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Response of shoot growth and gas exchange of *Picea abies* clones to rain acidity and the addition of ions

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Introduction

The novel forest decline observed in Europe and the U.S.A. may be caused by several factors, among them, air pollution is thought to be very important. Interference of pollutants with the ecophysiological performance of forest trees needs to be investigated in order to understand the actual working mechanisms. The aim of this study was to examine the effect of acidic wet deposition on CO_2 exchange, needle conductance and shoot growth of Norway spruce, particularly the effect of acidity and the addition of a realistic ionic mixture to simulated acidic precipitation.

Materials and Methods

Four year old potted plants of 3 Belgian *Picea abies* (L.) Karst. clones were grown in a greenhouse (clone number 1007, 1011 and 1019). The plants were sprayed 3 times a week throughout the growing season with a hand pumped sprayer. The 4 treatments were: pH 5.6⁻ and 5.6⁺: de-ionized water in equilibrium with the atmospheric CO_2 pressure, resp. without (–) and with (+) the ionic mixture mentioned below; pH 4.0⁻ and 4.0⁺: same as pH 5.6 but the solution was acidified to pH 4.0 with a mixture of sulfuric and nitric acids (SO_4^{2-}/NO_3^- weight ratio = 2.4). Ionic concentrations in mg/l were: 4.50 SO_4^{2-}, 2.00 NO_3^-, 1.20 NH_4^+, 0.99 Na^+, 1.45 Cl^-, 0.30 K^+, 0.60 Ca^{2+}, 0.30 Mg^{2+} and 0.40 HSO_3^- (Van Elsacker *et al.*, 1988).

Gas exchange was measured on fully grown current year shoots during the summer. CO_2 exchange rate *(CER)* was measured at PPFD saturation with a portable, closed-loop system (Van Elsacker and Impens, 1986). The number of data was 12 measurements x 4 treatments x 4 (parts of) days. Needle conductance *(Gn)* was measured with an automatic diffusion porometer developed at the laboratory (procedure comparable to Delta-T porometer). Data were calculated on a needle dry weight basis (gdw^{-1}). The number of *Gn* data was 13 measurements x 4 treatments x 3 (parts of) days for clone 1011, and 11 x 4 x 4, respectively, for the other clones. To analyze the gas exchange data, a 3-way analysis of variance with the factors pH, ions (– or +) and day was used; the factor 'day' allowed for temporal, environmental and ecophysiological variations.

The length of top and lateral current year shoots of 13 plants per treatment and per clone was measured every 3–4 d from bud break (mid-May) until growth had stopped (July, total of 13 measurement d). A non-linear regression procedure was used to fit a logistic growth function.

Results

Treatment means, pooled for the whole summer, of net CO_2 exchange *(CER)* and needle conductance *(Gn)* of the 3 clones are shown in Fig. 1a, b. CO_2 exchange rate was reduced for all clones at pH 4.0^+ as compared to the other 3 treatments, a significant pH x ions interaction was found for each clone. The Newman–Keuls test resulted in the following significant differences between the treatment means: 1) clones 1007, 1019: 4.0^+ 5.6^- 5.6^+ 4.0^-; clone 1011: 4.0^+ 5.6^- 4.0^- 5.6^+ (sorted from low to high, underlined treatments are not significantly different at $P < 0.05$).

The response of the conductance for water vapor *(Gn)* to simulated precipitation differed between clones. *Gn* of clone 1007 was not affected: no significant effect of pH, ions or any interaction was observed. Clone 1011 showed a reduced *Gn* at pH 4.0^+ and a significant interaction of pH x ions. The Newman–Keuls test yielded the following: 4.0^+ 5.6^- $5{,}6^+$ 4.0^-.

The conductance of clone 1019 was also reduced at pH 4.0^+ and a significant interaction of pH x ions x d was found. The Newman--Keuls test was not significant at $P < 0.05$ for the treatment means.

The growth analysis of clone 1007 is shown in Fig. 2a, b. The mean length of the top shoot (Fig. 2a) is plotted against time in days (d 1 = 1 May). The logistic growth function: $f(t) = A / [1 + \exp^{(b - k \cdot t)}]$, was very significant ($R > 0.72$) but there were no differences of the parameter estimates between the treatments ($P < 0.05$). Typical values were: A = 142–160 mm, b = 5.7–6.9, k = 0.13–0.15 d^{-1}. The point of inflexion, where half of the final length was reached, was on d 44–48 (= b/k). Absolute growth rates were also very similar as can be deduced from the slopes of

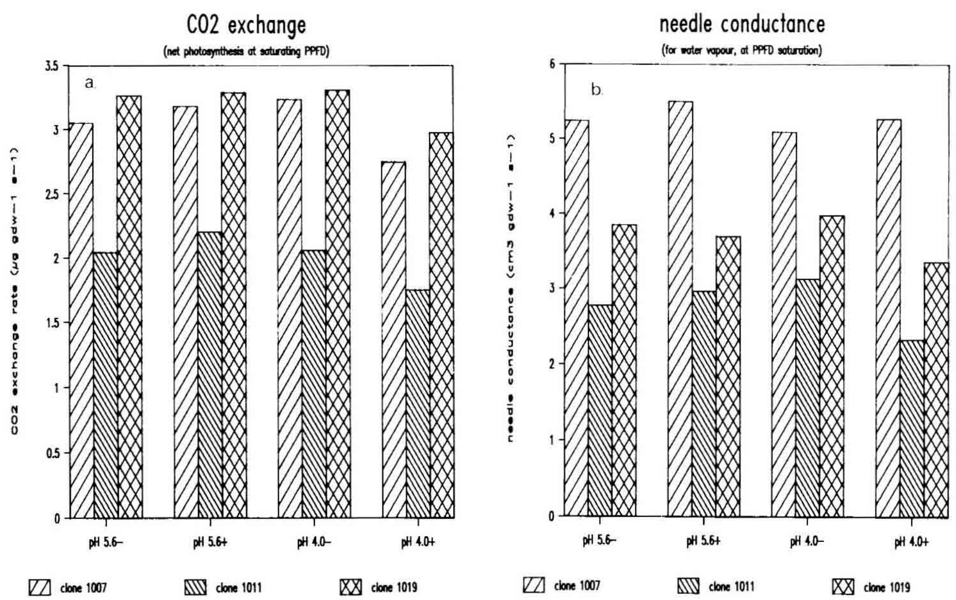

Fig. 1. Treatment means of (**a**) CO_2 exchange rate and (**b**) needle conductance at saturating PPFD of the tree clones.

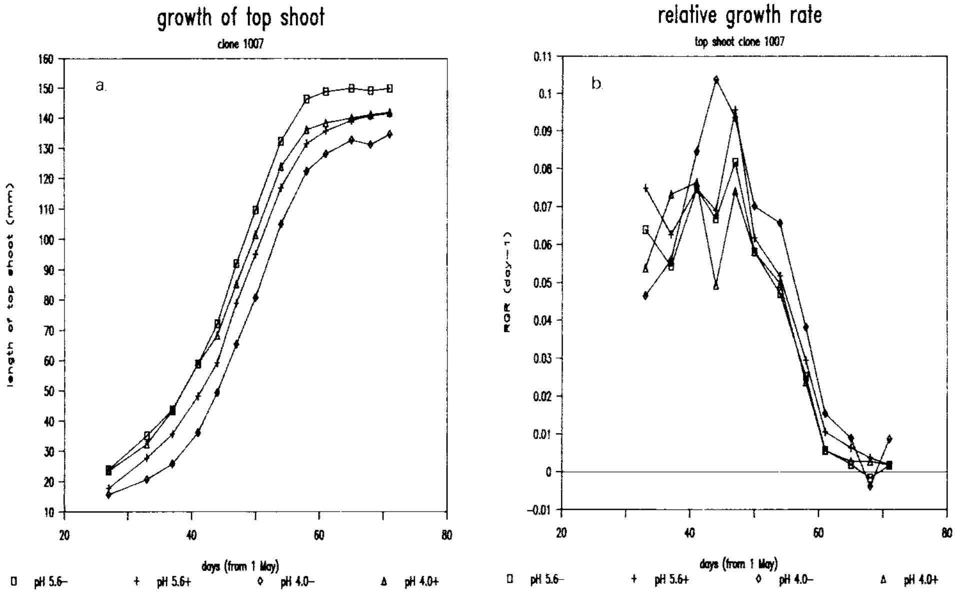

Fig. 2. Growth of top shoot of clone 1007: (**a**) changes in mean shoot length with time; (**b**) changes in mean relative growth rate with time. Lines only connect means of each treatment.

the curves in Fig. 2a. Relative growth rates *(RGR)* are plotted in Fig. 2b. The lines connecting the *RGR* values for different time periods of each pH treatment cross one another, there were no clear differences between the 4 treatments. Similar results (not shown here) were obtained for top shoot growth of clones 1011 and 1019, the latter showing lower final lengths (*A* = 112–136 mm), lower *b*-values (*b* = 4.8–5.7) and inflexion points on d 35–38. The growth of lateral shoots also did not show clear differences between the pH treatments.

Discussion and Conclusion

The reduction of *CER* and *Gn* at pH 4.0+ and the significant pH x ions interaction suggest a synergism between increasing acidity and the addition of the ionic mixture. The effect of acidic rain on the *Gn* of clone 1019 seemed to depend upon environmental and/or ecophysiological conditions (interaction pH x ions x d). A reduction of the photosynthetic capacity may have consequences for growth and production of forest trees, as observed for poplar (Van Elsacker *et al.*, 1988). However, length growth of top (and lateral) shoots in this experiment was not obviously changed by any simulated (acidic) precipitation treatment.

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