Comparison of the impact of blue spruce and reed *Calamagrostis villosa* on forest soil chemical properties

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ABSTRACT: The impact of blue spruce (*Picea pungens*) and reed (*Calamagrostis villosa*) cover on quantity and quality of upper soil layers was investigated. The research was conducted in the Jizerské hory Mts., Czech Republic (altitude 880 m, acidic spruce forest site type – 8K). Mean weight of dry matter of holorganic horizons was similar under both variants. Totally, there were accumulated 153 t/ha of dry matter of humus horizons in blue spruce and 174 t/ha in reed. Soil pH (KCl) varied from 3.7 to 3.2 under blue spruce stand and from 3.6 to 3.3 under reed. The differences of concentrations of nutrients (P, K, Ca, Mg) were not found significant either. Only L horizon showed significant differences: there were higher values of cation exchangeable capacity (T) and higher content of exchangeable bases (S) under reed. We found very similar forest-floor humus properties under both species. Therefore we can not state worsening of the soil conditions under blue spruce compared to areas covered with tested forest weed species.

Keywords: *Picea pungens*; forest weed; *Calamagrostis villosa*; upper soil layers quality and quantity; Jizerské hory Mts.

Nutrient content as well as other chemical and physical properties of soils are the consequence of bedrock, abiotic soil forming factors and impact of organisms – plants and animals. The inner ecosystem nutrient exchange has following sub-processes: production, conversion, mineralization, recycling (Otto 1994). Plants use nutrients included in atmosphere and soil liquids to build phytobiomass. One part of the biomass is through litterfall directly transported to soil and transformed by bio-chemical processes. Direct impact of specific plant species on soil characteristics differs (Singer, Munns 2005). Character of litterfall influences upper soil organic (humus) horizons primarily.

After the air pollution induced decay of forest stands in the mountain regions of the Czech Republic in 1970s to 1990s, there was a problem of autochthonous tree species planting failure on the climatically extreme localities. Norway spruce and European beech were main autochthonous species there. The problem was temporarily solved by allochthonous – introduced tree species plantings (Šindelář 1982).

Blue spruce (*Picea pungens* Engelm., B. s.) of North America was the most extended substitute tree species used in the higher mountain localities of the Czech Republic (Mauer et al. 2005). It was used as a substitute tree species in former Eastern Germany too (Ranft 1982). Until now, air pollution load decreased and blue spruce forest stands are being converted with the autochthonous tree species (mostly Norway spruce, but also European beech etc. – Balcar, Kacálek 2008).

Production potential of blue spruce is lower than of Norway spruce (Šika 1976; Novák, Slodičák 2004), negative impact of blue spruce on the forest soils is mentioned in the literature (Kantor 1989; Podrázský 1997; Remeš et al. 2002; Podrázský et

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al. 2005): neither it covers the soil surface enough nor protects soil from desiccation and worse chemical properties. Blue spruce has similarly unfavourable litterfall like Norway spruce, but in lower amounts, which leads to further soil degradation comparable with the long-term clear-cuts (Remeš et al. 2002). On the contrary, positive effect of young blue spruce stand shelter to interplantings of beech in higher mountain locations (more than 850 m a.s.l.) is mentioned (Balcar, Kacálek 2008).

Clear-cut reed *Calamagrostis villosa* (Chaix) J. F. Gmelin is the most common expansive clear-cut grass species in the central European mountains. Its expansion can help prevent high losses of nutrients, which take place after disturbance of the forest environment (Gorham et al. 1979), but it is also described as the most problematic species for natural as well as artificial regeneration (Janík 1998; Šerá et al. 2000; Kooijman et al. 2000). Positive effect of *Calamagrostis* grass cover (*C. villosa* and *C. arundinacea*) on the soil environment described Fiala et al. (2005). In their study, both species act as a nitrogen sink since they take up and immobilize this element in plant biomass and undecomposed litter. Consequently, the swards of grasses were demonstrated to mitigate the acidification of soil solution and the leaching of basic cations of Ca and Mg from soil.

This study aims to compare impact of 20 year lasting cover of blue spruce, and clear-cut reed *Calamagrostis villosa* on the former Norway spruce clear-cut to the upper soil layers quality and quantity.

MATERIALS AND METHODS

Our research was done on the locality of Plochý in the upper part of the Jizerské hory Mts., Czech Republic, altitude 880 m, NW slope to 5°, acidic spruce forest site type (8K). In this locality, blue spruce forest stand was planted from 1985 to 1990 (repair planting), after the forest decay of Norway spruce forest stand caused by air pollution disaster. Due to the planting failure, strips of the locality were for the whole period deforested and covered by clear-cut reed *Calamagrostis villosa*. In 2006, mean height of the blue spruce stand was 4.4 m, density was 2,340 trees/ha (Špulák 2007). Its stand canopy is closing, with very rare occurrence of forest weed.

In autumn 2006, transects of seven soil pits in a regular distance of 3 m in blue spruce (variant PP) and grass *Calamagrostis villosa* (CV) were settled. Horizons of L/Weed, F, H and Ah (layer of the mineral matter with high content of humus) were taken on every pit in an iron frame 25 × 25 cm. The parameters analyzed were: total dry weight, active and exchangeable acidity, nutrient contents by Mehlich III. (P, K, Ca, Mg – Mehlich 1984), characteristics of adsorption complex (by Kappen: S – content of exchangeable bases, T – cation exchangeable capacity, H – hydrolytical acidity and V – saturation of the adsorption complex with bases, Kappen 1929), oxidable C (Springer-Klee method) and total N (Kjeldahl method) content and exchangeable titration acidity.

Mean values and variances were computed by the Horn's quantile based method (Meloun, Militký 1998). Multilevel hierarchicaly designed ANOVA with Tukey test for multiple comparisons were used to assess the differences between variants. In some cases the data were transformed by logarithmic transformation.

RESULTS AND DISCUSSION

There was significantly higher thickness of litter (horizon L) and Ah horizon under *Picea pungens* and of humification horizon (H) under *Calamagrostis*. The thickness of all humus layers together was significantly higher in CV (Table 1). Process of the holorganic layer accumulation and formation may last many decades, even centuries (Singer, Munns 2005), so advance changes of its character are expected.

Table 1. Thickness of soil horizons (cm). Heterogeneous groups are designated by letters of the alphabet

Horizon	*Picea pungens*		*Calamagrostis villosa*	
	mean	st. dev.	mean	st. dev.
L	2.86a	*0.69*	1.93b	*0.32*
F	2.86	*0.83*	3.21	*0.51*
H	3.93a	*1.18*	6.50b	*0.23*
Ah	7.29a	*1.13*	3.79b	*1.46*
Humus layers total	9.64a	*1.78*	11.64b	*0.47*

Table 2. Mean values of the selected pedochemical characteristics. Heterogeneous groups are designated by letters of the alphabet

Variant	Horizon		pH/KCl	S (mval/kg)	T (mval/kg)	V (%)	Exchangeable acidity (mval/kg)	Exchangeable H (mval/kg)	Exchangeable Al^{3+} (mval/kg)
Picea pungens	L	P_L	3.7	9.6**a**	37.3**a**	27.6	36.4	9.5	23.5
		R_L	0.4	7.2	13.7	11.4	13.2	8.4	26.4
	F	P_L	3.3	19.8	70.3	27.3	87.2	9.7	80.7
		R_L	0.4	7.7	5.9	10.9	57.3	5.6	58.2
	H	P_L	3.4	12.4	60.1	20.1	125.2	3.8	121.6
		R_L	0.1	1.4	13.9	2.5	26.7	0.6	26.9
	Ah	P_L	3.2	8.0	37.6	21.7	102.3	3.0	99.0
		R_L	0.2	3.1	12.1	6.9	17.1	0.5	17.5
Calamagrostis villosa	L	P_L	3.6	15.6**b**	49.6**b**	33.2	49.1	14.1	35.8
		R_L	0.2	8.4	9.4	19.3	6.3	7.7	13.1
	F	P_L	3.5	17.8	67.9	27.2	89.1	9.0	80.0
		R_L	0.1	2.3	8.0	2.3	11.2	1.3	12.9
	H	P_L	3.4	13.3	59.2	22.4	114.1	5.1	109.4
		R_L	0.1	4.7	7.6	5.5	15.2	1.0	15.4
	Ah	P_L	3.3	7.1	33.6	21.1	90.8	2.9	87.8
		R_L	0.1	1.1	5.1	0.6	11.4	0.5	10.1

P_L – mean value computed by Horn's method, R_L – pivot range computed by Horn's method, S – base content, T – cation exchangeable capacity, V – saturation of the adsorption complex with bases

Mean weight of dry matter of litter/weed horizon was very similar – almost 48 g per soil pit. Soil under *Calamagrostis* showed higher accumulation of dry matter in F and H horizon, but not significantly (Table 4). Totally there were accumulated 153 t/ha of dry matter of humus horizons in PP variant and 174 t/ha in CV variant (Table 4). In our study, we found almost two times more dry matter of humus layers in PP comparing to outcomes of Podrázský et al. (2005), who studied forest stand of similar age in similar altitude in the Krušné hory (Ore) Mts., but on wet nutrient medium spruce forest site type. The question is also density of studied forest stand which was not included in the paper. Dry matter of humus layers in Norway spruce mature forest stands of mountain altitudes range according to Materna (2002) from 70 to 120 t/ha. Higher accumulation of humus in our study can be consequence of species as well as of stand density in the case of blue spruce.

Both soils were very strong acid (Klimo 1998), soil pH lowers with increasing soil depth (Table 2, Fig. 1). PP soils had higher variability of acidity (Fig. 1). Even more acid soils under blue spruce (3.11 pH/KCl in H horizon) found Kantor (1989) in his study of soil properties near large air pollution source (in 1980s). Air pollution is an important factor increasing soil acidification; Klimo et al. (2006) described forest soil acidification processes driven by air pollution. The end of hard air pollution income brought slight decrease of acidity (Borůvka et al. 2005). Soil acidity of Norway spruce forest soils in the Jizerské hory Mts. described by Mládková et al. (2006) ranged from 2.85 to 3.55 pH/KCl. On similar forest sites found Drábek et al. (2007) soil acidity of organic horizons ranging from 3.2 to 3.4 pH/KCl. Soils with grass cover (*C. villosa*) had slightly higher pH values comparing to adjacent Norway spruce forest stands. Soil acidity in our study was slightly higher comparing to studies cited above, without real difference between variants.

There was significantly higher content of exchangeable bases in CV litter (15.6 and 9.6 mval/kg). No differences in this parameter were found in the rest of horizons (Table 2). Soils show low saturation of the adsorption complex with bases (Sáňka, Materna 2004), also with no significant differences. Similar

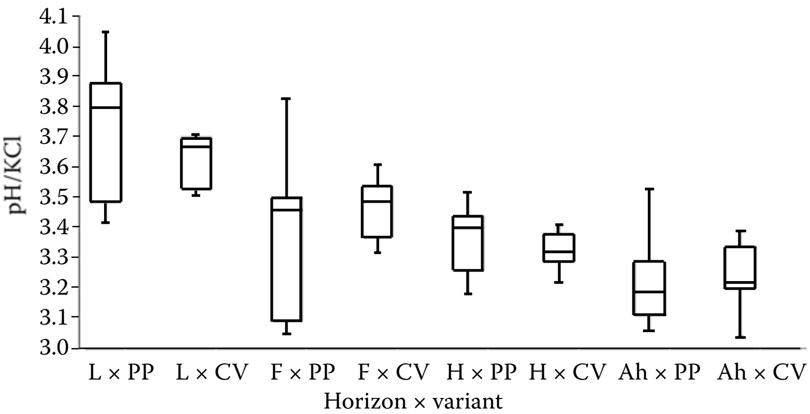

Fig. 1. Box plots of soil acidity (pH/KCl) by horizons. PP – soil pits under *Picea pungens*, CV – soil pits under *Calamagrostis villosa*

saturation with bases under 20-year-old blue spruce forest stand (28.2%) presented Kantor (1989).

There was higher content of exchangeable hydrogen cations in CV litter (14.1 and 9.5 mval/kg), values in other horizons were comparable. Mean content of exchangeable aluminum (Al^{3+}) optically differed in all horizons, but the differences were not significant.

There were found no significant differences in nutrient contents with the exception of phosphorus in Ah horizon. There was significantly more phosphorus in Ah of PP soil. With the exception of magnesium, the content of nutrients rapidly lowered with increasing depth of soil (Table 3).

Also share of carbon and nitrogen was very similar in both soil variants. Kantor (1989) found significantly lower content of oxidable carbon under PP (only 14.9% in humification horizon). His study was conducted in a lower altitude and all ten tested species had very low content of carbon in H horizon, so blue spruce was not an exception. Carbon share of soil under blue spruce in study of Podrázský et al. (2005) corresponds with our outcomes (34.6% in Grass horizon, 32.0% in L + F1, 25.6% in F2 + H and 13.0% in Ah).

Table 3. Mean nutrient content of soil horizons. Statistically heterogeneous groups are designated by letters of the alphabet

Variant	Horizon		P	K	Ca	Mg	Oxidable C	Total N
			(mg/kg)				(%)	
Picea pungens	L	P_L	59.0	950.0	1,079.0	250.0	35.4	1.5
		R_L	66.0	1,140.0	350.0	208.0	3.0	0.4
	F	P_L	38.0	625.0	1,167.0	356.0	33.3	1.7
		R_L	16.0	218.0	566.0	204.0	3.0	0.3
	H	P_L	17.0	367.0	797.0	234.0	26.7	1.4
		R_L	10.0	178.0	122.0	132.0	5.4	0.5
	Ah	P_L	6.0**a**	193.0	411.5	103.0	18.7	0.9
		R_L	6.0	132.0	107.0	64.0	6.2	0.2
Calamagrostis villosa	L	P_L	63.0	1,155.0	1,027.0	317.0	33.0	1.6
		R_L	18.0	394.0	358.0	194.0	14.2	0.3
	F	P_L	36.0	682.0	996.0	341.0	33.8	1.7
		R_L	8.0	276.0	232.0	122.0	2.6	0.2
	H	P_L	14.0	375.0	813.0	192.0	27.8	1.6
		R_L	4.0	70.0	202.0	16.0	6.5	0.3
	Ah	P_L	3.0**b**	158.5	468.5	105.0	16.8	0.8
		R_L	2.0	43.0	41.0	16.0	4.6	0.2

Table 4. Mean content of dry matter, nutrients and humus in humus layers per ha computed by Horn's mean

Variant/ha	Horizon	Dry matter (t)	P	K	Ca	Mg	Oxidable C	Total N	Humus
			(kg)				(t)		
Picea pungens	L	7.62	0.45	7.24	8.22	1.90	2.70	0.11	4.58
	F	42.50	1.61	26.56	49.59	15.13	14.15	0.72	24.06
	H	103.12	1.75	37.85	82.19	24.13	27.53	1.44	46.81
	Total	*153.23*	*3.82*	*71.64*	*140.00*	*41.16*	44.38	2.28	75.45
Calamagrostis villosa	L	7.74	0.49	8.94	7.95	2.45	2.56	0.12	4.34
	F	50.69	1.82	34.57	50.49	17.28	17.13	0.86	29.13
	H	115.12	1.61	43.17	93.59	22.10	32.00	1.84	54.41
	Total	*173.55*	*3.92*	*86.68*	*152.03*	*41.84*	51.69	2.83	87.88

Comparing total amount of nutrients in humus per ha we found no significant differences. In CV, average (Horn's mean) content of potassium was 20% higher (87 and 71 kg/ha) and average content of calcium was 9% higher (152 and 140 kg/ha). Contents per ha of other nutrients differed up to few percent. Total content of oxidable carbon was 16% higher by CV variant (52 and 44 t/ha) as well. Slodičák and Novák (2008) in blue spruce stand of very similar site (800 m a.s.l., acid category, S slope) in the Krušné hory Mts. found only 82 t of dry matter in humus horizons. Due to different method of chemical analysis used in their study (citric acid solution), the differences of nutrient contents are not objectively comparable. Under 25-year-old PP stand in lower altitude Podrázský (1995) found only 47.4 t of dry matter in humus horizons per ha. Actual quantity as well as quality of upper soil layers seems to be hardly limited by site conditions.

Despite of conclusions presented in the literature about the positive effect of *Calamagrostis* and negative effect of *Picea pungens* to the forest soil, we found very similar pedochemical characteristics of the holorganical horizons under both species. Therefore we can not state worsening of the soil conditions under blue spruce comparing to areas covered by tested forest weed species. However, we can expect positive microclimatic effect of the spruce for interplantings of selected target species. We can not also ignore complicated conditions on the sites with *Calamagrostis* for natural as well as artificial regeneration.

CONCLUSION

Comparing properties of the soil under blue spruce and *Calamagrostis* presented in this study resulted in detection of very little differences between upper horizons and the differences were in most cases not significant. Dry matter of the humus horizons was slightly higher under *Calamagrostis*. Only L horizon showed noticeable differences: there were higher values of cation exchangeable capacity (T), higher content of exchangeable bases (S) – significantly, as well as of exchangeable acidity (without significance) under *Calamagrostis*. From the point of view of holorganical horizons quality, both stands make almost identical conditions. Retrospectively, planting of blue spruce as a substitute tree species proves effective only considering other awaited effects of its forest stands, such as positive microclimate effect for plantings of selected target species.

Further research will be focused on differences in forest soil under other commonly used tree species after air pollution damage to forest stands in mountain regions of the Czech Republic.

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Porovnání vlivu smrku pichlavého a třtiny chloupkaté na chemické vlastnosti lesní půdy

ABSTRAKT: V článku je porovnáván vliv 21letého porostu smrku pichlavého (*Picea pungens*) a porostu třtiny chloupkaté (*Calamagrostis villosa*) na kvantitu a kvalitu svrchních půdních horizontů. Výzkum byl realizován ve smrkovém lesním vegetačním stupni v Jizerských horách (nadmořská výška 880 m, SLT – 8K). Z výsledků vyplývá, že pod porostem smrku pichlavého bylo akumulováno 153 tun sušiny holorganických horizontů na hektar, pod třtinou pak bylo 174 tun. Půdní reakce vykazovala obdobné hodnoty pod oběma porosty – 3,7 až 3,2 pH/KCl pod smrkem a 3,6 až 3,3 pH/KCl pod třtinou. Také rozdíly v koncentracích jednotlivých hlavních živin (P, K, Ca, Mg) nebyly statisticky průkazné. Signifikantně vyšší byla hodnota celkových výměnných bazických kationtů (S) a kationtové výměnné kapacity (T) pod porostem třtiny v horizontu opadanky (L). Celkově lze kvalitativní i kvantitativní charakteristiky půdních horizontů srovnávaných porostů hodnotit jako velmi podobné a nelze konstatovat zhoršení půdních vlastností pod porostem smrku pichlavého ve srovnání s plochou porostlou třtinou.

Klíčová slova: *Picea pungens*; buřeň; *Calamagrostis villosa*; kvalita a kvantita holorganických horizontů půdy; Jizerské hory

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