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Effect of increased nitrogen depositions and drought stress on the development of young Norway spruce *Picea abies* (L.) Karst. stands

Abstract: The effects of drought stress, stress by increased nitrogen depositions and the combined effect of the two stress factors on the growth of Norway spruce *Picea abies* (L.) Karst. were studied in two stands. The drought stress was induced by reducing atmospheric precipitations by 60% and the increased nitrogen depositions were simulated by repeated applications of ammonium sulphate at a rate corresponding to 100 kg N ha^{-1} $year^{-1}$. All stress factors under study affected the height increment of the above-ground part, the length and colour of needles, and the biomass, vertical distribution, functionality and mycorrhizal infection of fine roots. The root system responded to the simulated stresses right from the the very first year of their action, exhibiting a greater damage than the above-ground part of the plant. Drought acted as a stress factor stronger than the nitrogen depositions themselves. The strongest impact was recorded in the simultaneous influence of the stress factors.

Additional key words: height increment, biomass, fine roots, functionality, mycorrhiza

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Introduction

Forest tree species develop in a continual interaction with the outer environment, being exposed in the course of their life to natural stress factors such as pathogens and pests, high or low air temperatures, excessive water or drought. Some models elaborated by foreign laboratories in connection with the expected global climatic changes suggest that middle latitudes could experience a prolonged interval between precipitation events, particularly in the spring and summer seasons, and massive rains in the autumn, which would mean exposure of plants to drought stress (Chalupa 1995). As the tree species are organisms with a long life cycle and a limited capacity for evolutionary accommodation to sudden changes in the environment, they are likely to be the most affected plants.

In the last few decades, these natural stress factors were joined by stressors of anthropogenic origin such as sulphur compounds, halogens, hydrocarbons, hydrogen peroxide and a range of other oxidants, and, last but not least, also compounds of nitrogen whose emissions have been recently increasing every year by 5% as indicated by some estimates (Tamm 1989).

Inputs of this element represent an important site factor for the forests of central and northern Europe. Some years ago, nitrogen used to be an element which limited the growth and production of tree species; however, since about 1960, spruce and pine stands have exhibited incremental production which is put into context with the increasing depositions of nitrogen (Kennel 1994; Kreutzer 1994; Rothe 1994). It is known from literature that the increased nitrogen depositions positively influence the growth of the above-ground part (Linder and Rook 1984; Nilsson and Wiklund 1992), but can also show a negative effect on the root systems of tree species (Tölle 1967; Heinsdorf 1976; Alexander and Fairley 1983; Vogt et al. 1990). Most sensitive response is exhibited by fine roots (diameter < 1 mm) including mycorrhiza whose significance for tree nutrition is considerable.

Sufficient amounts of water and nutrients in appropriate proportions are considered to be the main factors controlling the growth of tree species and their vitality. Both the increased nitrogen depositions and the possible warming and occurrence of dry periods in the growing season can represent strongly hazardous factors for the forest tree species at both younger and older stages of growth. Disproportions between the development of the above-ground part and that of the root system under the influence of increased nitrogen depositions could, among other things, lead to the situation in which the plant will not be capable of satysfying its water requirements with its restricted root system, which can result in a number of generally unfavourable consequences from impaired vitality, retarded growth, decreased production up to death. This is why experiments were established within a research project funded by the Grant Agency of the Czech Republic, whose objective was to find out how Norway spruce (*Picea abies* (L.) Karst.), and particularly its root system, reacts to the increased depositions of nitrogen, the long-term effect of drought and to the cumulative effect of the two factors.

Material and methods

The effect of increased nitrogen depositions, drought stress and the cumulative influence of the two factors were studied in two young stands:

– Bukovinka (MZLU – Training Forest Enterprise Křtiny, Brno District) – age 12 years, altitude 535 m, forest type 4H1, eastern aspect, zone of air pollution danger D. The stand was established by using a reel planter after previous bedding. Three-year-old bare-rooted seedlings of spruce (3 + 0) of local origin were used as a planting stock.
– Herálec (Bohemian-Moravian Upland) – age 12 years, altitude 710 m, forest type 6K6, northern aspect, zone of air pollution danger C. The stand was established manually by hole planting, using 4-year-old transplants of spruce (2 + 2) of local origin as a planting stock.

There were four partial plots 20 × 20 m aligned in both stands. Replications of the individual variants were not applied. In each of the stands under study there was a special structure erected between tree rows on both of the aligned plots to capture and drain atmospheric precipitation outside the plots. The bearing wooden structure was provided with frames covered with transparent sheets placed at heights 120–20 cm above the soil surface. The goal of this measure was to reduce atmospheric precipitation by 60% and in this way induce drought stress. The stress from increased nitrogen depositions was simulated by the application of ammonium sulphate at a rate corresponding to 100 kg N ha^{-1} $year^{-1}$.

The experimental variants established in the two stands were as follows:

– Control: no treatment;
– Drought: atmospheric precipitation reduced by 60%;
– Nitrogen: ammonium sulphate applied onto the soil surface three times in the first half of the growing season (March, May, July) in amounts corresponding to 100 kg N ha^{-1} $year^{-1}$, atmospheric precipitation not being reduced;
– Nitrogen + Drought: ammonium sulphate applied onto the soil surface three times in the first half of the growing season (March, May, July) in amounts corresponding to 100 kg N ha^{-1} $year^{-1}$, atmospheric precipitation being reduced by 60%.

The two stands were studied for the morphological and physiological response of the above-ground part and the root system, and for changes in the chemical, physical and biological properties of soil. The above-ground part of the measurements was focused on total height, increment, diameter at breast height (d.b.h.), length of needles, number and completeness of needle years, and amount of free aminoacids. The root system part of the measurements was focused mainly on fine roots (diameter < 1 mm). Analyses of the fine roots were made from soil cores of 5 cm diameter and 30 cm depth. For the procedure of sample processing see Mauer and Palátová (1996).

The fine roots obtained were analysed for length, number of root tips, vertical distribution and biomass. The functionality of the fine roots was detected by uptake of marked phosphorus (Langlois and Fortin 1984), their viability by reduction of 2,3,5 triphenyltetrazolium chloride (Joslin and Henderson 1984), and mycorrhizal infection by quantitative assessment of glucosamine after acidic hydrolysis of chitin (Plassard et al. 1982, Vignon et al. 1986).

Results

Bukovinka stand (see Table)

The height increment of the above-ground part was most affected in the second year of monitoring, the effect of simulated stresses being somewhat lesser in the following years. A pronounced adverse response of plants was recorded in variants Drought

Table 1. Response of plants in the Bukovinka and Herálec stands to stress factors (results in % of Control)

Experimental Series		Bukovinka				Herálec	
Year of stress impact		1st	2nd	3rd	4th	1st	2nd
Parameter	Variant						
Above-ground part increment	Control	n.m.	100.0	100.0	100.0	100.0	100.0
	Drought	n.m.	49.8	66.1	70.0	94.6	85.2
	Nitrogen	n.m.	134.0	121.7	103.3	97.1	118.5
	N + D	n.m.	72.5	88.1	88.1	79.1	90.5
Stem diameter (d1.3)	Control	n.m.	100.0	100.0	100.0	100.0	100.0
	Drought	n.m.	99.6	95.1	88.6	105.3	91.1
	Nitrogen	n.m.	117.9	103.6	110.2	93.2	96.3
	N + D	n.m.	100.4	97.3	96.5	85.9	82.2
Needle length	Control	n.m.	100.0	100.0	100.0	100.0	100.0
	Drought	n.m.	90.1	67.5	66.2	95.3	80.5
	Nitrogen	n.m.	114.4	109.9	114.1	103.7	128.9
	N + D	n.m.	95.5	87.4	71.8	100.0	125.8
Biomass of fine roots	Control	100.0	100.0	100.0	100.0	100.0	100.0
	Drought	57.1	53.5	37.9	45.6	105.9	89.6
	Nitrogen	106.5	90.4	84.0	83.9	98.8	108.9
	N + D	88.6	75.2	28.8	47.1	53.5	80.8
Mycorrhizal infection (humus layer)	Control	100.0	100.0	100.0	100.0	100.0	100.0
	Drought	89.8	102.8	77.7	116.3	101.6	98.6
	Nitrogen	122.7	118.8	69.3	89.7	104.0	112.9
	N + D	106.2	129.9	81.5	103.2	100.2	114.9
Functionality of fine roots	Control	n.m.	100.0	100.0	100.0	n.m.	n.m.
	Drought	n.m.	63.6	27.8	39.5	n.m.	n.m.
	Nitrogen	n.m.	60.2	65.9	56.3	n.m.	n.m.
	N + D	n.m.	63.1	39.5	63.1	n.m.	n.m.

n.m. – not measured

and Nitrogen + Drought (29 and 12% decrease in comparison with Control, resp.). The significant stimulating effect of nitrogen (var. Nitrogen) gradually decreased to an insignificant variance recorded in the last year of study.

Stem diameter was not affected in the first years. Unfavourable changes were recorded in the variants Drought and Nitrogen + Drought only in the later period of time (11 and 3% decrease in comparison with Control, resp.). The introduction of nitrogen stimulated the diameter growth for the whole time of study (increase by 10% in comparison with Control, resp.).

Needle length was adversely affected in the variants Drought and Nitrogen + Drought (34 and 28% decrease in comparison with Control, resp.), although at the beginning the effect of these stress factors was indifferent and changed into an inhibition effect only later. The increased nitrogen depositions (var. Nitrogen) were demonstrated to have stimulated needle length (14% increase in the comparison with Control) for the entire period of study.

The vitality of plants was not visually affected at the beginning. However, in the last year of study the plants recorded changes in vitality, which were most pronounced in the variants Drought and Nitrogen + Drought with mere 15 and 26% of trees, respectively, enjoying full health. The nitrogen depositions themselves (var. Nitrogen) did not affect vitality.

The content of free aminoacids was decreased in the variants with induced drought (var. Drought and Nitrogen + Drought) and increased in the variant with nitrogen (var. Nitrogen). Unlike the Control, all variants showed methionine. The Nitrogen variant recorded a considerably increased content of asparagine and a decreased level of ornithine; also, this was the only variant that exhibited a significant amount of arginine.

The biomass of fine roots markedly decreased due to drought (var. Drought) and due to the cumulative effect of stress factors (var. Nitrogen + Drought) as early as the first year. The Nitrogen variant showed biomass reduction only after the second year of study. All experimental variants recorded the greatest reductions in the fine roots biomass in the third year of study. As compared with the Control variant, in the last year of study the variants with induced drought stress (var. Drought and Nitrogen + Drought) exhibited reductions by 54% while the Nitrogen variant showed a reduction by 16%.

The vertical distribution of fine roots changed particularly in the variant Nitrogen + Drought, in which a displacement occurred of fine roots into deeper soil layers. The application of nitrogen did not affect the distribution of fine roots in the soil profile.

Although mycorrhizal infection decreased in the first year of study, especially in the Drought variant, the inhibition effect turned into stimulative in the following period; all experimental variants exhibited an increased mycorrhizal infection in the last year of study.

The functionality of fine roots was markedly decreased in all variants in the first years of experiment. Later on, no significant changes were recorded in the variants with nitrogen application (44 and 37% decrease as related to Control, resp.). However, the functionality of fine roots further decreased in the Drought variant (drop by 60% as compared with Control).

The vitality of fine roots was most affected in the humus layer right from the very first year of experimental study. The stress factors involving drought (var. Drought and Nitrogen + Drought) decreased vitality while the application of nitrogen (var. Nitrogen) showed no such effect. The vitality of fine roots in the layer 0–5 cm was adversely affected as late as the last year of study, again in the variants of Drought and Nitrogen + Drought. The 5–15 cm layer did not exhibit any significant influence on vitality.

Herálec stand (see Table)

The height increment of the above-ground part was negatively influenced after the first year of study only by the cumulative stress (var. Nitrogen + Drought). In the second year of monitoring, the increment was adversely affected already in both variants with induced drought (decrease by 15% in var. Drought, decrease by 10% in var. Nitrogen + Drought as related to Control). The input of nitrogen (var. Nitrogen) increased the increment by 18%.

Stem diameter was affected only by the cumulative stress (var. Nitrogen + Drought; decrease by 18% as related to Control).

Needle length was adversely affected only in the Drought variant (20% decrease as compared with Control). The increased depositions of nitrogen (var. Nitrogen) and the cumulative stress (var. Nitrogen + Drought) demonstrably stimulated needle length in both experimental years (increase by 29 and 26%, resp., as related to Control).

The vitality of plants was affected in the variants with drought (var. Drought and Nitrogen + Drought) but not in the Nitrogen variant.

The biomass of fine roots markedly decreased (by 20%) only in the variant with the cumulative stress (var. Nitrogen + Drought) while the Nitrogen variant exhibited the biomass of fine roots increased by 9% as related to Control.

The vertical distribution of fine roots was changed only in the Nitrogen + Drought variant, in which a displacement occurred of fine roots into deeper soil layers.

Mycorrhizal infection did not change in the Drought variant while the variants with nitrogen stimulated the development of mycorrhiza in all soil layers studied.

The vitality of fine roots was adversely affected in all soil layers although the effect was insignificant.

Conclusions

1. The simulated stress factors markedly affected the biometrical parameters of the growth of the above-ground part.
– Drought induced: suppressed height increment and stem diameter, reduced needle length, defoliation, symptoms of deficiency (yellowing of needles), and impaired vitality;
– Nitrogen induced: stimulation of most increments, deep green colour of needles, and partial impairment of tree vitality.
2. The simulated stress factors markedly affected the development of the root system (response to both drought and nitrogen being similar in trends) and induced: reduced biomass and length of fine roots, impaired functionality and vitality of fine roots, change in the distribution of fine roots by displacement of the root system into deeper soil layers.
3. In the course of study, the adverse effect of drought was in the majority of cases stronger than the adverse effect of nitrogen which was observed to have a stimulating effect on the above-ground part parameters for the whole experimental period.
4. The root system was at all times adversely affected by the input of nitrogen despite the positive response of the above-ground part.
5. Although none of the studied stresses had to necessarily show lethal impacts, they always resulted in the weakening of plants.
6. The stress factors studied exhibit a greater impact on stands growing outside their ecological optimum and stands growing on sites which do not entirely fit in with the growing requirements of spruce.

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