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Nutrition of silver fir (*Abies alba* Mill.) and its comparison with Norway spruce (*Picea abies* L. H. Karst) from the same forest sites in the Czech Republic

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Abstract: Forests in central Europe were affected by heavy bark beetle outbreak during the years 2014–2022. Decline of Norway spruce brought other species of forest trees, including the fir, to the fore. The nutritional level of silver fir is one of the studied topics. Needles in 14 Norway spruce (NS) – silver fir (SF) mixed forest stands from 4 regions in the Czech Republic have been sampled to survey their nutrition level. Nutrition of NS is often near or below the deficiency limit, while nutrition of SF was assessed as sufficient or good. Differences between both regions and tree species were found. SF drew more nutrients from the soil profile than NS on the same forest site. Differences between NS and SF in nutrient concentrations in needles were significant for N, Ca, Mg, Zn and S and non-significant for P and K.

Keywords: mixed forest; mixed forest nutrition; nitrogen; nitrogen to main nutrient ratio; nutrients ratio; trees nutrition

According to palaeoecological studies, silver fir was a very common tree species within the European continent in the past (Wick, Möhl 2006; Tinner et al. 2013; Birks, Tinner 2016). A decrease in its representation in forests can be explained and the most important explanations include: (*i*) land-use pressure, specifically excessive anthropogenic fire and site browsing disturbance; (*ii*) forest management using clearcuts and oriented to even-aged unmixed stands; and (*iii*) sensitivity to abiotic and biotic factors, particularly SO_2 pollution and climate change (Schütt et al. 1984; Uhlířová, Kapitola 2004; Elling et al. 2009; Hájek et al. 2016; Mauri et al. 2016; Ugarković et al. 2021).

Silver fir tolerates a wide variety of soil types with different nutrient content and alkalinity conditions, except compact and hydromorphic soils. It usually requires deep, aerated and humid soils, as well as high air humidity. It roots deeper than most other conifer species and is also less affected by wind throws. The fir demand for oxygen content in the soil is relatively low; for example, it can grow in deeper and wetter soils than Norway spruce. It is a typical shade-tolerant species, and in open areas, it suffers from frost and bark scorch (Meister 1999; Macías et al. 2006; Mauri et al. 2016).

The proportion of silver fir in forests stands has decreased from 18% to 0.9% in the last 200–250 years in the Czech Republic (Vacek et al. 2002; Uhlířová, Kapitola 2004), and in 2000–2020, its proportion changed from 0.9% to 1.2% (Ministry of Agriculture 2021). More detailed information about the silver

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fir in the Czech Republic can be found in Novák and Dušek (2021). Increasing the share of fir in forest stands is desirable for several reasons: (*i*) silver fir is an ecological and functional tree species, which stabilises soil and retains water; (*ii*) it is less vulnerable to wind and snow or ice breakage than Norway spruce; (*iii*) it is a very important tree species for maintaining high biodiversity in forest ecosystems; (*iv*) fir has wide plasticity to environmental conditions and the ability to coexist with many tree species in mixtures due to its ability to survive long periods in the understorey and to respond when light conditions become more favourable; and (*v*) silver fir is also an economically important tree species (Schütz 2002; Tinner et al. 2013; Mauri et al. 2016; Dobrowolska et al. 2017; Podrázský et al. 2018; Schwarz, Bauhus 2019; Walder et al. 2021). This explains the increased interest in silver fir and its ecological requirements as well as the possibility of increasing its share in forest stands. One of the studied aspects is the nutrition of silver fir and its comparison with other tree species. This topic is the main aim of this paper to assess the nutrition of silver fir in comparison with Norway spruce growing on the same forest sites.

MATERIAL AND METHODS

Sampled plots. Plots for needle sampling were selected in regions where mature fir stands were present and grew together with Norway spruce or other tree species (Table 1, Figure 1). Needle sampling was carried out in 2020 and 2021. Each forest stand was sampled only once. During these two years, Norway spruce died on a few sites due to bark beetle outbreak, and needles were not sampled on these plots.

Foliage sampling. Needle sampling to define their nutrient level and air pollution load was undertaken in autumn (September–October). Five specific trees were sampled for each plot. Three branches of the top part of the crown (from the upper third of the tree crown) were taken from each tree. Rope techniques were used to climb to the treetops. For each plot, a pooled sample of the current-year needles was created. These foliar samples were prepared in accordance with ICP Forests methodology (Rautio et al. 2020). As a result of sampling, we had pooled samples from each forest stand for each tree species. Only in the Město Albrechtice forest district we sampled five forest stands (Table 1).

Laboratory analyses. The samples of the assimilation organs were prepared in accordance with standard methods (Rautio et al. 2020). The amount of elements in the foliage (K, Ca, Mg and P) was determined using ICP-OES after needle decomposition in a microwave oven. The total S and N content was determined using the Leco CNS element analyser (Elementar Analysensysteme GmbH, Germany).

Data analyses. Exploratory data analysis was carried out to identify outliers or extreme values. After

Table 1. Main characteristics of sampled plots

Locality	Code	Sampled species	Age in 2020	Soil type	Altitude (m a.s.l.)	Coordinates	
						N	E
	TA1		98	dystric cambisols	441	49.37031	14.67157
Tábor	TA2	fir, spruce	135	eutric cambisols	460	49.40468	14.56528
	TA3		127	haplic cambisols	410	49.41124	14.63623
	ROZ1		116	dystric cambisols	590	49.55465	13.80564
Rožmitál	ROZ2	fir, spruce	195	dystric cambisols	775	49.56654	13.78048
	ROZ3		113	dystric stagnic cambisols	705	49.55021	13.76718
	MA1	fir	115	dystric cambisols	340	50.23428	17.57684
	MA2		137	haplic cambisols	450	50.18584	17.61807
M. Albrechtice	MA3		124	haplic podzols	540	50.21188	17.53056
	MA4	fir, spruce	169	dystric cambisols	640	50.1519	17.50676
	MA5		187	dystric cambisols	710	50.1238	17.40442
	VT1		126		490	49.76294	17.68828
Vítkov	VT2	fir, spruce	123	dystric cambisols	615	49.78469	17.58132
	VT3		83		715	49.78295	17.54618

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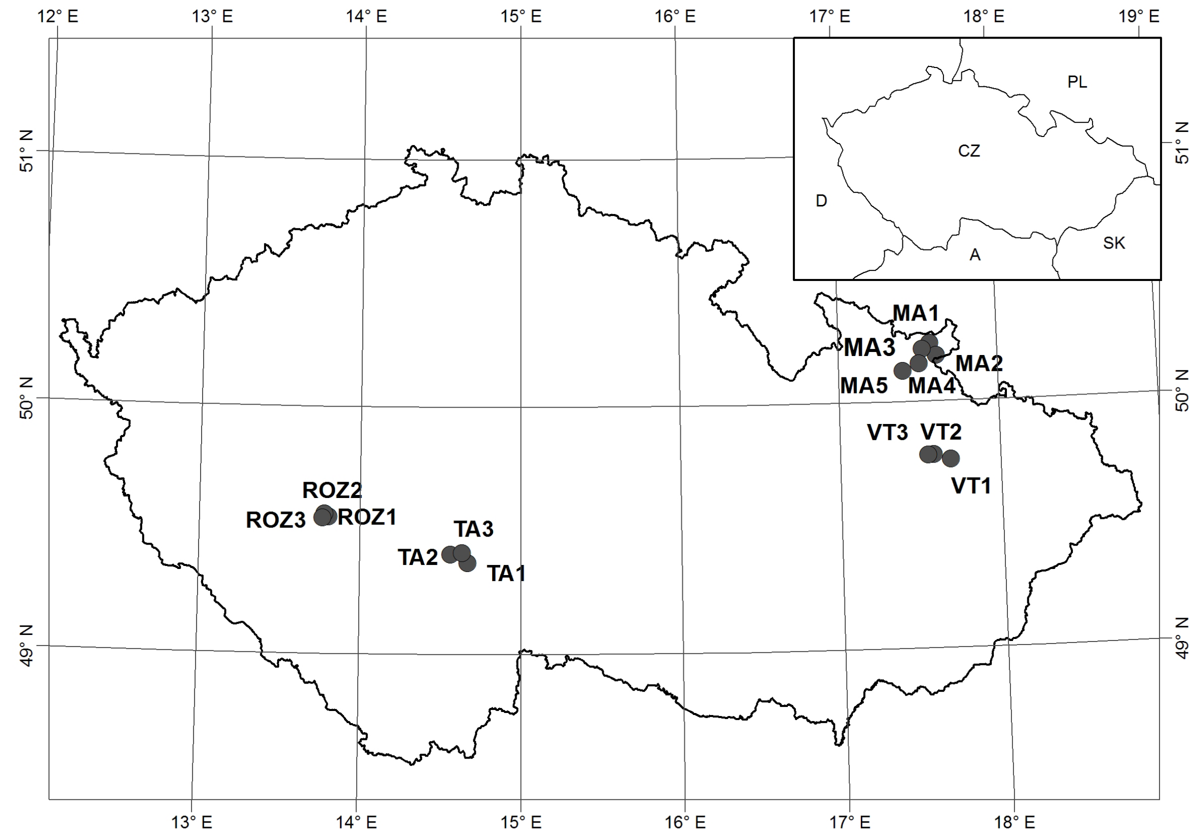

Figure 1. Location of sampled plots within the Europe and within the Czech Republic

carrying out the exploratory data analysis, normality was tested using the Shapiro-Wilk *W* test. Datasets were tested as independent samples; then, parametric tests (Student's *t*-test), if normality was not rejected, or nonparametric tests (Mann-Whitney *U* test), in case normality was rejected, were performed after the Shapiro-Wilk *W* test was used. All statistical evaluations of the data were subsequently conducted using the Statistica 12 CZ programme (Version 12, 2013).

RESULTS AND DISCUSSION

Nutrition of silver fir (SF). The nitrogen concentration in current-year needles varied between 12 g·kg^{-1} and 18 g·kg^{-1}. The median nitrogen concentration was above 14 g·kg^{-1} for the analysed trees and plots (Figure 2). This is comparable with previous studies carried out in Germany, Poland or Slovakia (Bäumler et al. 1995; Maňkovská et al. 2004), as well as with a study from the Czech Republic (Novotný et al. 2010; Dušek et al. 2020).

The median of phosphorus concentration was between 1.2 g·kg^{-1} and 1.4 g·kg^{-1}, and the concentration varied between 0.8 g·kg^{-1} and 2.6 g·kg^{-1}. This matches the values from Bäumler et al. (1995) and Maňkovská et al. (2004). In Novotný et al. (2010), who focused on silver fir growing in the Bohemian Forest (Šumava) at high elevations, the phosphorus concentration of current-year needles was higher than in samples from other regions of the Czech Republic. The potassium concentration in current-year needles varied between 5 g·kg^{-1} and 8 g·kg^{-1} (median above 6.5 g·kg^{-1}). This is a lower value than that reported by Bäumler et al. (1995) and Maňkovská et al. (2004), but it is still above the limit of deficiency determined by Hüttl (1986). This is very important because potassium is responsible for the regulation of the water regime, as well as for frost resistance.

Magnesium is a very mobile and flexible nutrient, and coniferous species can relocate it from older needles to current-year needles, which are most photosynthetically active. We found concentrations between 1 g·kg^{-1} and 3 g·kg^{-1}. These values showed a sufficient or good level of magnesium nutrition.

Calcium is bound to the cell walls and is not as flexible as other main nutrients. This means that

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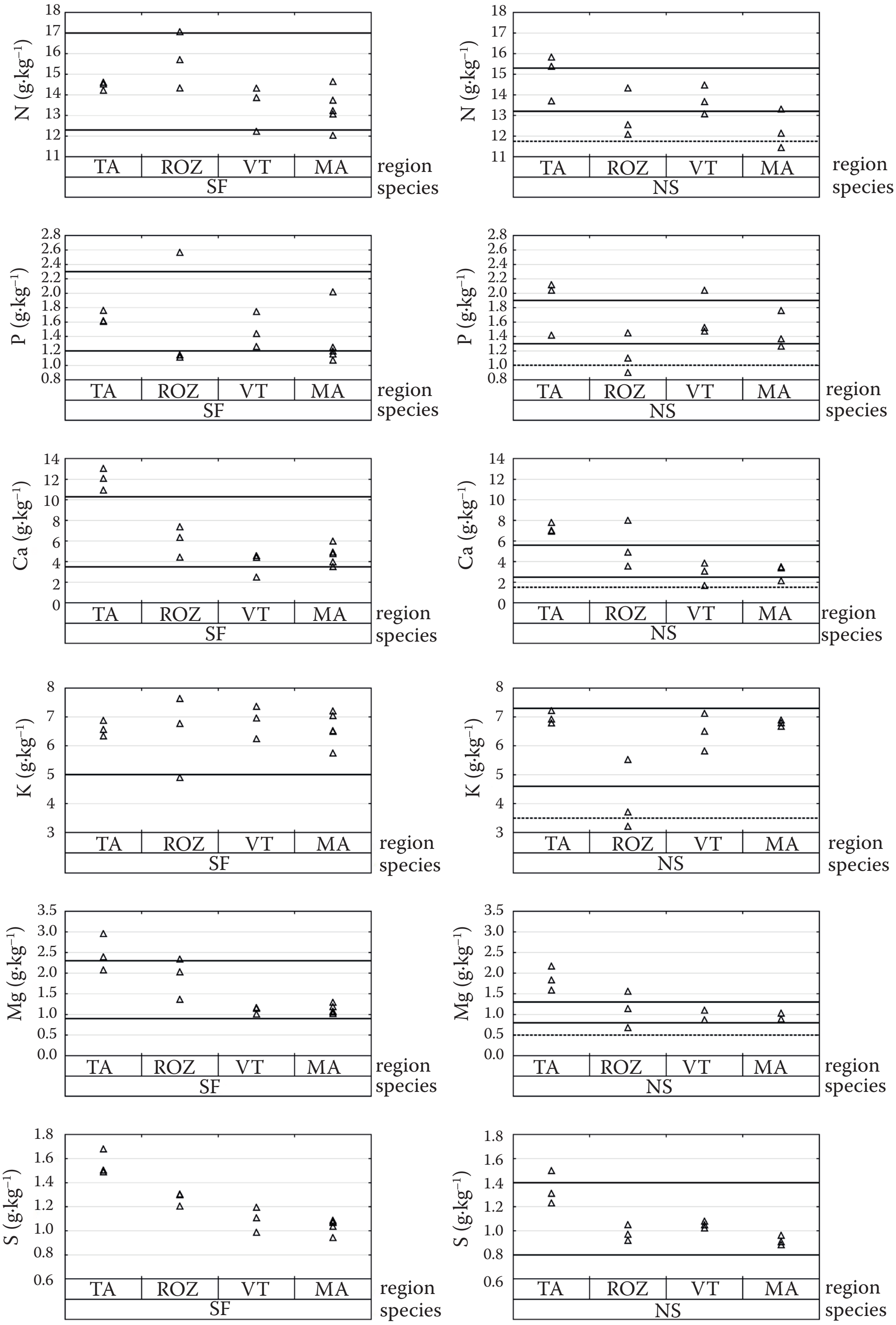

Figure 2. Variability plots with factors "species" and "region" for nutrients concentration in current year needles – the area between the two black lines is the range of optimal nutrition, below the dashed line, the tree species is in the deficiency range [lines are shown according to Göttlein et al. (2011)]

SF – silver fir; NS – Norway spruce; TA – Tábor; ROZ – Rožmitál; VT – Vítkov; MA – M. Albrechtice

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its concentration usually rises with the age of the needles. The concentration in current-year needles varied between 2 g·kg^{-1} and 13 g·kg^{-1} (median about 5 g·kg^{-1}). Similar results were reported by Bäumler et al. (1995) and Maňkovská et al. (2004).

We observed huge variability in nutrient concentrations between the sampled regions (Figure 2). The highest concentration of elements (Ca, Mg, P, S) was found in samples from the Tábor municipal forest. Large differences between regions were also observed in the concentrations of magnesium. Regions also differ partly in the concentration of calcium and potassium.

Nutrition of Norway spruce (NS). The nitrogen concentration in current-year needles varied between 1.1 g·kg^{-1} and 1.6 g g·kg^{-1}. The nitrogen concentration below 1.3 g·kg^{-1} is considered as a low concentration (Materna 1963; Göttlein et al. 2011); see Figure 2.

The phosphorus concentration in current-year needles was very different according to regions, and varied between 0.9 g·kg^{-1} and 2.1 g·kg^{-1}. In the Rožmitál region it was below the deficiency limit 1.2 g·kg^{-1} (Figure 2).

The lowest potassium concentration in NS current-year needles was found also in the Rožmitál locality, where it was between 3.2 g·kg^{-1} and 5.5 g·kg^{-1}. However, in other sampled regions, its concentration ranged between 5.8 g·kg^{-1} and 7.2 g·kg^{-1} in current-year needles (Figure 2).

The highest magnesium concentration was found in the Tábor locality (between 1.6 g·kg^{-1} and 2.2 g·kg^{-1}), and it was comparable with the other three sampled regions (0.7–1.6 g·kg^{-1}). The lower calcium concentration values were about 2.0 g·kg^{-1}, which was near the deficiency limit (Figure 2).

A decrease of sulphur content in Norway spruce needles (Lomský et al. 2012, 2013; Novotný et al. 2017) is connected with the reduction of SO_2 pollution during the 1990s (Hůnová et al. 2004, 2014). Nowadays, sulphur is often assessed as nutrient in-

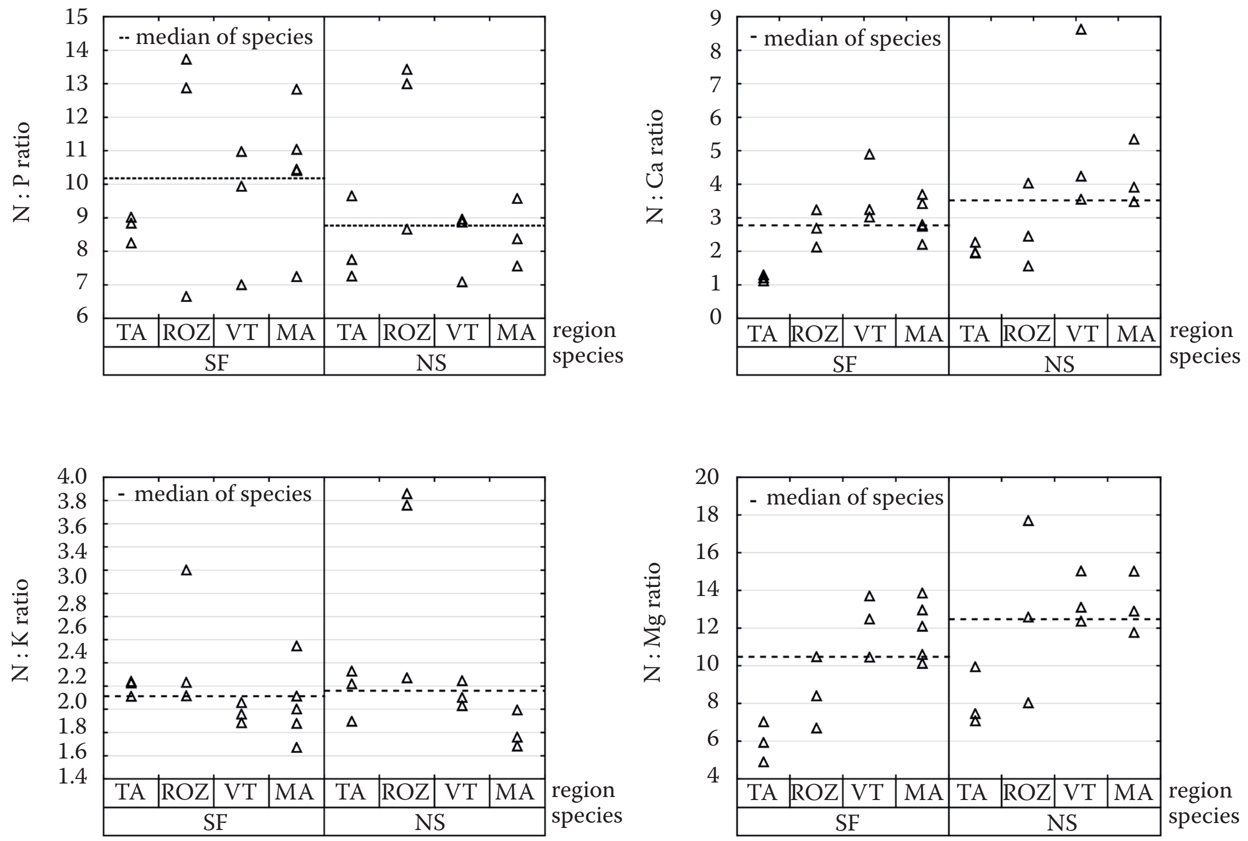

Figure 3. Variability plots for ratio between nitrogen and selected macro nutrients in current year needles categorized according to tree species and locality

SF – silver fir; NS – Norway spruce; TA – Tábor; ROZ – Rožmitál; VT – Vítkov; MA – M. Albrechtice

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stead of as stress element, especially when the sulphur concentration drops below 1 g·kg^{-1}. We found a decrease of sulphur concentration near to or below this value within all localities except Tábor (Figure 2).

Comparison of nutrient content in silver fir (SF) and Norway spruce (NS) needles. NS nutrition was similar but not the same as that of SF. The biggest differences were observed between SF and NS in the concentration of nitrogen, magnesium, and partly calcium. The nutrient concentrations found in NS needles were usually lower than in SF needles. These differences were probably associated with the rooting system of the evaluated tree species; SF is able to use deeper soil layers to draw water and nutrients in comparison with NS. If assessed according to Göttlein at al. (2011), the nutrition level was sufficient for SF. Nutrition of NS was in the range of latent nutrient deficiency especially for nitrogen and phosphorus.

Although the concentration of selected macronutrients differed between the evaluated tree species, the ratio of nitrogen to other main nutrients was similar. The ratio between nitrogen and other nutrients was used to determine the balance according to ICP Forests thresholds (Figure 3).

Statistically significant differences in the nutrition between SF and NS were found at the significance level of < 0.001 for nitrogen, magnesium and sulphur, at the significance level of < 0.01 for calcium, non-significant differences were found for phosphorus and potassium using the Mann-Whitney *U* test.

CONCLUSION

Different tree species have various abilities and efficiencies for nutrient uptake from the soil and have different demands and requirements for the amount of nutrition. This means that tree species growing on the same forest site can differ significantly in the nutrition level. Differences ranged from 5% to 200%. Differences greater than 100% were surprising because samples were taken in mixed or immediately adjacent spruce-fir stands. Therefore, we assumed that differences in soil conditions were not significant and that differences in nutrition levels would not be so huge. The reason for this could be explained by different amounts and architectures of roots; Norway spruce has a flat root system and its main rooting zone usually covers a depth between 0 cm and 40 cm of mineral soil. The roots of silver fir reach much deeper and are able to obtain nutrients from almost the whole soil profile. This means that in general, silver fir has a higher amount of nutrients at its disposal compared to Norway spruce, regardless of whether they are growing on the same site. The next reason could be different demands for the supply of nutrients. We concluded that silver fir grows well on the same forest sites as spruce and is able to gain sufficient nutrients from the whole soil profile. Symptoms of nutrient deficiency could most probably be visible only on acidic and poor sites where the mineral soil (or its top layer) is strongly acidic, and base cations are depleted or leached to the deeper soil layers.

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