a decline of 10% and needles treated with 120 ppb O_3 continuously showed a decrease of 30% when compared to controls. Last year's needles

had reduced photosynthesis by about 5% after treatment with ambient air + 38 ppb O_3.

In discussing our results, we always have to keep in mind that this fumigation experiment was performed with only one tree. These results indicate that at timberline, where pollutants other than O_3 were largely absent (Smidt, 1983), ozone concentrations of the ambient air did not alter gas exchange or chlorophyll fluorescence significantly within one vegetation period. Ozone concentrations slightly higher than that in ambient air, however, could stimulate stomatal opening leading to higher ozone uptake into the needles and reducing their photosynthetic rates in spite of the higher stomatal conductance. Thus we conclude that O_3 concentrations higher than 100 ppb persisting for long time periods or a general further increase of O_3 above present ambient levels would reduce photosynthesis in spruce, which, in combination with bad climatic or poor soil conditions, might result in a greater susceptibility to climatic and biotic damage.

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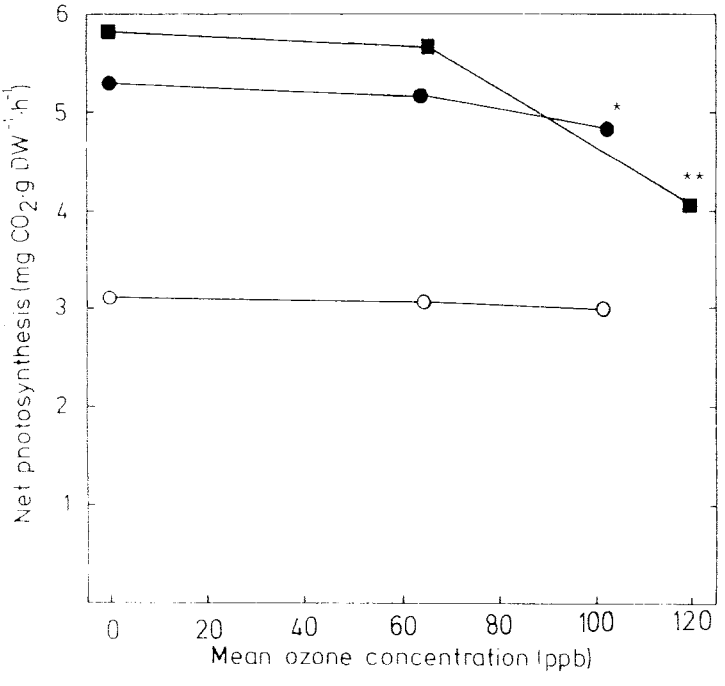

Fig. 2. Net photosynthesis of Norway spruce in response to mean ozone exposure after 12 wk of fumigation. ■: current needles, investigated 1986; ●: current needles, investigated 1987; O: last yr's needles, investigated 1987. * Statistically different from control: $P < 0.05$. ** Statistically different from control and ambient air: $P < 0.02$.

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