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Impact of Scots pine admixture in European beech stand on dissolved organic carbon and nitrogen leaching from organic and humic horizons of Dystric Arenosols in Northern Poland

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ABSTRACT: The effect of Scots pine admixture in European beech stand on the leaching of dissolved organic carbon (DOC), dissolved organic nitrogen (DON), nitrate nitrogen (NO_3-N) and ammonium nitrogen (NH_4-N) from organic and humic horizons of Dystric Arenosols was studied in northern Poland in 2008–2009. Three zero-tension lysimeters under organic and humic horizons were installed in pure beech and mixed pine-beech stands. Water samples were collected after each rainfall, measured volumetrically, filtered and analysed. In each sample pH and concentrations of DOC, DON, NH_4-N and NO_3-N were analysed. Stronger acidification of leachates was observed in mixed stand compared to pure beech. About twice higher concentration of DOC and its fluxes per unit area were determined in mixed stand. The fluxes of DOC from unit mass of soil were less varied. In general, lower concentrations of DON, NH_4-N and NO_3-N as well as fluxes of the components (calculated in $mg \cdot kg^{-1} DM \cdot year^{-1}$ and $mg \cdot m^{-2} \cdot year^{-1}$) were observed in mixed stand.

Keywords: European beech; Scots pine; leaching; carbon cycling; nitrogen cycling

Plant communities play an important role in quantity and quality transformation of water in forest ecosystems. The direction and the range of transformation are related to tree and herb species composition, plant density and year season (Herwitz 1993; Janek 2000; Kowalkowski et al. 2002; Jóźwiak, Kozłowski 2004). Throughfall is enriched with many organic and inorganic components in relation to rainfall. Further enrichment of water with products of weathering, products of soil organic matter decomposition and other soluble substances follows on contact with abiotic and biotic compounds of the soil. At the same time some components of solution are absorbed by the soil sorption complex or taken up by plant roots. The chemical composition of soil solution varies in time and space and is a result of the chemical composition of supplying waters, physical, chemical and sorption properties of the soil, its biological activity and type of water regime. Climate and weather conditions also play an important role. They affect the intensity of physical and chemical processes in the soil, shaping the annual dynamics of microorganism activity and concentration of particular components of soil solution (Christ, David 1996; Anderson et al. 2002; Dawson et al. 2008; Schmidt, Glaser 2011).

Ectohumus is an important source of the components of soil solution such as ions and dissolved organic matter. The components can be accumulated in lower parts of the soil profile being the basis of some soil-forming processes, or can leach to the ground and surface waters (Kalbitz et al. 2000; Yano et al. 2004; Dawson et al. 2008; Norström et al. 2010). Annual fluxes of dissolved organic carbon, dissolved organic nitrogen and mineral forms of the element in leachates in relation to plant litterfall quantity and quality, and storage of the components in organic and humic horizons can be good indicators of the ecological state of an ecosystem and direction of processes taking place in the soil (Smolander, Kitunen 2002; Fröberg et al. 2005; Evans et al. 2006).

The aim of the study was to compare the intensity of dissolved organic carbon (DOC), dissolved organic nitrogen (DON), ammonium nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) leaching from organic and humic horizons of Dystric Arenosols under beech and mixed pine-beech stands in northern Poland.

MATERIAL AND METHODS

Site description

The studies were conducted in Łysomice Forest Subdistrict (Leśny Dwór Forest District, northern Poland) in 2008–2009. The average annual sum of precipitation is about 770 mm with a maximum in July and average annual temperature is 7.6°C. The studies were conducted in two stands (40 × 40 m) located in adjacent divisions of forest. The first stand was located in a pure 120-years-old beech (European beech) forest (division No. 148a), and the second in a mixed beech-pine-spruce forest (division No. 147a). In mixed stand 66% was 70 to 110 years-old beech (European beech), 19% was about 120-years-old pine (Scots pine), and 15% about 70-years-old spruce (Norway spruce). The height of trees in beech stand was 25–29 m. In mixed stand it was 21–27 m for beech, 27 m for pine and 22–28 m for spruce. Beech was yield class II and III, pine and spruce belonged to class II. In mixed stand the studies of lysimetric waters were conducted in the pine-beech part, beyond the range of spruce impact.

Water sampling, analysis and statistical analysis

One year before the start of the experiment three zero-tension lysimeters 24 × 32 cm were installed under organic (O) and humic (A) horizons in each stand. Samples of leachates were collected after each rainfall in the years 2008–2009. Each sample was measured volumetrically, filtered using hard paper filters and analysed. The pH value was determined potentiometrically, DOC concentration by the Tiurin method after evaporation of water sample, the sum of DON and NH_4-N by the Kjeldahl method (100 ml of sample digestion in H_2SO_4 with addition of K_2SO_4 and selenium, distillation with NaOH using a VELP UDK 127 distilling unit, determination of ammonia by titration with 0.02M HCl), NH_4-N colorimetrically with Nessler's reagent (Pokojska 1999), NO_3-N colorimetrically with sodium salicylate (Pokojska 1999). The concentration of DON was calculated as follows: DON = Kjeldahl N – NH_4-N, and the concentration of total dissolved nitrogen (TDN) as the sum of DON, NH_4-N and NO_3-N. Concentration of the components was calculated in milligrams per cubic decimetre ($mg \cdot dm^{-3}$).

Volume-weighted mean seasonal and annual values of pH and concentrations of the components of solution were calculated. At the end of the experiment soil material overlaying on each lysimeter was carefully collected, dried to constant mass at 105°C and weighed. Annual fluxes of particular components from O and A horizons were calculated per one kg of dry mass of soil material ($mg \cdot kg^{-1}$ $DM \cdot year^{-1}$) and per one m^2 of area ($mg \cdot m^{-2} \cdot year^{-1}$).

Statistical differences between the stands in pH and concentrations of DOC, DON, NH_4-N, NO_3-N and TDN were tested by Student's *t*-test.

Soil analysis

At a distance of about 5 m from lysimeters, soil profiles were described and soil was sampled. The following properties were analysed: textural group on the basis of particle size distribution analysis with sieve and pipette methods (textural fractions were divided according to the classification of Polish Soil Science Society 2008), pH was determined potentiometrically in water and 1M KCl solution, total organic carbon (TOC) concentration using the Tiurin method (for mineral samples), and Alten's method (for organic samples) and nitrogen (TN) by the Kjeldahl method (Bednarek et al. 2004) using a VELP UDK 127 distilling unit.

RESULTS

Soil properties

Dystric Arenosols formed of sandy deposits were noticed in both stands. Moder type of humus was

Table 1. Selected properties of the soils

	Horizon	Depth (cm)	Textural group	pH		TOC (%)	TN (%)	TOC:TN
				H_2O	KCl			
Beech stand	Ol	4–2	–	5.01	4.33	52.56	0.948	55
	Ofh	2–0	–	4.34	3.59	44.57	1.566	28
	AEs	0–5	sand	3.77	2.93	3.77	0.194	19
	Bhs	5–9	sand	3.90	3.22	1.58	0.083	19
	BhsBv	9–31	sand	4.50	4.04	0.66	0.038	17
	C1	31–61	sandy loam	4.70	3.85	–	–	–
	C2	61–86	loam	4.73	3.74	–	–	–
	C3	86–140	loamy sand	4.98	3.90	–	–	–
Mixed stand	Ol	6–4	–	4.33	3.66	54.93	0.686	80
	Of	4–2	–	4.36	3.68	50.35	1.263	40
	Oh	2–0	–	3.62	2.62	37.66	1.167	32
	AEs	0–5	sand	3.72	2.80	2.05	0.090	23
	Bhs	5–13	sand	4.17	3.30	0.94	0.043	22
	BhsBv	13–27	sand	4.66	3.92	0.56	0.035	16
	BvC	27–49	sand	4.93	4.25	0.24	0.018	13
	Ab	49–75	sand	4.94	4.11	0.29	0.019	15
	Bvb	75–88	sand	4.51	4.12	0.16	0.014	12
	C	88–138	sand	4.65	4.23	–	–	–

observed in beech stand and mor in mixed stand. The pH of the soils (pH_{H2O}) was strongly acid for O horizons (4.33–5.01) and also for A horizons (3.72–4.98) (Table 1). TOC content in A horizon of the soils was 3.77% in beech stand and 2.05% in mixed stand. Considerable content of TOC was also observed in Bhs horizons – 1.58% in beech stand and 0.94% in pine-beech stand. Investigated soils differed in nitrogen content. A higher content of the element was observed in pure beech stand compared to mixed stand (Table 1).

Water fluxes

The flux of leachates from O horizon in beech stand was 322.5 mm in 2008 and 340.5 mm in the next year. In mixed stand it was 353.2 mm and 297.7 mm, respectively. The average flux of lysimetric water under A horizons in beech stand was 119.4 mm in 2008 and 99.6 mm in the next year, and in mixed stand 99.4 mm and 57.6 mm in subsequent years (Fig. 1). Interception of organic horizons was 22–41% and 78–85% in O and A horizons, respectively. Maximum fluxes of lysimetric waters were observed during autumn and winter.

pH

Statistically significant differences between the stands were observed in pH of lysimetric waters from O and A horizons. The mean pH value of leachates under O horizons was 5.05 in beech stand and 3.81 in mixed stand. In leachates under A horizon pH was 4.55 and 3.79, respectively (Fig. 2).

DOC

The two-year average concentration of DOC in leachates under O horizons was 43.56 mg·dm^{-3} in beech stand and 68.40 mg·dm^{-3} in mixed stand. A reduction of the DOC concentration was observed in lysimetric waters under A horizons in relation to organic ones – to the level of 26.03 mg·dm^{-3} in beech stand and 43.46 mg·dm^{-3} in pine-beech stand (Table 2). The concentration of DOC in leachates

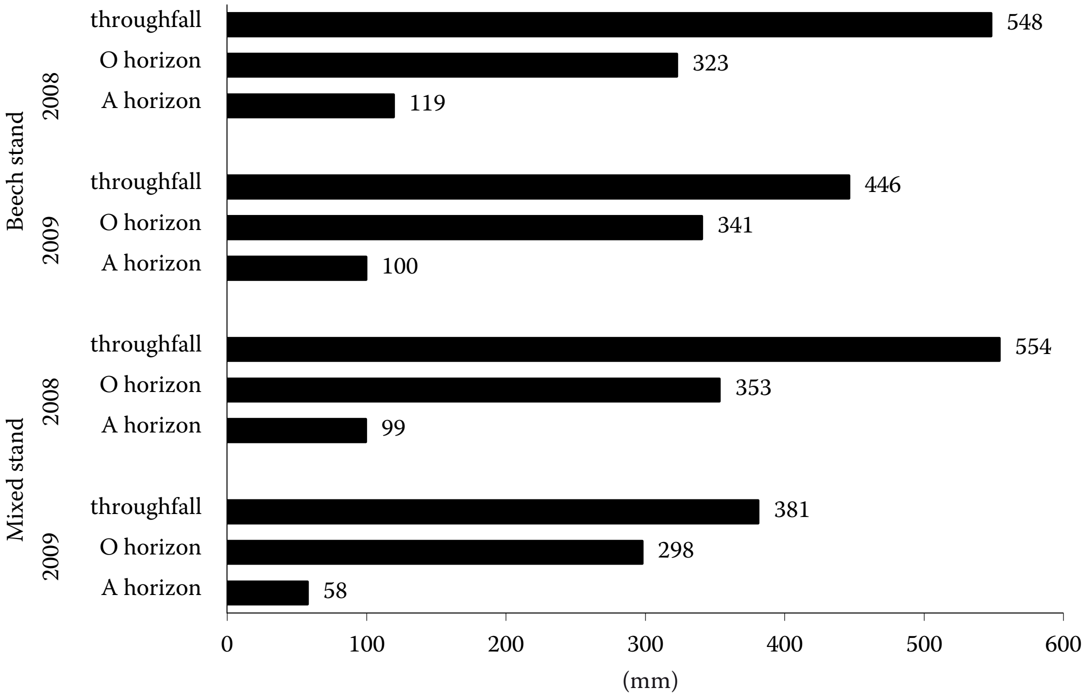

Fig. 1. The quantity of throughfall and lysimetric waters in beech and mixed stands in 2008 and 2009

varied in time. Maximum values were observed during summer and autumn, while minimum values were recorded in spring (Fig. 2). Such dynamics is the effect of different biological activity of the soil during the year. Differences between the stands in DOC concentration in leachates resulted from the mass of soil material over lysimeters. The intensity of DOC leaching calculated in mg·kg^{-1} DM·year^{-1} was comparable in both stands (Table 3). For O horizon of beech stand it was 2,818.33 and 2,768.21 mg·kg^{-1} DM·year^{-1} in subsequent years and for mixed stand 2,728.72 and 2,229.67 mg per kg DM·year^{-1}, respectively. Much lower intensity of DOC leaching was observed under A horizons – 38.18 and 23.63 mg per kg^{-1} DM·year^{-1} in beech stand and 40.76 and 22.65 mg per kg DM·year^{-1} in mixed stand. The flux of DOC calculated in mg·m^{-2}·year^{-1} for O horizons was 14,570.78 and 14,311.67 mg·m^{-2} ·year^{-1} in beech stand and 24,503.88 and 20,022.47 mg per m^{2} ·year^{-1} in mixed stand. For A horizons it was 3521.91 and 2,179.36 mg·m^{-2}·year^{-1} and 4,383.82 and 2,435.71 mg per m^{2}·year^{-1}, respectively (Table 4). Differences between the stands in concentrations and fluxes of DOC in throughfall and leachates were statistically significant in most cases (Table 5).

Table 2. Two-year mean values of pH, concentrations of DOC, DON, NO_3-N, NH_4-N and TDN (mg·dm^{-3}) and the DOC:TDN ratio

Component	Beech stand		Mixed stand	
	O horizon	A horizon	O horizon	A horizon
pH	4.89 ± 0.47	4.43 ± 0.39	3.71 ± 0.41	3.73 ± 0.27
DOC	43.56 ± 17.49	26.03 ± 8.88	68.40 ± 22.53	43.46 ± 15.20
DON	2.21 ± 1.25	1.24 ± 1.16	2.19 ± 0.67	1.15 ± 0.74
NO_3-N	2.00 ± 1.26	0.51 ± 0.40	1.07 ± 0.32	0.65 ± 0.20
NH_4-N	0.33 ± 0.31	0.47 ± 0.63	0.07 ± 0.07	0.23 ± 0.23
TDN	4.54 ± 2.56	2.21 ± 1.84	3.33 ± 1.12	2.02 ± 1.10
DOC:TDN	9.60 ± 3.40	11.80 ± 5.00	20.50 ± 2.40	21.50 ± 3.10

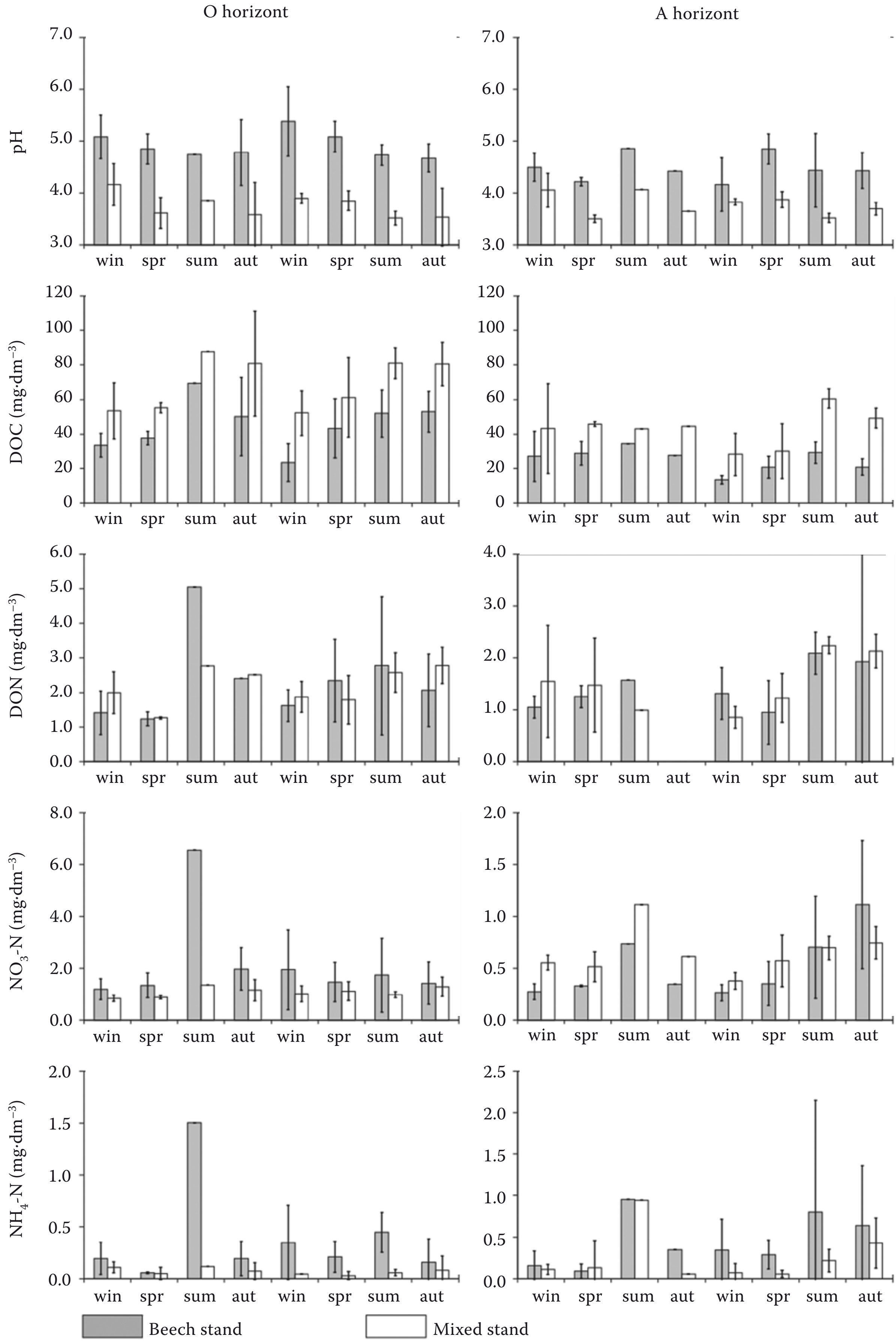

Fig. 2. Mean seasonal values of pH and concentrations of DOC, DON, NO_3-N and NH_4-N (error bars – standard deviation; win – winter; spr – spring; sum – summer; aut – autumn)

Table 3. Annual fluxes of DOC and forms of dissolved nitrogen (mg·kg^{-1}DM·year^{-1})

Component	Year	Beech stand		Mixed stand	
		O horizon	A horizon	O horizon	A horizon
DOC	2008	2,818.33	38.18	2,728.72	40.76
	2009	2,768.21	23.63	2,229.67	22.65
DON	2008	141.33	1.22	84.85	0.80
	2009	142.67	1.72	73.67	0.87
NO_3-N	2008	147.56	0.56	41.50	0.62
	2009	108.37	0.65	36.40	0.32
NH_4-N	2008	24.21	0.54	3.41	0.23
	2009	18.74	0.58	1.71	0.10
TDN	2008	313.10	2.32	129.76	1.66
	2009	269.77	2.94	111.78	1.30

DON, NH_4-N and NO_3-N

The two-year average concentration of DON in leachates under O horizon was 2.21 mg·dm^{-3} in beech stand and 2.19 mg·dm^{-3} in mixed stand. For NH_4-N form it was 0.33 and 0.07 mg·dm^{-3}, whereas for NO_3-N form 2.00 and 1.07 mg·dm^{-3}, respectively (Table 2). Higher intensity of leaching of each form of nitrogen calculated in mg·kg^{-1} DM·year^{-1} was observed in beech stand compared to mixed stand (Table 3). Especially large differences were noticed for NH_4-N. Annual fluxes of TDN from O horizon in beech stand were 313.10 mg·kg^{-1} DM·year^{-1} in 2008 and 269.77 mg·kg^{-1} DM·year^{-1} in the next year, while in mixed stand they were 129.76 and 111.78 mg·kg^{-1}DM·year^{-1}, respectively. The fluxes of DON calculated per unit area were comparable for both stands, whereas for NH_4-N and NO_3-N forms some differences were observed (Table 4). Higher values were observed in pure beech stand. The fluxes of TDN were higher in beech stand (1,618.72 mg·m^{-2}·y^{-1} in 2008 and 1,394.73 mg·m^{-2}·y^{-1} in 2009) than in mixed stand (1,165.23 mg·m^{-2}·y^{-1} and 1,003.74 mg·m^{-2}·y^{-1} in subsequent years).

In general, a reduction in the concentration of studied forms of nitrogen was observed in leachates under A horizon compared to O horizon. The two-year average concentration of DON in leachates under A horizon was 1.24 mg·dm^{-3} in beech stand and 1.15 mg·dm^{-3} in mixed stand, for NH_4-N form 0.47 and 0.23 mg·dm^{-3}, and for NO_3-N form

Table 4. Annual fluxes of DOC and forms of dissolved nitrogen (mg·m^{-2}·y^{-1})

Component	Year	Beech stand		Mixed stand	
		O horizon	A horizon	O horizon	A horizon
DOC	2008	14,570.78	3,521.91	24,503.88	4,383.82
	2009	14,311.67	2,179.36	20,022.47	2,435.71
DON	2008	730.67	112.51	761.93	86.23
	2009	737.59	158.24	661.60	93.57
NO_3-N	2008	762.89	51.30	372.68	66.99
	2009	560.27	59.52	326.83	34.50
NH_4-N	2008	125.16	49.99	30.62	25.00
	2009	96.87	53.17	15.31	11.28
TDN	2008	1,618.72	213.80	1,165.23	178.22
	2009	1,394.73	270.92	1,003.74	139.35

Table 5. Significance of differences between the stands in selected properties of leachates under O and A horizons

Component	O horizon	A horizon
pH	+++	+++
DOC ($mg\cdot dm^{-3}$)	+++	+++
DON ($mg\cdot dm^{-3}$)	–	–
NO_3-N ($mg\cdot dm^{-3}$)	++	–
NH_4-N ($mg\cdot dm^{-3}$)	++	+
TDN ($mg\cdot dm^{-3}$)	–	–

– no significant differences, + significant differences at $P < 0.05$, ++ significant differences at $P < 0.01$, +++ significant differences at $P < 0,001$

0.51 and 0.65 $mg\cdot dm^{-3}$, respectively (Table 2). Higher intensity of leaching of each form of nitrogen was observed in beech stand compared to mixed stand (Tables 3 and 4). The fluxes of TDN calculated per unit soil mass were many times lower in leachates under A horizon than under O horizon. Differences between the stands in the concentration of DON, NH_4-N and NO_3-N in lysimetric waters were not statistically significant in most cases (Table 5).

DISCUSSION

Plant litterfall production and transformation of the chemical composition of rainfall water are important mechanisms influencing forest plant communities as soil-forming factors. Litterfall, throughfall and stemflow are sources of different chemical compounds, macroelements and microelements for forest soils (Bray, Gorham 1964; Bell 1978; Augusto et al. 2002; Parzych, Trojanowski 2009; Astel et al. 2009; Jonczak et al. 2010). Permanent input to the soil of organic residues and waters having specific parameters can cause in the long run changes in the chemical and microbiological composition of the soil, and initiate or intensify some processes (Norden 1994; Nilsson et al. 1999; Augusto et al. 2002). The evolution of plant communities in the natural environment is slow and the soil evolves with them. In timber forests changes in the tree species composition are rapid, and cause anisotropic and often important quality and quantity changes in the soil environment. The extent of changes is the larger, the more different species are introduced into chemical and ecological properties in relation to species which occurred earlier. Coniferous species were commonly introduced into the forests of northern Europe in the last centuries. In the area of Middle Pomerania Scots pine and Norway spruce were planted in lieu of European beech. In recent times coniferous species have often been admixtures in naturally regenerated beech forests.

In general, large differences in plant litterfall properties and in the direction and range of rainwater transformation are observed between coniferous and deciduous tree species (Augusto et al. 2002; Kaiser et al. 2002; Berger et al. 2009; Jonczak 2011). Coniferous litterfall compared to deciduous litterfall is poor in nutrients (especially in nitrogen and phosphorus), has higher C:N and C:P ratios, is more acidic and more resistant to decomposition. These regularities were confirmed for plant litterfall in the investigated stands and described by Jonczak (2011).

Coniferous and deciduous species influence the chemistry of waters in a different way. The presence of pine as admixture in beech stand had a strong effect on the properties of leachates. The pH of lysimetric waters under O and A horizons was significantly lower in the stand with an admixture of pine. The effect of the soil pH decrease can be a reduction of soil biological activity and an increase of mobility of some components, such as soil organic matter, iron and aluminium (Wesselink, Mulder 1995; Christ, David 1996; De Witt et al. 1999; Anderson et al. 2000; Augusto et al. 2002; You et al. 2006; Remeš, Kulhavý 2009).

Dissolved organic matter (DOM) is a product of microbiological decomposition of organic litter, mostly in ectohumus. Plant litterfall properties, quantity and quality of soil microorganisms affect the intensity of DOM production and its properties (Scott et al. 1998; Kaiser et al. 2002; Lindroos et al. 2008). The intensity of DOM production varies during the year, and is related to the dynamics of weather conditions which determine the biological activity of soil (Tipping et al. 1999). The concentration of DOC in the studied tree stands varied also in time (Fig. 2). Average concentration of DOC, as the basic component of DOM, was higher in pine-beech stand compared to pure beech. Smaller differences were observed between the stands in annual fluxes of DOC leached per unit mass of soil material. The intensity of DOC fluxes from O and A horizons per unit area was higher in mixed stand.

Beech litterfall is poor in nitrogen compared to most European deciduous tree species, but richer than pine (Holzwarth et al. 2011). In the studied tree stands the average annual concentration of nitrogen in beech litterfall ranged from 8.37 $g\cdot kg^{-1}$ to

10.75 g·kg^{-1}, whereas for pine it was only 4.31 to 5.20 g·kg^{-1} (Jonczak 2011). Different abundance of nitrogen of litterfall and soils was reflected in the concentration and fluxes of dissolved forms of nitrogen in leachates. Higher fluxes of DON, NH_4-N, NO_3-N and TDN were determined in beech stand (Tables 3 and 4). An about twice higher DOC:TDN ratio was observed in throughfall and leachates in mixed stand compared to pure beech stand (Table 2). Similar relations were recorded for beech and pine litterfall (Jonczak 2011).

CONCLUSIONS

The admixture of Scots pine in European beech stand had a strong impact on the chemistry of leachates under O and A horizons of the studied soils. Stronger acidification of leachates was observed in beech-pine stand compared to pure beech. A significantly higher concentration of DOC was noticed in mixed stand. Differences between the stands in DOC concentration in leachates resulted from different mass of soil material overlaying the lysimeters. Fluxes of DOC per unit mass of soil were comparable in both stands. Higher fluxes of DOC per unit area were observed in mixed stand, where the thickness of A horizon was larger. In general, lower concentrations of DON, NH_4-N, NO_3-N and TDN and annual fluxes of these forms of nitrogen calculated per unit mass of soil as well as per unit area were observed in the stand with an admixture of pine, but the observed differences were not statistically significant in most cases. Observed pH and concentrations of nitrogen in leachates were related to the chemical properties of O and A horizons of soils and properties of beech and pine litterfall.

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