Ann. Sci. For. (1989) 46 suppl., 577s-580s
Forest Tree Physiology, E. Dreyer *et al.*, eds.

The influence of acid mist upon transpiration, shoot water potential and pressure–volume curves of red spruce seedlings

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Introduction

Widespread forest decline has been documented in Europe and NE-U.S.A. (Johnson, 1987; Woodman, 1987). This decline increases with increasing altitude (McLaughlin, 1985). One hypothesis to explain the decline and its altitude dependence is that excessive proton input has a deleterious effect upon tree growth. Acid input to the foliage and soil *via* wet and dry deposition may be a major factor in causing decline directly or indirectly by predisposing the tree to additional biotic and/or abiotic stress factors.

The maintenance of a favorable water status is a priority for continued growth and survival, and many of the symptoms associated with forest decline (crown thinning, root necroses) may be expected to influence plant water status. This paper presents some of the results of a detailed study of the influence of acid mist on the water relations of red spruce seedlings.

Materials and Methods

Red spruce seeds were germinated and grown for 16 mo in a greenhouse maintained at 16–20°C. On 16/7/87 100 seedlings were placed inside each of 8 open top chambers (OTCs) at a site in Scotland, U.K. (55°50'N; 2°13'W; 200 m altitude). Four different pH treatments (pH 2.5, 3.0, 4.0 and 5.0) with simulated acid mist were supplied using dilutions of an equimolar solution of $(NH_4)_2SO_4$ and HNO_3.

Each chamber received twice weekly sprays with an equivalent of 2 mm precipitation per spray. Spraying commenced on 24/7/87 and continued until 20/12/87.

The following measurements were made: 1) shoot water potential was determined at 09:00 h on 23/10/87 using a portable Scholander pressure bomb (Hellkvist *et al.*, 1974). Eight replicate branches from pH 2.5, 3.0, 4.0 and 5.0 treated trees were measured. 2) Day and night transpiration rates were determined on 16/11/87 for 10 entire seedlings, of pH 2.5 and pH 5.0 treatments and 10 attached shoots enclosed in a cuvette. 3) Eight replicate shoots (rehydrated overnight as attached branches) from pH 2.5, 3.0 and 5.0 treated seedlings were subjected to pressure–volume analysis (Kim and Lee-Stadelmann, 1984; Stadelmann, 1984).

Results

Fig. 1 shows that branch water potential (Ψ_w) decreased from –0.07 to -1.2 MPa as treatment pH decreased from 5.0 to 2.5.

Day and night transpiration rates were 1.19 ± 0.06 mmol·s^{-1}·tree^{-1} (day) and 0.54 ± 0.06 mmol·s^{-1}·tree^{-1} (night) for whole trees treated with pH 2.5 mist, and 1.5 ± 0.14 mmol·s^{-1}·tree^{-1} (day) and 0.68 ± 0.09 mmol·s^{-1}·tree^{-1} (night) for pH 5.0 treated trees. Night:day ratio was 0.45 for both. The slightly greater values for pH 5.0 treated trees per tree was due to the slightly larger pH 5.0 trees. However, day and night transpiration rates for branches, expressed on a unit area basis, did not differ significantly (pH 2.5: 0.23 ± 0.04 mmol·m^{-2}·s^{-1} (day), 0.099 ± 0.006 mmol·m^{-2}·s^{-1} (night); pH 5.0: 0.22 ± 0.03 mmol·m^{-2}·s^{-1} (day), 0.015 mmol·m^{-2}·s^{-1} (night)).

Table I is a summary of the data derived from pressure–volume curves. Maximum turgor decreased from 2.35 to 1.3 MPa as treatment pH decreased. The relative water content *(RWC)* associated with zero turgor (Ψ_p=0) and the maximum bulk volumetric elastic modulus (ε_v) decreased as treatment pH decreased. Solute potential (Ψ_π) at zero turgor decreased with increasing treatment pH.

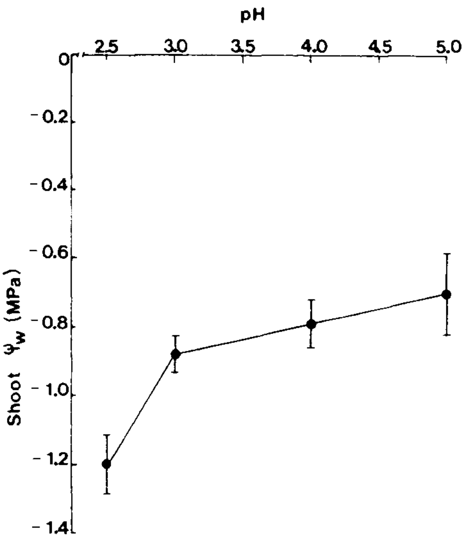

Fig. 1. Branch water potential (Ψ_w MPa) of red spruce seedlings receiving mist of 1 of 4 pHs.

Table I. Values of various water relations parameters derived from pressure–volume analysis of red spruce seedlings receiving acid mists.

Parameter	*pH value*		
	2.5	*3.0*	*5.0*
Ψ_p max (MPa)	1.3	2.2	2.35
RWC at Ψ_p=0	0.78	0.83	0.86
ε_0 (MPa)	12.7	32.7	44.5
Ψ_π at Ψ_p= 0 (MPa)	–2.0	–2.4	–2.45

Fig. 2 shows changes in ε_v with turgor (top) and *RWC* (bottom) for pH 2.5, 3.0 and pH 5.0 treated branches. ε_v increased linearly with turgor and increased curvilinearly with *RWC*. pH 5.0 treated trees maintained the largest ε_v at all turgors, pH 2.5 treated trees maintained the smallest, with pH 3.0 intermediate between the two. For all *RWC*s greater than 90%, this trend was observed, whilst at *RWC*s less than 90% 3 crossover points in the data occurred.

Discussion and Conclusion

The development of water stress is characterized by a decline in Ψ_w. In this study, as treatment pH decreased, branch Ψ_w decreased, revealing a mild but significant water stress. Water stress occurs when the rate of water loss exceeds the rate of uptake. It was clear that the rates of day and night transpiration did not differ between treatments. From needle drying curves (data not shown), cuticular resistance did not differ between treatments. This result is in contradiction to those of several investigators who noted a significant effect of acid rain/mist upon cuticle structure and/or resistance. The lack of

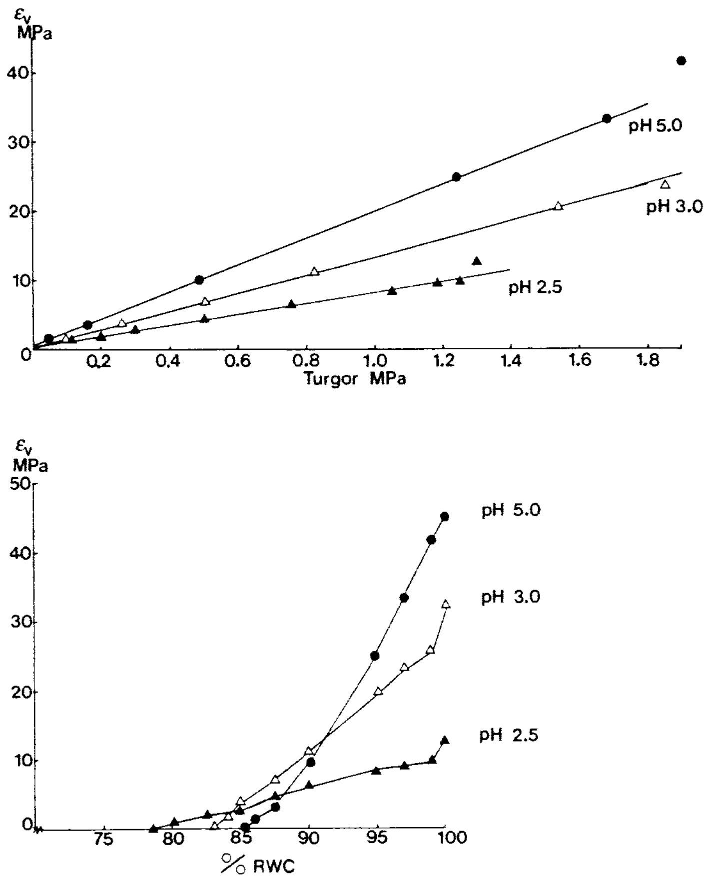

Fig. 2. Bulk volumetric elastic modulus (ε_V, MPa) of branches of acid mist-treated seedlings as a function of turgor (top) or relative water content (bottom).

apparent effect in the present study may be due to an efficient repair mechanism or because changes in structure can occur without concomitant changes in cuticular resistance. It is suggested that uptake and/or supply of water may be impaired in the roots or acid-treated seedlings. Pressure–volume analysis revealed significant effects of the acid mist. Maximum turgor (Ψ_p, max) decreased with decreasing treatment pH. This decreased Ψ_p, max reflects a reduction in solute accumulation. A significant reduction in solute potential associated with zero turgor (Table I) was also observed as treatment pH increased, further reflecting a decrease in solute accumulation with decreased pH of the treatment mist. Turgor (Ψ_p) was maintained to lower *RWC*s at pH 2.5 than pH 3.0 treated branches. This can result from either increased solute accumulation or reduced ε_V. The former did not occur; the latter did (Table I). A reduction in ε_V indicates a more elastic cell wall, possibly the result of the acidification of the apoplast leading to proton-induced cell wall loosening (Davies, 1973).

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