How the different tree species composition can alter throughfall, chemical properties of subsurface runoff and soil chemistry

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Abstract

This study deals with the evaluation of chemical changes of throughfall, subsurface runoff and soil chemistry in forest stands with different tree species composition. The research plots were placed in spruce (*Picea abies (L.) Karst.*) and beech (*Fagus sylvatica (L.)*) forest stands of the second generation aged 34 and 40 years in the central part of the Drahanská vrchovina Upland in the Czech Republic on acid Cambisol of the silver fir-beech forest vegetation zone. Considerably lower pH values of throughfall (as effect of tree crowns) and seepage waters (as effect of crown and soil) were found in spruce forest stands in comparison with beech stands. In subsurface lysimetric waters, higher concentrations of Na were detected in beech stands (statistically significant differences). Unlike the low soil pH value in H layer of the surface humus under spruce stands any indication of washing basic cations in seepage waters was observed recently. A remarkable improving character of beech for soil pH and base saturation was found. Our results prove the importance of the increased proportion of beech (*Fagus sylvatica*) in the species composition of forest stands at sites of autochthonous mixed forest stands in Central Europe.

Key Words

Forest, tree species composition, subsurface runoff, soil chemistry, Czech Republic

Introduction

Effects of forest stands (canopy density) become evident at the creation of the amount of runoff and chemical composition of throughfall (Berger *et al.* 2008). The forest floor is a connecting link between stand and soil and its condition and form are one of the key factors relating to the nutrients cycle and dynamics of decomposition as well as to the problem termed acidification (Waring and Running 1998; Emmer 1999; Sparks 2003). The importance of the tree species composition and character of soil organic matter (the complex of all non-living organic components of the soil) is increased in air-polluted areas in mountain and upland regions predominated by coniferous forests (Kulhavy *et al.* 2004).

Material and methods

Sites studied: The study is based on research carried out at permanent field plots in the Drahanská vrchovina Upland, Czech Republic. In the region, acid granodiorite of the Brno massif creates a parent rock and modal oligotrophic Cambisol (Nemecek *et al.* 2001) is the main soil type. Forest type is Abieto-Fagetum mesotrophicum with *Oxalis acetosella* (Pliva 1987). A more comprehensive description of the two experimental stands composed of (1) Norway spruce (*Picea abies (L.) Karst.*) and (2) European beech (*Fagus sylvatica (L).*) is given in Table 1.

Sampling: The sampling was carried out in 2004, 2006 and 2008 always at the end of the growing season (in November). Samples of the forest floor were taken at 10 repetitions in each of the horizons and years, and in the organomineral horizon (A) in 5 repetitions in each year. Water samplings were carried out in the period 2006-2008 once every 14 days in the growing season. In the winter season, water was sampled once a month only from undercrown collectors. Seepage waters were sampled using zero-tension lysimetres under A_o horizon.

Analyses of soil, throughfall and seepage water: The values of pH were determined using potentiometry (CSN ISO 10390) by means of a digital pH meter OP-208/1 (Radelkis Budapest, Hungary). Carbon and nitrogen were determined from samples devoid of coarse particles after fine grinding or comminution on a LECO TruSpec analyser (MI USA) (Zbiral *et al.* 1997). Available values were determined after extraction via an acid solution of ammonium nitrate and ammonium fluoride (Mehlich 1984; Zbiral 1995) using the method of flame atomic absorption spectrometry (Ca and Mg) and the method of atomic emission spectrometry (Na and K). Cation exchange capacity (CEC) was determined using the summation method (Zbiral *et al.* 1997). The determination of the soil adsorption complex by hydrogen was carried out using the method of double measurement (Zbíral *et al.* 1997). Dissolved organic carbon (DOC) was determined by an

adapted method according to Robertson *et al.* (1999). Then, the content of DOC was determined using Shimadzu TOC-VCSH/CSN analyser (Shimadzu Corporation, Japan). The pH value of the water samples was determined by potentiometry according to the CSN ISO 10523 standard, and the conductivity of precipitation and seepage waters was determined by conductometry according to the CSN EN 27888 standsard. The sub-samples of water for the determination of metals (Na, K, Mg, and Ca) were acidified by adding 0.5 ml of reagent-grade nitric acid per 100 cm^3 and analyzed using the flame atomic absorption spectrophotometry for Ca and Mg determination, and flame atomic emission spectrophotometry in case of Na and K (spectrometer AA 30 F4 VARIAN, air-acetylene flame

Statistical analysis: Statistical analyses were carried out in the Statistics Program (Stat-Soft Inc., Tulsa USA). Data were transformed by a decimal logarithm for further statistical processing. Potential differences in precipitation and soil water of the spruce and beech stands were tested by a two-sample t-test. Significance was assessed at the level $\alpha = 0.05$.

Table 1. Basic characteristics of the forest stands.

	Age	Stand structure [%]	Humus form[†]	Surface humus [t/ha dry weight][†††††]	Soil type	A.S.L. [m]	Rainfall [mm]	Temp. [°C]	Forest type
Spruce stand	34	spruce 100	moder	35.9	Modal oligotrophic Cambisol[†]	632	717[††††]	6.5[††††]	5S1 - *Abieto-Fagetum mesotrophicum* with *Oxalis acetosella*[†††]
Beech stand	40	beech 100	mull-moder	18.8	Cambisols (CM)[††]				

[†]soil taxonomy by Nemecek *et al.* 2001; [††]WRB; [†††]taxonomy by CFMI (Czech Forest Management Institute); [††††]Hadas 2002; [†††††]Mensik *et al.* 2009

Results

Table 2. Results of the throughfall and seepage water analysis in the spruce and beech stands (T-test, mean - arithmetic mean; t - t-value; P- probability).

	Throughfall				Seepage water			
	Spruce stand	Beech stand	T- test		Spruce stand	Beech stand	T- test	
	mean	mean	T	P	mean	mean	t	P
pH	5.423	5.913	-3.81	<0.001**	5.070	5.627	-3.66	<0.001**
DOC [mg/l]	9.506	6.935	-7.39	<0.001**	23.679	27.582	1.83	0.07
Ca [mmol/l]	0.028	0.018	1.89	0.06	0.018	0.021	-0.22	0.83
Mg [mmol/l]	0.012	0.008	2.55	0.01*	0.013	0.012	0.97	0.33
Na [mmol/l]	0.018	0.017	0.86	0.39	0.043	0.077	-3.52	<0.001**
K [mmol/l]	0.079	0.101	0.55	0.54	0.132	0.167	-1.19	0.24
Conductivity [µS/cm]	42.42	40.40	1.18	0.23	46.80	54.03	-1.01	0.32

Table 3. Results of soil analysis (mean - arithmetic mean; H - layer of humus; Ah - layer of organomineral horizon; pH - soil acidity; C/N - total carbon to total nitrogen ratio; DOC - dissolved organic carbon; CEC - cation exchange capacity; BS - base saturation).

Stand	H layers of forest floor						Ah layer of soil horizon					
	pH (H$_2$O)	pH (KCl)	C/N	DOC (mg/g)	CEC [mmol/ 0.1 kg]	BS [%]	pH (H$_2$O)	pH (KCl)	C/N	DOC (mg/g)	CEC [mmol/ 0.1 kg]	BS [%]
Spruce stand	3.5*	2.7*	24.0[NS]	1.2[NS]	360.7[NS]	20.3*	3.7	2.7	27.0	1.2	173.9	13.8
Beech stand	4.7*	4.1*	19.0[NS]	0.8[NS]	285.7[NS]	38.7*	4.3	3.2	18.0	0.8	173.0	32.9

* Statistically significant differences ($\alpha < 0.05; 0.01$); [NS] not significant

Throughfall water: Mean pH values of the throughfall waters in the spruce stand were 5.42, and in the beech stand 5.91 during the period of monitoring. pH values of the throughfall were lower in the spruce stand (t = -3.8; P < 0.001). The mean concentrations of individual cations in throughfall of the spruce stand and in the beech stand are given in Table 2. Statistically significant differences were determined only in the magnesium and DOC concentration (t = 2.6; P = 0.006 and t = -7.39, P < 0.001) with higher concentrations always in the spruce stand.

Soil: The highest pH values in H horizon were found in a beech stand, soil reaction (in H_2O) is moderately up to heavily acid. In pH (H_2O, KCl) at the level of significance ($\alpha < 0.01$), statistically significant differences occurred between the beech stand and spruce stand (Table 3). The lowest C/N ratio occurs in forest floor in H horizon in a pure beech stand (19), the highest C/N ratio is in the spruce stand (24). Statistically significant differences were not detected in the C/N ratio, the content of DOC and CEC in forest floor (H) and the organomineral horizon (Ah) between spruce and beech at the level of significance $\alpha = 0.05$. Statistically significant differences were detected in the BS in forest floor (H) between spruce and beech stands and mixed stands at the level of significance $\alpha = 0.05$.

Seepage water underneath the forest floor: The mean pH values of seepage waters underneath the forest floor during the period monitored in the spruce stand were 5.1 and in the beech stand 5.6 this difference is highly significant (Table 2). The mean conductivity of seepage waters underneath the forest floor for the period monitored in the spruce stand and in the beech stand was 46.8 (54.0) µS/cm. The Al concentrations in the spruce stand were 0.02 mmol/l and in the beech stand 0.03 mmol/l. The concentration of sodium was statistically lower in the spruce stand (t = -3.5; P < 0.001).

Conclusion

Based on the results, it is possible to notice that forest canopy can alter the chemical composition of precipitation as well as properties of the surface humus and upper layers of a mineral soil. Soil reactions (pH) and the saturation of a sorption complex by bases (BS) were affected most. These affects were worse in case of the 34-year old spruce stand than in case of the 40-year old beech stand. Slight positive soil-improving effect of beech could be noticed. Our results demonstrated favourable reclamation effects of beech in the species composition of forest stands of upland areas of Central-Europe and the suitability of increasing the proportion of beech at sites where allochthonous spruce monocultures predominate at present.

Acknowledgement

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