Phyton (Austria) Special issue: "Root-soil interactions"	Vol. 40	Fasc. 4	(179)-(184)	25.7.2000

Effects of Nutrient-Deficient Soil on Gas-Exchange, Chlorophyll Fluorescence and C-Allocation in Young *Picea abies* (L.) Karst.

By

F. WERTHER[1)] & W. M. HAVRANEK[1)]

Key words: Nutrient deficiency, *Picea abies*, chlorophyll fluorescence, gas–exchange, stomatal conductance, soil drought.

Summary

WERTHER F. & HAVRANEK W. M. 2000. Effects of nutrient-deficient soil on gas-exchange, chlorophyll fluorescence and C-allocation in young *Picea abies* (L.) Karst. – Phyton (Horn, Austria) 40 (4): (179) - (184).

We measured gas exchange, chlorophyll fluorescence and dry weight of 4-year-old potted spruce seedlings, half of which were fertilised, under field conditions. The soil was a nutrient deficient calcareous soil of a natural stand in the Northern Alps of Tyrol. All unfertilised seedlings (U) showed a strong N-deficiency leading to yellow-green needles while fertilised plants (F) were well supplied with all nutrients.

In general, net photosynthetic rates were about twice as high in F, whereas leaf conductance was lower in F than in U, indicating that Pn difference was not caused by stomatal aperture. Effective quantum yield was also higher in F than in U. Gas-exchange and quantum yield were positively correlated to needle N content. It was mainly N deficiency which caused a biomass reduction in U, and an increase in the root / shoot ratio.

Introduction

Severe forest decline in Austria has been reported from areas of the Northern Limestone Alps where several stress factors could act together in causing poor forest conditions: nutrient-deficient soils, frequent soil drought and a high ozone load. Such a location is, for example, the Loisach Valley in the Northern Tyrolean Alps (HAUPOLTER 1997) where crown transparency is very high and nutrient deficiency is evident in spruce. In a first step of stress analysis, we investigated the

[1)] Federal Forest Research Centre, Div. Forest Tree Physiology, Rennweg 1, A-6020 Innsbruck, Austria.

effects of nutrient deficiency on C-allocation, gas-exchange and chlorophyll fluorescence.

Materials and Methods

Two-year-old spruce seedlings of a local provenance were potted into 8-liter pots using the nutrient-deficient calcareous forest soil from Schöberle (Loisach – valley), a site with severe forest damage, in spring 1996. We took the soil from the surface to a depth of 30 cm, sieved it to eliminate stones (> 0,8 cm) and mixed it thoroughly. The soil had very little humus, a low water holding capacity, a pH of 7-7.3 and low nitrogen content. Half of the seedlings were fertilised (F) with a commercial fertiliser while the rest were kept in unfertilised soil (U), and placed in a nursery. After the new flush was completed in the next year, seedlings were brought to the Klimahaus nursery at Mt. Patscherkofel (1950m a.s.l.). There, three twigs from each of 12 seedlings in both treatments were marked and used for repeated comparative measurements of gas exchange (ADC-porometer) and chlorophyll fluorescence (Mini-PAM, Walz) between 10 a.m. and 3 p.m. on sunny days throughout the summer 1997 under field conditions. Gas exchange was measured at least once per sampling day for each seedling, sometimes even several times, and averaged for treatment group and day. Photosynthetic quantum yield was measured parallel to gas exchange on most of the sampling dates and means per day were calculated as for gas exchange data. The plants received only natural precipitation and were therefore exposed to some soil drought which, unfortunately, was not recorded. Photosynthetic parameters were calculated after CAEMMERER & FARQUHAR 1981 and related to total needle area. Chlorophyll fluorescence parameters were calculated after SCHREIBER & al. 1994. At the end of the experiment nutrient contents of current year needles and biomass distribution were analysed for each seedling .

Statistical treatment: The normally distributed (Kolmogorov – Smirnow test) daily means of the gas-exchange and chlorophyll fluorescence data were tested for significant differences between (F) and (U) with the Student t-test. Stepwise multiple regression analysis was used to determine the correlation between nutrient contents on the one hand, and gas-exchange and quantum yield on the other.

Results and Discussion

Mean nutrient contents of U- and F- seedlings are shown in Table 1. N, P and K, as well as the N/P ratio were significantly lower, but Mg and Ca contents were higher in U than in F seedlings. All U plants were strongly N-deficient. A weak P- deficiency occurred in some U and in a few F plants. All other macro- and micro-nutrients (Fe, Zn, Mn) were sufficient in U and F by reference to GUSSONE 1964 and FÜRST 1996a, b. Compared to these seedlings the needles of mature trees at Schöberle were less N, P, (Cu and Mn)-deficient.

Total seedling dry weight of U was only about 50 % of that of F. Root dry weight, however, was less reduced in U which resulted in higher root/needle and root/shoot ratios than in F, indicating a significant relative increase in C-allocation to roots in U.

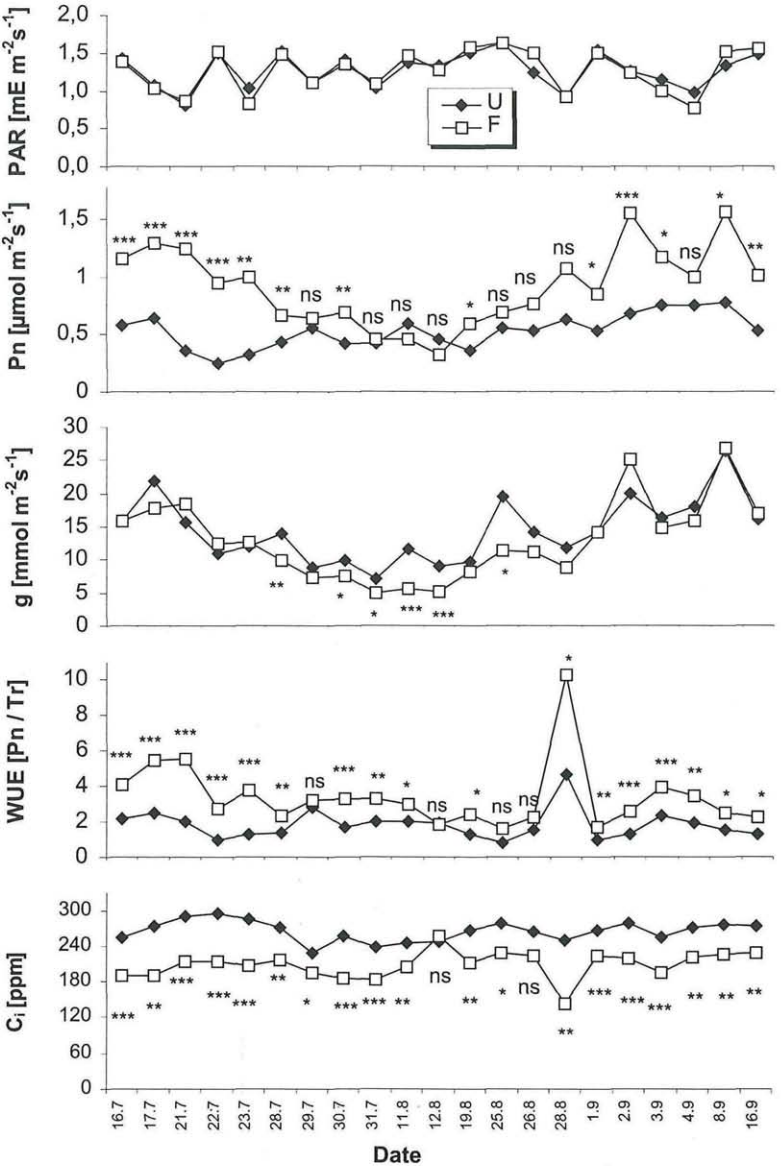

Fig. 1. Comparison of gas-exchange parameters of U- and F-seedlings for various dates during the vegetation period. Gas exchange was measured synchronously in U and F between 10 a.m. and 3 p.m. in the field. All measurements per day and treatment (12<n>36) were averaged and the significance of difference between both treatments is shown as: *** p = 0.001, ** p = 0.01, * p = 0.5, n.s. = not significant. Note that the x-axes in figures 1 and 2 are not time scales but indicate the sequence of measuring dates.

Table 1. (a): Nutrient content of current year needles and (b): biomass distribution of unfertilised (U) and fertilised (F) spruce seedlings after two years of treatment. dw = dry weight, n = number of seedlings; significance of difference between U and F: *** p = 0.001, ** p = 0,01, * p = 0.05, n.s. = not significant.

Picea abies (a) [% dw]	Unfertilised Mean ± SD	Fertilised Mean ± SD	n=12 p	(b) dw [g]	Unfertilised Mean ± SD	Fertilised Mean ± SD	n=12 p
N	0.65 ± 0.11	1.57 ± 0.18	***	Seedling	65.0 ± 11.6	118.9 ± 32.9	***
P	0.10 ± 0.18	0.12 ± 0.09	*	Needle	10.5 ± 3.0	22.6 ± 6.3	***
K	0.49 ± 0.08	0.78 ± 0.20	**	Shoot	23.6 ± 4.1	47.1 ± 13.2	***
Ca	0.77 ± 0.20	0.34 ± 0.07	***	Root	17.7 ± 4.0	24.7 ± 6.7	*
Mg	0.23 ± 0.06	0.11 ± 0.03	***	R / S ratio	0.75 ± 0.1	0.53 ± 0.06	***
N / P ratio	6.55 ± 1.75	13.20 ± 2.57	***	SLA [m²/ kg]	10.95 ±1.63	10.28 ± 2.0	n.s.

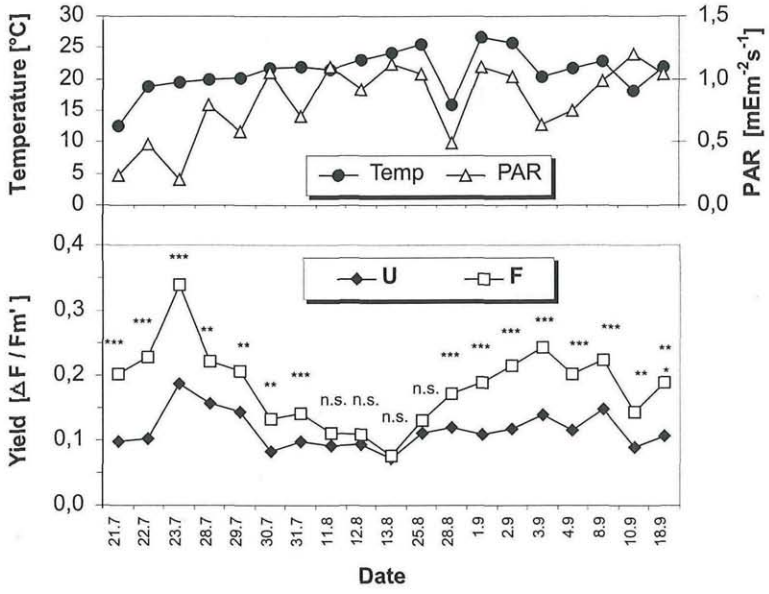

Fig. 2. Mean quantum yield (ΔF/Fm') of U- and F- seedlings for various dates during the vegetation period. Photosynthetic quantum yield was measured synchronously in U and F between 10 a.m. and 3 p.m. in the field. Means of PAR and temperature during the measurements are depicted in the upper part of fig. 2.

Net photosynthesis (Fig.1, Pn) was significantly higher in F during moist periods in July and September but was even slightly lower than in U during dry periods at the end of July and in August. Nitrogen deficiency is reported to limit sink activity of growing meristems which may lead to the down-regulation of photosynthetic source activity (LOGAN & al. 1999). The stronger reduction of Pn with decreasing soil moisture in F compared to U was mainly due to a more effective stomatal closure indicated by lower leaf conductance in F (Fig.1, g). Except for periods with soil water stress, WUE was always higher and C_i lower in F than in U

(Fig. 1, WUE, C_i), due to a distinctively higher photosynthetic capacity in F seedlings. Measurement of chlorophyll fluorescence, which allows insight into the state of photosystem II, confirmed this result. Quantum yield, the photochemical efficiency of photosystem II, was also always significantly lower in U compared to F (cf. LOGAN & al. 1999). However, the generally low yield values obtained on sunny days during midday (see temperature and PAR means), as well as the low rates of Pn, indicate considerable stress in the potted seedlings. This may be explained by the rather low light saturation of Pn in spruce seedlings which at this high altitude nursery were exposed to excess light conditions and occasional drought.

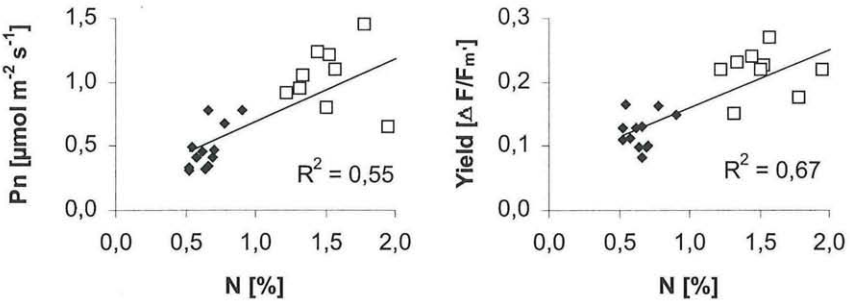

Fig. 3. Correlation between nitrogen content and net photosynthesis (left), and quantum yield (right) in current year needles of unfertilised (filled symbols) and fertilised seedlings (open symbols). Points represent mean values for each seedling, which were calculated from data measured during midday on 18 summer days.

Both Pn and quantum yield were positively correlated to the N content of the needles (Fig. 3). Although other nutrients (P,K) were also slightly deficient in a few seedlings, only N was accepted by multiple regression analysis as a significant correlation factor. Higher transpiration rates (cf. g in Fig.1) may have passively increased Ca and Mg contents in needles of U compared to F, while sufficient uptake of N, (P and K) was impossible.

Conclusions

These first results demonstrate that addition of a fertiliser to a nutrient-deficient calcareous forest soil substrate had a strong positive effect on growth, gas exchange rates and quantum yield. Unfertilised spruce seedlings invested relatively more carbon into their root system than fertilised seedlings, which may have led to a better exploitation of the nutrient and water resources of the soil. Strong N deficiency led to yellow-green needles and to a reduced photosynthetic performance. Further implications on pigment and antioxidant contents are expected but analysis is not yet complete.

References

FÜRST A. 1996a. Blatt- und nadelanalytische Untersuchungen im Rahmen des Waldschaden-Beobachtungssystems – Ergebnisse 1989 bis 1993. - FBVA - Bericht 93: 101-109.

— 1996b. Eisen-, Mangan- und Zinkversorgungsgrad der Fichte im Jahr 1993 in Österreich. - FBVA – Bericht 93: 111-120.

GUSSONE H. A. 1964. Faustzahlen für die Düngung im Walde. - BLV - Bayerischer Landwirtschaftsverlag, München - Basel - Wien.

HAUPOLTER M. 1997. Loisachtal: Waldboden und Baumernährung. - FIW - Abschlußbericht II. Bodenmelioration degradierter Waldstandorte der nördlichen Kalkalpen Tirols. - Inst. Waldökologie Univ. f. Bodenkultur Wien.

LOGAN B. A., DEMMIG-ADAMS B., ROSENSTIEL T. N. & ADAMS III W.W. 1999. Effect of nitrogen limitation on foliar antioxidants in relationship to other metabolic characteristics. - Planta 209: 213-220.

SCHREIBER U., BILGER W. & NEUBAUER C. 1994. Chlorophyll fluorescence as a nonintrusive indicator for rapid assessment of in vivo photosynthesis. - In: SCHULZE E. D. & CALDWELL M. M. (Eds.), Ecophysiology of photosynthesis. Ecological Studies Vol. 100, pp. 49-70. - Springer-Verlag Berlin.

VON CAEMMERER S. & FARQUHAR G. D. 1981. Some relationships between the biochemistry of photosynthesis and the gas exchange of leaves. - Planta 153: 376-387.