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Effects of silver fir (*Abies alba* Mill.) on the humus forms in Norway spruce (*Picea abies* (L.) H. Karst.) stands

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Abstract

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The effects of silver fir (*Abies alba* Miller) on the soil compared to Norway spruce (*Picea abies* (Linnaeus) H. Karsten) were evaluated. Altitude of the study site is 790 m a.s.l., mild slope of 10° facing SW, forest site is spruce-beech on acid soil. The forest floor and top soil horizons (L + F1, F2 + H, Ah) were sampled in 4 replications beneath unmixed Norway spruce and silver fir groups. Comparing the soil-forming effects of both species, few significant differences were found in the Ah horizon – contents of total C, N, exchangeable Al and plant available Ca were higher beneath spruce. The soil improving role of silver fir compared to spruce was confirmed at the studied locality.

Keywords: forest soils; soil chemistry; humus accumulation; coniferous species influence on soil

Silver fir (Abies alba Miller) represents an important species of the natural forest composition in Central Europe (Podrázský, Remeš 2010) and it is considered as a relevant site improving and stabilizing tree species. Based on the data of the Forest Management Institute (see also the Czech acronym ÚHÚL), the natural proportion of silver fir was ca. 20% (Ministry of Agriculture of the Czech Republic 2016). Its decline in the Czech forests has been noticeable since the 18th century (Málek 1983; Průša 1990) and culminated in the 20th century. As a general reason for its decline, the large-scale use of the clear-cut silvicultural system connected with artificial regeneration on large clear-cuts is supposed (Málek 1983; Zatloukal 2001), there is less consensus as for other negative factors affecting this species. For example Jankovský (2005) stated that fir decline is only minimally attributable to air pollution, in contrast to frequent belief, it is among the most important factors in many other cases. Černý (1989) documented that fir decline finished visibly in the 1980, as a main cause he considered high infestation by *Dreyfusia nordmannianae* (Eckstein, 1890). Silver fir is sensitive in reflecting the climate changes, such as decrease of the precipitation amount, changes of air humidity and soil moisture, dry periods or heavy frosts.

There arises a question how the condition of this species was influenced by the end of the so called "Little Ice Age" – 14th to 19th centuries (Behringer 2010), when silver fir decline accelerated after it. With respect to climatic changes and air pollution, fir decline was more prominent in some parts of its area. It is to suppose that there are provenances/populations more resistant compared to our native ones (Šindelář 1975). Further limiting factors are physiological effects; lethal is the effect of high population densities of hoofed game.

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The Report on the condition of forests and forestry (Ministry of Agriculture of the Czech Republic 2016) documents a low increase of the silver fir share from 23,138 ha (0.9% of forested lands) to 28,699 ha (1.1%) between 2000 and 2015. The regenerated area is 800–1,000 ha yearly. One of the reasons for the large fir support is obviously its ranging among site improving and stabilizing tree species with subsidies for re-introduction. The recommended share in the forests is 4.4% of the forested area at the national level.

The stabilizing function of silver fir in forest stands seems to be realistic. Fir forms a root system penetrating into deeper soil horizons, of the heart-shape, even on more heavy soils (Fér, Pokorný 1993; Úradníček et al. 2009). Windthrows are very rare. Silver fir can support the static stability of forest stands, especially on compacted and gleyed soils of middle and higher elevations. On the other side, the site improving role of this species is more supposed than documented by research data, despite of numerous studies, evaluating the ecological characteristics, silviculture, regeneration, protection of this species in natural as well as managed forests (Málek 1983; Černý 1989; Jankovský 2005; Bartoš, Kacálek 2013; Martiník, Dušek 2015).

The site improving function is generally understood as the ability of tree species to contribute to the formation of favourable litter and improvement of the soil chemistry. The upper soil layers are enriched by nutrients and the nutrient are getting plant-available. Also the soil physical characteristics show favourable trends (Šindelář et al. 2005, 2007).

Šindelář and Frýdl (2005) documented that silver fir litter contributes to the formation of favourable humus forms in mixed stands. Podrázský and Remeš (2005) compared the soil chemistry of humus horizons in the stands with natural species composition (oak, fir) with spruce monoculture; they found higher bases and base saturation compared to spruce. A unique study by Seifert (1957) compared the soil microbial activity in gaps planted by fir in the old spruce stand – he documented comparable soil chemistry but higher microbial activity beneath fir. From the more recent sources, Třeštík and Podrázský (2017) also documented a minimum effect of the fir compared to spruce as for the basic soil chemical properties. Although the surface humus accumulation was significantly lower beneath fir, the soil chemical characteristics differ to the minimum extent.

The aim of the present study is to document results from another site, comparing Norway spruce and silver fir effects on the humus forms at the same site conditions. A hypothesis is postulated that silver fir supports the formation of humus form with more rapid nutrient turnover and of more favourable soil chemical characteristics.

MATERIAL AND METHODS

The study site is located at the Číhalka locality (50°22'40''N, 16°21'43''E), formerly established by Forestry and Game Management Research Institute, Opočno Research Station. It is located at the Deštné Forest District, Forests of Kristina Colloredo-Mansfeld property. The altitude is around 790 m a.s.l., 68-years-old stands are on a mild slope of 10° facing SW, the forest site is acid spruce-beech. The geological bedrock is composed of mica-schists.

Humus form sampling took place in the pure parts dominated by Norway spruce or silver fir in autumn 2016. Within each stand type, 4 replications were selected and sampled. Forest floor layers – L + F1, F2 + H, which are O1 + Of1, Of2 + Oh according to Green et al. (1993), were sampled quantitatively using an iron frame 25 × 25 cm, top soil (Ah) horizon was not sampled quantitatively.

The analyses of forest floor horizons were aimed at: (*i*) amount of dry matter at 105°C, (*ii*) total nutrient contents (P, K, Ca, Mg) after mineralization with sulphuric acid and selenium (Zbíral 2001).

For all horizons it was determined: (*i*) active and potential soil reaction (1N KCl), exchangeable acidity (Al, H), basic characteristics of the sorption complex by Kappen (1929) (base content, hydrolytic acidity, cation exchange capacity, base saturation), (*iii*) total carbon content – Springer-Klee method (Ciavatta et al. 1989), (*iv*) total nitrogen content by Kjeldahl (Kirk 1950), (*v*) plant available nutrients (P, K, Ca, Mg) by Mehlich III (Mehlich 1984).

For statistical analyses, one-factor ANOVA analysis was used with subsequent Scheffe's post-hoc test for the analysis of differences in the horizons of comparable depth between tree species at a significance level of 0.05. Significantly different values are marked by bold letters and asterisks.

RESULTS

The surface humus was comparable in both stand parts accumulating 112 t·ha^{-1} beneath silver fir and 106.6 t·ha^{-1} beneath Norway spruce. The humus (combustible matter – C_{ox}) content in particular horizons was also very similar in both stands, with

Table 1. Amount of surface humus, total carbon and humus content and total nitrogen content beneath Norway spruce and silver fir

Horizon	Dry matter($t \cdot ha^{-1}$)		Humus (%)		C_{ox} (%)		C/N ratio		Total N (%)	
	fir	spruce	fir	spruce	fir	spruce	fir	spruce	fir	spruce
L + F1	14.5	18.8	65.87	62.86	38.21	36.46	23	23	1.662	1.612
F2 + H	97.5	87.8	61.45	59.67	35.65	34.61	23	20	1.537	1.761
Ah			11.02*	30.09*	6.39*	17.46*	21	17	0.305*	1.001*

L + F1 = O1 + Of1, F2 + H = Of2 + Oh according to Green et al. (1993), Ah – top soil horizon, *significant differences between tree species, C_{ox} – combustible matter

Table 2. Exchangeable titration acidity, exchangeable H and Al content beneath Norway spruce and silver fir

Horizon	Titration acidity ($mval \cdot kg^{-1}$)		Exchangeable H^+ ($mval \cdot kg^{-1}$)		Exchangeable Al^{3+} ($mval \cdot kg^{-1}$)	
	fir	spruce	fir	spruce	fir	spruce
L + F1	67.88	68.94	26.44	37.00	41.44	31.94
F2 + H	143.45	154.58	27.03	38.03	116.43	116.55
Ah	70.66*	133.25*	8.48	18.92	62.19*	114.33*

L + F1 = O1 + Of1, F2 + H = Of2 + Oh according to Green et al. (1993), Ah – top soil horizon, *significant differences between tree species

the exception of the top soil higher in humus C_{ox} and total N beneath spruce (Table 1). The C/N ratio was very similar too, with slightly more favourable values beneath spruce.

In the forest floor, the values of exchangeable acidity and its components were not significantly different (Table 2). Only in the top soil, the total titration exchangeable acidity was significantly higher beneath the Norway spruce stand, especially due to the high content of exchangeable aluminium. This indicates a more chemically aggressive environment in the soils of the spruce stand.

The soil pH (both types) did not show any visible trends, the values were nearly the same in the corresponding horizons of both stand parts (Table 3). The base content was insignificantly higher in the fir forest floor and in the spruce top soil. The cation exchange capacity was higher in deeper forest floor beneath fir and higher in the top soil beneath spruce. High variability resulted in insignificant results despite differences in base saturation.

The contents of the plant available nutrients show a significant trend moving only downward, to the deeper horizons. There were no visible differences between stand parts with dominance of particular tree species, only the available calcium content was higher in the Ah horizon of the Norway spruce stand (Table 4). Other differences in the plant available contents between both species were not significant.

The total nutrient contents were determined only in the holorganic horizons (Table 5). In this case the differences between both species were not significant either, despite that only in the case of total phosphorus the content in the L + F1 horizon of the fir stand was double. In the case of other horizons and other nutrients the values of contents were practically identical.

DISCUSSION AND CONCLUSIONS

There are few publications concerning the soil-forming role of silver fir. Despite this fact, this species is considered as a tree species contributing to the stability of forest stands and as a tree capable

Table 3. Soil pH and soil adsorption complex characteristics beneath Norway spruce and silver fir

Horizon	pH/H_2O		pH/KCl		*S* ($mval \cdot 100\ g^{-1}$)		*T* ($mval \cdot 100\ g^{-1}$)		*V* (%)	
	fir	spruce	fir	spruce	fir	spruce	fir	spruce	fir	spruce
L+F1	3.81	3.83	2.99	2.98	10.91*	7.25*	61.49	43.36	17.78	19.39
F2+H	3.39	3.41	2.50	2.46	3.00*	1.68*	86.50*	73.43*	3.49	2.10
Ah	3.46	3.46	2.54	2.60	0.49*	2.54*	22.94*	58.83*	2.38	5.21

L + F1 = O1 + Of1, F2 + H = Of2 + Oh according to Green et al. (1993), Ah – top soil horizon, *significant differences between tree species, *S* – base content, *T* – cation exchange capacity, *V* – base saturation

Table 4. Plant available nutrient content beneath Norway spruce and silver fir (Mehlich III)

Horizon	P		K		Ca		Mg	
	fir	spruce	fir	spruce	fir	spruce	fir	spruce
L + F1	35.0	34.0	492.0	400.5	1,758.5	1,558.0	229.5	209.0
F2 + H	21.0	21.0	299.5	257.5	932.0	1,097.0	176.0	184.5
Ah	7.25	11.67	68.5	115.0	282.8	418.3*	68.5*	86.7

L + F1 = O1 + Of1, F2 + H = Of2 + Oh according to Green et al. (1993), Ah – top soil horizon, *significant differences between tree species

Table 5. Total nutrient content beneathNorway spruce and silver fir (forest floor)

Horizon	N (%)		P (%)		K (%)		Ca (%)		Mg (%)	
	fir	spruce	fir	spruce	fir	spruce	fir	spruce	fir	spruce
L + F1	1.621	1.630	0.045	0.022	0.070	0.060	0.161	0.158	0.0265	0.0260
F2 + H	1.555	1.739	0.054	0.050	0.165	0.185	0.009	0.010	0.0230	0.0245

L + F1 = O1 + Of1, F2 + H = Of2 + Oh according to Green et al. (1993)

to improve the forest soil. Although the silver fir was in focus in many studies in the field of silviculture, ecology, forest regeneration, dynamics in managed as well as natural forests and forest protection (Málek 1983; Černý 1989; Jankovský 2005; Bartoš, Kacálek 2013; Martiník, Dušek 2015), the forest floor and soil conditions were studied rarely. Dominance of silver fir was mentioned, however, as a result of different soil properties (Buriánek et al. 2014; Lasota et al. 2015), especially in natural conditions. The studied differences between tree species focused especially on Norway spruce, and broadleaves (Augusto et al. 2002; Hagen-Thorn et al. 2004).

Seifert (1957) emphasized the importance of soil microbiological studies, able to determine the differences in biological activities, even in the absence of significant soil-chemical variations. The study documents the effects of the conversion of mature (aged 80–100 years) Norway spruce in gaps with 20-years-old silver fir. Especially the closed canopy fir groups affected the soil biological characteristics favourably, e.g. the nitrification as one of the most important mineralization activities. In this mentioned case, the trend of increased decomposition activities correlated with a decrease in the amount of surface humus with higher nitrogen content, at low changes of soil chemical characteristics. A question can be raised whether the gap formation in the closed spruce stand (from 80 to 100 years) is more responsible for these changes in microsite conditions.

Podrázský and Remeš (2010) documented insignificant differences in the soil pH and base saturation of humus forms beneath Norway spruce and silver fir. Significantly lower content of total humus, total carbon and nitrogen and lower ratio C/N found beneath fir indicated greater litter decomposition and transformation rates. The total forest floor phosphorus contents were comparable, while the fir forest floor was significantly higher in total potassium. The plant available nutrients did not show any clear trends. Weak aspects of this study were the heavy regeneration cut a few years ago and the admixture of codominant oaks (40%) in the fir stand. On the contrary, the spruce stand was dense and monospecific. Despite this fact, differences between both stands in the upper soil chemistry were not big. The gaps planted by broadleaves showed considerably higher differences from the old spruce stand. Evaluating similar studies, it has to be understood the local and/or regional character of similar experiments, the transfer of results in other regions is difficult and limited. On the other hand, more general and extensive studies depress the importance of particular species effects and emphasize other variables, such as bedrock or mezo- and macroclimate (Augusto et al. 2002; Hagen-Thorn et al. 2004).

The most recent study by Třeštík and Podrázský (2017) was aimed at documenting the effects of silver fir on the forest soil status in 86–88-years-old mixed spruce-fir stands. Also in this case, both the forest floor and top soil were investigated. The amount of the silver fir surface humus (L + F + H) was considerably lower compared to Norway spruce, both species accumulating 39.6 and 73.7 $t \cdot ha^{-1}$, respectively. Properties of particular soil horizons did not substantially differ between both species though slightly more favourable conditions were beneath fir. The total nitrogen content was insignificantly higher beneath silver fir, indi-

Table 6. Foliar content of particular macronutrients in the needles of Norway spruce and silver fir, indicating sufficient nutrition (Bergmann 1988)

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Norway spruce	1.35–1.70	0.13–0.25	0.50–1.20	0.35–0.80	0.10–0.25
Silver fir	1.30–1.80	0.13–0.35	0.50–1.10	0.60–0.90	0.12–0.30

cating richer litter and a better process of humification. The total nutrient contents of nitrogen and calcium were higher beneath silver fir, the magnesium content beneath spruce. Thus the authors can conclude that the silver fir of the above-mentioned locality does not play any significant chemical soil improving role compared with the Norway spruce.

In any case, this problem needs more research. The minor differences between Norway spruce and silver fir quality are attributable to the litterfall properties. Bergmann (1988) documented the limits for sufficient nutrition expressed as foliar nutrient contents and showed that they were nearly the same for spruce and fir (Table 6). So very similar litter quality as for nutrient content on the same site can be supposed. Other factors such as biodegradability can also play a role.

Paradoxically, much more attention was paid to the soil-forming role of grand fir (*Abies grandis* (Douglas ex D. Don) Lindley) with clearly site improving effects (Podrázský, Remeš 2010; Fulín et al. 2013; Fulín 2015). The site improving role of silver fir needs more research. To this moment, its positive role in the soil development has to be considered as less expressed. So the hypothesis, formulated in the introductory part, was confirmed only partly, silver fir shows humus forms with lower surface humus accumulation, but with soil chemistry very comparable to that of Norway spruce.

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