DOI: 10.1515/frp-2015-0035
Available online: www.lesne-prace-badawcze.pl

Leśne Prace Badawcze / *Forest Research Papers*
December 2015, Vol. 76 (4): 360–369

ORIGINAL RESEARCH ARTICLE

e-ISSN 2082-8926

Comparing *Empetro nigri-Pinetum* and *Vaccinio uliginosi-Betuletum pubescentis* soils in terms of organic matter stocks and ecochemical indices in the Słowiński National Park

Jerzy Jonczak[1], Agnieszka Parzych[2]

Pomeranian University in Słupsk, [1]Intitute of Geography and Regional Studies, Partyzantów 27, 76–200 Słupsk, Poland;
[2]Institute of Biology and Environmental Protection, Arciszewskiego 22b, 76–200 Słupsk, Poland

*Tel. +48 59 8400501, e-mail: jerzy.jonczak@gmail.com

Abstract. We conducted comparative studies on soil organic matter stocks and indices of the soil's ecochemical state under *Empetro nigri-Pinetum* (En-P) and *Vaccinio uliginosi-Betuletum pubescentis* (Vu-Bp) in the Słowiński National Park. The investigated plant communities are associated with Arenosols that developed from eolian sands and are exposed to high groundwater levels. The presence of fossil Histosol at a depth of 75 cm in the Vu-Bp stand, which lies below the current groundwater level, is the factor that sets both stands apart. The fossil soil strongly differs from Arenosol in terms of its chemical composition. A high abundance of nutrients in bioavailable forms in the soil is one of the reasons for natural renewal of downy birch in the stand, which presence in turn affects the turnover of elements and the properties of Arenosol. The results of our studies confirm the existence of strong feedback between the soil and plant communities. Soils under the mixed pine-birch Vu-Bp stand are characterized by smaller stocks of organic matter and total organic carbon (TOC) contained in the ectohumus as compared to the soils under the pure pine En-P stand. The opposite is found in the humic horizon. Additionally, in the Vu-Bp stand we observed greater accumulation of total nitrogen (TN) in ectohumus, which is reflected in lower TOC:TN ratios. The contents of TN and TOC:TN ratios in humic horizons were similar in both stands. The soils under En-P were more strongly acidified, especially in O-horizons. Mineral horizons in both stands were characterized by a very small sorptive capacity, which increased in ectohumus and fossil soil. Significant differences between the stands were observed in the ionic composition of sorptive complexes. The soils under Vu-Bp stand were more strongly saturated with basic cations, predominantly calcium. In soil solums of both stands, we observed a deficit of bioavailable potassium and magnesium, which was partially compensated by significant amounts of these components in ectohumus and fossil soil in the Vu-Bp stand. Despite a strongly acidic pH, molar Ca:Al ratios suggest that there are no phytotoxic effects due to free aluminium in ectohumus, while they are unlikely in mineral horizons. The risk of phytotoxic effects is reduced by the influx of calcium from groundwater.

Keywords: Arenosols, soil organic matter, sorptive properties, nutrients, aluminium toxicity

1. Introduction

Interactions between soils and plants of forest ecosystems are very strong and have feedbacks character. Soil, as key component of these ecosystems creates specified nutritional, water and oxygen conditions, influencing plant species composition. Spatial variability in soil properties is important factor affecting variability of plant communities in different spatial scales within particular climate and vegetation zones. A parallel influence of plants and animals on soils and the processes taking place in them is termed bio-perstructions, which constitute one of the three main mechanisms of soils transformations and their evolution (Kowalkowski 2006, Altermann et al. 2008).

Plant commmunities influence soil properties by litterfall production, quantitative and qualitative transformation of rain waters, uptake of water and nutrients and secretion of ions and chemical compounds by root systems as well as

Submitted: 11.01.2015, reviewed: 11.05.2015, accepted after revision: 10.07.2015.

by impact of growing roots on soil structure. Appearing in the places of dead roots free spaces are becoming important paths of groundwater migration. A deep transformations of soil cover in forest ecosystems may follow also due to windthrows (Peterson et al. 1990, Jonczak et al. 2012), especially on slopes (Norman et al. 1995). Plant litterfall plays a special role among these mechanisms. Its annual production and properties and affected by a complex of site conditions intensity of decomposition in a longer time determine type of humus, biological activity and chemical properties of soils. Long-term inflow of litterfall of specific chemical composition may result even in modification of the direction of soil development (Augusto et al. 2002). Formed in ectohumus in a result of plant residues decomposition and then leaching by percolating into the soil waters labile fractions of soil organic matter constitutes precursors of humic compounds and carriers of various substances, including metals (Kalbitz et Wennrich 1998, Jonczak 2012, Jonczak et Parzych 2012).

The strongest influence on forest soils have trees, which is confirmed by spatial variability of soil properties under mixed stands, which are closely related to ranges of crowns of individual tree species (Jonczak et Mackiewicz 2012). However in some ecosystems soils can be considerably influenced also by undergrowth vegetation, which species composition affects as differentiating agent especially on the properties of O and A horizons, contributing to the development of spatial plant-soil micromosaics (Dziadowiec et al. 2002).

The aim of this study was to compare the content and stocks of soil organic matter, total organic carbon, total nitrogen and pH, sorptive properties and the content of bioavailable forms of some metals in the soils under *Empetro nigri-Pinetum* and *Vaccinio uliginosi-Betuletum pubescentis* forest communities of Słowiński National Park associated with nutrient-poor dune habitats with high groundwater level. The presence of fossil soil at depth 75 cm in *Vaccinio uliginosi-Betuletum pubescentis* and tree species composition are factors differentiating the investigated stands.

2. Material and methods

Comparative studies of the soils under *Empetro nigri-Pinetum* (En-P) and *Vaccinio uliginosi-Betuletum pubescentis* (Vu-Bp) plant communities located in Słowiński National Park were carried out in spring 2012. Annual sums of precipitation for this area range from 550 to 850 mm and average annual temperatures are about 7,7°C (Parzych 2011). The study plots with dimensions of 25 x 25 meters were located in forest division 21a, within the area of stabilized by forest vegetation dunes, under which in VuBp stand, at the depth of 75 cm is the edge part of fossil bog. Tree layer in En-P stand consists of a 145-year-old Scots pine (*Pinus sylvestris* L.) with dominant diameters at breast height 15–30 cm (average 21 cm) and in Vu-Bp stand of 65-year-old Scots pine (*Pinus sylvestris* L.) and 52-year-old downy birch (*Betula pubescens*) of varied diameters at breast height, with average values 36.9 cm and 13.1 cm respectively (Fig. 1). Trees density during the study year was 848 pcs per hectare in En-P stand and 880 pcs per hectare in Vu-Bp stand, with percentage of pine at 38% and birch at 62%.

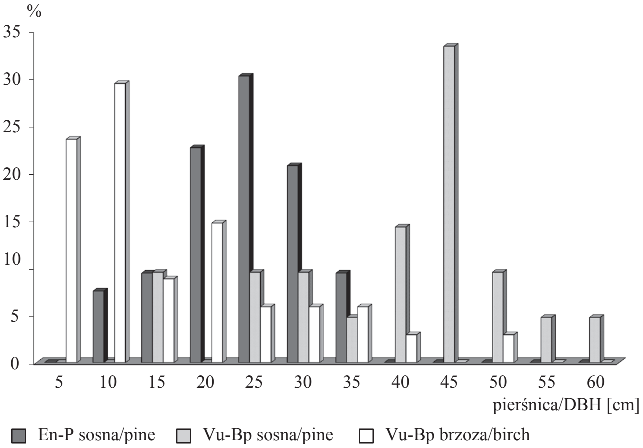

Figure. 1. The structure of tree stands by diameter at breast height

Soil organic and humic horizons at both stands were sampled in 25 points distributed in a regular grid. Organic horizons were sampled using a core sampler of diameter 20 cm. From humic horizons were taken about 0.5 kg samples of disturbed structure and samples of undisturbed structure using 100 cm^3 steel rings. In every sampling point were also done measurments of the thickness of A-horizon. In each stand was done soil pit, soils were described and sampled from every horizons for the purposes of laboratory analysis.

Samples of organic horizons after removing of fresh parts of plants were dried until the constat weight in 65°C, weighted, mixed and milled into powder. Samples of mineral horizons after removing of plant remains were dried in 40°C and sieved through 2.0 mm sieve to remove gravel fraction. The following properties of soils were analyzed:

- bulk density and actual moisture by drying-weight method,
- particle-size distribution by sieve method applying division into granulometric fractions after Polish Soil Science Society 2008 (PTG 2009),
- pH potentiometrically in suspention with water and 1 $mol \cdot dm^{-3}$ KCl solution using soil:water/KCl ratios 1:10 for organic samples and 1:2.5 for mineral samples,

- the content of soil organic matter (SOM) as loss on ignition in 550°C,
- the content of total organic carbon (TOC) by Alten method in organic samples and Tyurin method in mineral samples,
- the content of total nitrogen (TN) by Kjeldahl method using distilling unit VELP UDK-127,
- the content of bioavailable forms of P, K, Ca, Mg, Mn and Zn after soil extraction in 0.05 mol·dm^{-3} solution of HCl. Concentrations of P in extracts were analyzed by molybdenum blue method while the remaining metals by microwave plasma atomic emission spectrometry (Agilent 4100 MP-AES),
- exchangeable acidity (H_w) and exchangeable aluminium (Al_w) by Sokolov method,
- the content of exchangeable basis after samples extraction in CH_3COONH_4, pH = 7. Concentrations of basis in extracts were analyzed by microwave plasma atomic emission spectrometry (Agilent 4100 MP-AES),

Based on the results of analysis were also calculated:

- average contents of SOM, TOC and TN as well as average values of pH and TOC:TN ratios for organic and humic horizons at both stands,
- stocks of SOM, TOC and TN in organic and humic horizons of both stands,
- cation exchange capacity (CEC),
- base saturation (BS).

Data for both stands were compared statistically using Student’s t-test.

3. Results and discussion

3.1. General characteristics of the soils

Soils of the investigated stands represent Arenosols developed from Holocene eolian sands (Table 1) with mor type of humus in En-P stand and moder type with small patches of mor type in Vu-Bp stand. Ectohumus thickness in soil profiles was 8 cm in En-P and 10 cm in Vu-Bp stand, whereas thickness of humic horizons 10 cm and 23 cm respectively. A sharp transition between A-horizon and parent material in the soil of Vu-Bp stand indicates its post-agricultural character. Organic horizons of the investigated soils were poor in nitrogen, which is reflected in very wide TOC:TN ratios, especially in En-P stand. Humic horizons characterized by very low content of TOC, reaching only 1.8 g·kg^{-1} in En-P stand and 3.6 g·kg^{-1} in Vu-Bp stand, and TN, which content was 0.2 g·kg^{-1} in both stands (Table 2). Soils are strongly acid, however pH slightly increased with depth. Soils of En-P were stronger acidified as compared to Vu-Bp. In Vu-Bp stand, at the depth of 75 cm occured fossil organic soil composed of peaty horizon (2Ot) which is underlain by lacustrine deposits (2Lc). Presence of this soil is important factor influencing habitat conditions in Vu-Bp stand and differentiating both stands. High, relatively stable over time groundwater level, which is about 90 cm in En-P stand and 70 cm in Vu-Bp stand (Trojanowski et Parzych 2011), is the another important factor influencing conditions of plants development.

Table 1. Selected physical properties of the soils under *Empetro nigri-Pinetum* and *Vaccinio uliginosi-Betuletum pubescentis* in the Słowiński National Park

Horizon	Depth [cm]	The content of granulometric fractions [%]			Soil textural group	Bulk density [g·cm^{-3}]	Actual moisture [% v/v]	Colour after Munssel
		sand	silt	clay				
				En-P				
AC	0-10	99.0	1.0	0.0	pl	1.50	9.3	10YR 5.5/2
Cgg	10-80	99.6	0.4	0.0	pl	1.65	32.1	10YR 5.5/4
				Vu-Bp				
A(p)	0-23	99.4	0.6	0.0	pl	1.48	6.8	10YR 5/2.5
C	23-55	99.8	0.2	0.0	pl	1.53	7.4	10YR 6/4
Cgg	55-75	100.0	0.0	0.0	pl	1.57	33.7	2.5Y 5/3.5
2Ot	75-87					0.33	73.6	10YR 2/3
2Lc	87-97					0.33	79.8	2.5Y 3/1.5
3Cgg	97-120	99.6	0.4	0.0	pl	1.47	36.5	2.5Y 5/3

Table 2. Selected chemical properties of the soils under *Empetro nigri-Pinetum and Vaccinio uliginosi-Betuletum pubescentis* in the Słowiński National Park

Horizon	Depth [cm]	pH_{H2O}	pH_{KCl}	Loss on ignition [g·kg^{-1}]	Corg. [g·kg^{-1}]	Nt [g·kg^{-1}]	C:N
				En-P			
Ol	8-6	4.16	3.43	981.7	537.8	4.8	113.0
Of	6-2.5	3.40	2.60	958.3	511.5	8.1	63.0
Oh	2.5-0	3.22	2.37	855.2	477.1	7.0	68.2
AC	0-10	4.07	3.51	3.5	1.8	0.2	9.5
Cgg	10-80	4.87	4.24				
				Vu-Bp			
Ol	10-8	4.84	4.36	956.0	520.6	10.6	48.9
Of	8-4	4.10	3.47	671.2	390.6	11.2	34.9
Oh	4-0	3.79	2.89	330.3	193.8	6.4	30.1
A(p)	0-23	4.21	3.57	7.0	3.6	0.2	17.3
C	23-55	4.39	3.87				
Cgg	55-75	4.84	4.21				
2Ot	75-87	4.85	4.19	641.0	356.4	9.8	36.4
2Lc	87-97	4.94	4.35	313.4	181.5	25.8	7.0
3Cgg	97-120	5.44	4.56				

3.2. Stocks of soil organic matter, organic carbon, nitrogen and C:N ratios

Dead above-ground and underground plant remains termed litterfall constitute the primary source of soil organic matter in forest ecosystems. Litterfall mass, dynamics and chemistry are influenced by a complex of factors characterizing plant communities, including species composition, health condition, density and physiology (Stachurski et Zimka 1975, Dziadowiec et al. 2007, Jonczak 2011, 2013, Jonczak et Parzych 2014), a complex of factors characterizing site conditions, especially soil physical and chemical properties, water regime and climate conditions (Prescott et al. 1999), as well as by a complex of factors disrupting ist production, as droughts, flows, pest outbreaks and different symptoms of anthropopressure (Dziadowiec et Plichta 1985, Jonczak et Czarnecki 2008). Conditioned mainly by properties of initial materials (Berg et Staaf 1980, Albers et al. 2004, Jonczak 2009, Tablot et al. 2012) and a complex of abiotic (Cortez 1998, Drewnik 2006, Jonczak 2014) and biotic environmental factors (Dziadowiec 1990, van der Heijden et al. 2008) rate of litterfall decomposition, covering processes of mineralization ond humification, determines type of forest humus as well as its stocks and properties. Especially large differences in litterfall chemistry and decomposition rate are observed between deciduous and coniferous tree species (Augusto et al. 2002, Jonczak 2011).

The impact of species composition of plant communities on soils properties is the quickest and the strongest reflected in their ectohumus and than in humic horizons. It is also clear in the investigated soils and concerns both contents and stocks of the analyzed components (Table 3, 4). Soils under mixed pine-birch Vu-Bp stand characterized by significantly lower stocks of SOM and TOC in ectohumus at larger stocks and contents of these components in humic horizons as compared to pure pine En-P stand (Table 5). Average stocks of SOM in ectohumus in En-P stand were 6729 g·m^{-2} whereas in Vu-Bp stand 4241 g·m^{-2}. Stocks of TOC were 3696 g·m^{-2} and 2469 g·m^{-2} respectively. In humic horizons we noticed stocks of SOM at 1141 g·m^{-2} in En-P stand and 2000 g·m^{-2} in Vu-Bp stand and TOC 523 and 972 g·m^{-2} respectively (Table 3, 4). Total stocks of SOM in ectohumus and A-horizons are on average 21% higher, and TOC 18% higher in En-P stand. In general statistically significant differences between soils of the investigated stands were also observed in the content and stocks of TN, which were larger in Vu-Bp stand. Despite the observed differences the contents of this component in both stands were low, which is reflected in very wide in ectohumus and medium in A-horizons TOC:TN ratios. The gradual narrowing of TOC:TN ratios with depth is typical for forest soils and is associated with immobilization of nitrogen by microorganisms. This phenomenon is commonly observed in the studies on litterfall decomposition, regardless of its type (Dziadowiec 1990, Jonczak 2014).

Lower stocks of SOM and TOC in ectohumus at larger contents and stocks of these components in humic horizons, larger contents and stocks of TN and narrower TOC:TN ratios observed in the soils of Vu-Bp stand are evidence of more favorable environmental conditions for litterfall decomposition and more intensive biological turnover as compared to En-P stand. The presence of naturally renewing birch in Vu-Bp stand, which produce more susceptible to decomposition and more abundant in nutrients litterfall as compared to pine (Astel et al. 2009), is the main factor differentiating the investigated stands. Nitrogen, which in forest soils, especially such nutrient-poor as Arenosols, is abundant in deficit amounts, plays a key-role among the nutrients. Its bioavailability strongly influence species composition of forest vegetation (Matuszkiewicz et al. 2013), as well as soil fauna and microorganisms (Aira et al. 2006). The presence of birch in Vu-Bp is in turn conditioned by the presence within the range of tree root systems of fossil Histosol, which is much more abundant in nutrients as compared to Arenosol.

3.3. Reaction and sorptive properties of the soils

Reaction, which is one of the most important indices of soil ecochemical state, influences many of their properties, including forms and mobility of elements (e.g. Christ et David 1996, Anderson et al. 2000, Yano et al. 2004), their bioavailability (e.g. Czekała et al. 1996, Burzyńska 2009) and toxicity of some of them (Gough et al. 1979, Kowalkowski 2002, Vardar et Ünal 2007). It is therefore a good indicator of plant growth conditions and soil biological activity (Wang et al. 2006), allowing also to inference about the properties of soil organic matter and directions of its transformation (Tonon et al. 2010). Reaction of the investigated soils, both in organic and humic horizons was within strongly acid, although varied among the stands and individual soil horizons (Table 3, 4). In O-horizons pH was significantly lower in En-P stand whereas in A-horizons comparable in both stands.

The studied Arenosols characterized by a low, typical for the soils developed from eolian sands, sorptive capacity, which in En-P stand was just a 0.62–0.81 $\mathrm{cmol_{(+)}\cdot kg^{-1}}$, and in Vu-Bp stand 0.73–1.03 $\mathrm{cmol_{(+)}\cdot kg^{-1}}$ (Table 6). CEC of sandy soils is strongly affected by humic substances (Pokojska 1986), but in solum of the investigated soils humus occur only in small quantities. A multiple times higher CEC was observed in ectohumus (52.34–67.16 $\mathrm{cmol_{(+)}\cdot kg^{-1}}$ in En-P stand and 19.66–66.63 $\mathrm{cmol_{(+)}\cdot kg^{-1}}$ in Vu-Bp stand) and in fossil soil (48.25–76.79 $\mathrm{cmol_{(+)}\cdot kg^{-1}}$). However the odtained for these horizons values of CEC should be considered as overestimated, because beside exchangeable cations are also extracted labile fractions of elements (Pokojska 1986). A clear differences were observed between the investigated stands in percentage of the individual exchangeable cations in soil sorption complex. Higher saturation with basic cations in the soil of Vu-Bp stand is due to their biogenic translocation from fossil organic soil and periodical influence of groundwater. Ca^{2+} is the main basic and H^{+} the main acidic cation in the investigated soils (Table 6).

Acidic pH of soils promote activization of free aluminium, which under certain conditions and appriopriate amount becomes toxic to plants. However there is no uniform opinions on the limit values of pH. It is often assumed at pH < 4.5 (Grauer et Horst 1992), alhough some authors move it until a pH < 5.5 (Ryan et Delhaize 2010), and even pH < 6.0 (Moskal 1954). Phytotoxic effect has not enly ionic form of aluminium but also other forms of this metal, for example tridecamer, which is about 10 times more toxic as compered to Al^{3+} (Parker et Bertsch 1992, Pokojska 1994). Phytotoxic influence of aluminium is inhibited by humic substances (Gerke 1994) and calcium (Ryan et al. 1994, Matsumoto 2000). Molar ratio Ca:Al is commonly used measure in the assessment of the risk of aluminium stress (Kowalkowski 2002). Values of this ratio in En-P stand ranged from 3.1 to 44.8 in ectohumus and from 0.6 to 0.8 in mineral horizons, whereas in Vu-Bp stand from 9.8 to 82.2 and from 0.7 to 1.2 respectively and 123.0–138.4 in fossil soil (Table 6). The noted Ca:Al ratios, at relatively high saturation with exchangeable basis indicate that aluminium stress in ectohumus is impossible and in mineral horizons is unlikely.

3.4. The content of bioavailable forms of metals

Extraction of the soils associated with coniferous forests with 0.05 $\mathrm{mol\cdot dm^{-3}}$ solution of HCl allows to estimete their fertility and bioavailability of nutrients. Mineral horizons which contain less than 20 $\mathrm{mg\cdot kg^{-1}}$ of phosphorus and potassium, less than 10 $\mathrm{mg\cdot kg^{-1}}$ of calcium and 5 $\mathrm{mg\cdot kg^{-1}}$ of magnesium are considered as poor in these elements (Ostrowska et al. 2001). The content of P in mineral horizons of the soils

Table 3. Mean values of selected properties in organic and humic horizons of the soils in En-P (n=25)

Properties	Soil horizons			
	Ol	Of	Oh	AC
pH_{H2O}	3.90 ± 0.17	3.42 ± 0.13	3.34 ± 0.13	4.13 ± 0.11
Content of soil organic matter [$g \cdot kg^{-1}$]	964.1 ± 15.5	884.6 ± 133.3	663.2 ± 174.3	6.5 ± 3.5
Content of TOC [$g \cdot kg^{-1}$]	533.9 ± 16.9	465.5 ± 69.8	372.2 ± 97.2	3.0 ± 1.6
Content of TN [$g \cdot kg^{-1}$]	6.82 ± 0.88	9.34 ± 1.86	7.50 ± 1.80	0.19 ± 0.05
TOC:TN	79.7 ± 12.0	50.7 ± 8.1	49.8 ± 9.7	17.3 ± 11.0
Stocks of soil organic matter [$g \cdot m^{-2}$]	944 ± 496	2045 ± 629	3739 ± 1498	1141 ± 592
Stocks of TOC [$g \cdot m^{-2}$]	524 ± 277	1075 ± 323	2097 ± 828	523 ± 264
Stocks of TN [$g \cdot m^{-2}$]	6.6 ± 3.6	21.8 ± 7.5	42.1 ± 15.7	34.3 ± 14.9

Table 4. Mean values of selected properties in organic and humic horizons of the soils in Vu-Bp (n=25)

Properties	Soil horizons		
	Ol	Ofh	A(p)
pH_{H2O}	4.82 ± 0.22	4.02 ± 0.28	4.18 ± 0.16
Content of soil organic matter [$g \cdot kg^{-1}$]	928.2 ± 63.3	414.2 ± 124.2	8.3 ± 2.6
Content of TOC [$g \cdot kg^{-1}$]	499.1 ± 31.2	241.4 ± 77.3	4.0 ± 1.5
Content of TN [$g \cdot kg^{-1}$]	8.76 ± 1.68	8.80 ± 2.03	0.23 ± 0.06
TOC:TN	59.3 ± 13.0	27.2 ± 5.9	18.0 ± 6.1
Stocks of soil organic matter [$g \cdot m^{-2}$]	531 ± 213	3710 ± 1897	2000 ± 818
Stocks of TOC [$g \cdot m^{-2}$]	286 ± 114	2183 ± 1183	972 ± 434
Stocks of TN [$g \cdot m^{-2}$]	4.8 ± 1.7	79.5 ± 37.9	55.5 ± 19.7

in En-P stand ranged from 9.9 to 46.2 $mg \cdot kg^{-1}$, whereas in Vu-Bp stand from 23.8–41.3 $mg \cdot kg^{-1}$, which suggest occuring of element in suitable amounts to meet the demands of autotrophs (Table 7). There was also not observed deficit of calcium. Relatively high contents of these elements may result from their periodical inflow with groundwater, which also suggest gradients of vertical distribution of these elements in soil profiles. A considerably under limit values were amounts of potassium and magnesium, suggesting strong deficit of these elements, which is accelerated by strongly acid pH of the soils. In mineral horizons of the soils under both stands we also observed low contents of manganese and zinc. A multiple times higher contents of bioavailable forms of every studied elements were noticed in strongly infiltrated by tree roots ectohumus. The contents of P, K, Ca, Mg and Zn in Oh subhorizons were 2–3 times higher in En-P stand as compared in Vu-Bp. The content of Mn showed a reverse trend. The highest amounts of P, Ca, Mg and Mn were observed in fossil soil in Vu-Bp stand (Table 7). Vertical moving of these components by groundwater from fossil soil into mineral horizons of Arenosol and the influence of birch admixture are main reasons of the observed higher concentrations of these elements in soil solum in Vu-Bp stand as compared to En-P.

4. Conclusions

Results of comparative studies conducted in associated with dune habitats En-P and Vu-Bp stands in Słowiński National Park reflect well feedbacks between the

Table 5. Statistical significance of differences between the soils of En-P and Vu-Bp in their selected properties [- no statistically significant differences; + differences statistically significant at $p<0,05$; ++ differences statistically significant at $p<0,01$; +++ differences statistically significant at $p<0,001$]

Properties	Soil horizons		
	Ol	together	AC and A(p)
pH_{H2O}	+++	+++	-
Content of soil organic matter [$g \cdot kg^{-1}$]	++	+++	+
Content of TOC [$g \cdot kg^{-1}$]	+++	+++	+
Content of TN [$g \cdot kg^{-1}$]	+++	-	+
TOC:TN	+++	+++	-
Stocks of soil organic matter [$g \cdot m^{-2}$]	+++	+++	+++
Stocks of TOC [$g \cdot m^{-2}$]	+++	+++	+++
Stocks of TN [$g \cdot m^{-2}$]	+	-	+++

Table 6. Sorptive properties of the soils in En-P and Vu-Bp

Horizon	Content of exchangeable ions						TEB	H_w	BS	CEC	Ca:Al. [$mol \cdot mol^{-1}$]
	Na^+	K^+	Ca^{2+}	Mg^{2+}	H^+	Al^{3+}					
	$cmol_{(+)} \cdot kg^{-1}$										
En-P											
Ol	0.00	2.81	18.91	7.83	17.40	5.40	29.55	22.79	56.5	52.34	5.3
Of	0.00	2.98	16.84	4.82	34.33	8.18	24.64	42.52	36.7	67.16	3.1
Oh	0.00	1.98	14.06	5.36	33.65	0.47	21.40	34.12	38.5	55.52	44.8
AC	0.00	0.03	0.08	0.03	0.52	0.2	0.14	0.67	17.3	0.81	0.8
Cgg	0.00	0.03	0.07	0.05	0.28	0.2	0.14	0.5	23.3	0.62	0.6
Vu-Bp											
Ol	0.00	6.65	33.31	16.02	10.04	0.61	55.98	10.65	84.0	66.63	82.2
Of	0.00	2.13	29.63	9.46	9.94	0.67	41.22	10.62	79.5	51.84	66.0
Oh	0.00	0.62	7.26	2.67	7.98	1.11	10.56	9.10	53.7	19.66	9.8
A(p)	0.00	0.13	0.12	0.05	0.45	0.27	0.31	0.72	29.9	1.03	0.7
C	0.00	0.13	0.09	0.03	0.30	0.18	0.25	0.48	33.6	0.73	0.7
Cgg	0.00	0.13	0.14	0.06	0.28	0.17	0.33	0.45	42.1	0.78	1.2
2Ot	0.05	0.50	66.69	7.02	1.81	0.72	74.26	2.53	96.7	76.79	138.4
2Lc	0.04	0.28	41.15	4.89	1.39	0.50	46.36	1.89	96.1	48.25	123.0
3Cgg	0.00	0.14	0.60	0.10	0.16	0.06	0.84	0.22	79.0	1.06	14.2

Table 7. The content of bioavailable forms of some metals in En-P and Vu-Bp

Horizon	P	K	Ca	Mg	Mn	Zn
	mg·kg^{-1}					
			En-P			
Oh	142.9	332.9	1685.7	360.6	10.7	22.3
AC	9.9	3.9	7.6	1.7	0.1	0.2
Cgg	46.2	4.7	31.0	2.8	0.2	0.2
			Vu-Bp			
Oh	50.3	97.7	818.2	180.9	42.3	12.2
A(p)	23.8	1.8	17.5	3.0	0.4	0.2
C	31.3	0.7	21.7	0.8	0.2	0.0
Cgg	41.3	1.3	29.0	3.6	0.1	0.0
2Ot	362.0	17.3	9465.0	566.7	51.2	11.5
2Lc	100.7	38.4	5004.4	368.9	36.0	3.7
3Cgg	18.7	1.0	77.5	7.1	0.2	0.1

soils and plant communities in varying in terms of ecological conditions forest ecosystems. The occurence at a small depth, within the range of root systems fossil Histosol in Vu-Bp stand, which strongly differ from laying above it Arenosol in terms of chemical properties, is a key factor differentiating both stands. Under conditions of high groundwater level fossil soil considerably influence properties of Arenosol, species composition of plant communities and running in ecosystem processes. The presence of peaty bed determines, among others, natural renewing of downy birch, which in turn influence soil properties.

The soils under mixed pine-birch Vu-Bp stand as compared to pure pine En-P stand characterized by:

- significantly lower stocks of SOM and TOC in ectohumus at higher stocks and conternts of these components in humic horizons. Total stocks of SOM were lower on average by 21% and TOC by 18%,
- significantly higher contents of TN in ectohumus and comparable contents in humic horizons. Stocks of TN were significantly higher in both horizons,
- significantly narrower TOC:TN ratios in ectohumus at comparable ratios in humic horizons,
- significantly less acidic pH in organic horizons, although in every subhorizons it was within strongly acid,
- higher saturation of sorptive complex by exchangeable basis,
- lower contents of bioavailable P, K, Ca, Mg and Zn in ectohumus at higher contents of bioavailable P, Ca and Mg and lower content of K in mineral horizons.

Low abundance of nitrogen, which is confirmed by very wide TOC:TN ratios, is the characteristic feature of the soils in both stands, despite the observed differences between them. Plants in the stands are functioning under the conditions of strong acidified soils and strong deficit of potassium and magnesium. Despite strongly acid pH, the risk of phytotoxic influence of free aluminium does not occur in ectohumus and is unlikely in soil solum, which is confirmed by suitable high values of Ca:Al molar ratios. This risk is reduced by periodical influx of calcium with groundwater.

Acknowledgements

The studies were supported from statutory of Pomeranian University in Słupsk, task No. 13/3/13

Conflict of interest

The author reports no conflicts of interest in this work.

References

Aira M., Monroy F., Domínguez J. 2006. C to N ratio strongly affects population structure of Eisenia fetida in vermicomposting systems. *European Journal of Soil Biology*, 42: 127-131.

Albers D., Migge S., Schaefer M., Scheu S. 2004. Decomposition of beech leaves (Fagus sylvatica) and spruce needles (Picea abies) in pure and mixed stands of beech and spruce. *Soil Biology and Biochemistry*, 36: 155-164.

Altermann M., Jäger K-D., Kopp D., Kowalkowski A., Kühn D., Schwanecke W. 2008. Zur Kennzeichnung und Gilederung von periglaziär bedingten Differenzierungen in der Pedosphäre. Waldökologie, *Landschaftsforschung und Naturschutz*, 6: 5-42.

Anderson S., Nilsson S.I., Saetre P. 2000. Leaching of dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) in mor humus as affected by temperature and pH. *Soil Biology and Biochemistry*, 32: 1–10.

Astel A., Parzych A., Trojanowski J. 2009. Comparision of litterfall and nutrient return in a Vaccinio uliginosi-Betuletum pubescentis and a Empetro nigri-Pinetum forest stands in northern Poland. *Forest Ecology and Management*, 257: 2331-2341.

Augusto L., Ranger J., Binkley D., Rothe A. 2002. Impact of several common tree species of European temperate forests on soil fertility. *Annals of Forest Science*, 59(3): 233–253.

Berg B., Staaf H. 1980. Decomposition rate and chemical changes of Scots pine needle litter. II. Influence of chemical composition. *Ecological Bulletin*, 32: 373–390.

Burzyńska I. 2009. Wpływ odczynu gleby na współzależność między zawartością rozpuszczalnych form cynku w układzie: gleba-roślina łąkowa. *Ochrona Środowiska i Zasobów Naturalnych*, 40: 246-253.

Christ M.J., David M.B. 1996. Dynamics of extractable organic carbon in spodosol forest floors. *Soil Biology and Biochemistry*, 28(9): 1171–1179.

Cortez J. 1998. Field decomposition of leaf litters: relationships between decomposition rates and soil moisture, soil temperature and earthworm activity. *Soil Biology and Biochemistry*, 30(6): 783-793.

Czekała J., Jakubus M., Gładysiak S.T. 1996. Zawartość form rozpuszczalnych mikroelementów w zależności od odczynu gleby i roztworu ekstrakcyjnego. *Zeszyty Problemowe Postępów Nauk Rolniczych*, 434: 371–381.

Drewnik M. 2006. The effect of environmental conditions on the decomposition rate of cellulose in mountain soils. *Geoderma*, 132: 116–130.

Dziadowiec H. 1990. Rozkład ściółek w wybranych ekosystemach leśnych. Wydawnictwo UMK, Toruń: ss 137.

Dziadowiec H., Jonczak J., Czarnecki A., Kacprowicz K. 2007. Masa, dynamika i skład chemiczny opadu roślinnego w różnowiekowych plantacjach odmiany uprawnej topoli czarnej - Hybryda 275. *Roczniki Gleboznawcze*, 58(3/4): 68-77.

Dziadowiec H., Kwiatkowska A., Woźniak S. 2002. Zróżnicowanie poziomu organicznego i próchnicznego gleb w mozaice roślinno-glebowej w Górznieńsko-Lidzbarskim Parku Krajobrazowym. *Roczniki Gleboznawcze*, 53(3/4): 23-31.

Dziadowiec H., Plichta W. 1985. The effect of nun month (Lymantria Monacha L.) outbreak on characteristics of litter fall in the pine forest. *Ekologia Polska*, 33(4): 715-728.

Gerke J. 1994. Aluminum complexation by humic substances and aluminum species in the soil solution. *Geoderma*, 63: 165-175.

Gough L.P., Shacklette H.T., Case A.A. 1979. Element concentrations toxic to plants, animals and man. *Geological Survey Bulletin*, 1466: 1-80.

Grauer U.E., Horst W.J. 1992. Modeling cation amelioration of aluminum phytotoxicity. *Soil Science Society of America Journal*, 56: 166-172.

Jonczak J. 2009. Leaf litterfall decomposition in age-differentiated stands of poplar clone Hybrid 275, *Polish Journal of Soil Science*, 42(2): 159-167

Jonczak J. 2011. Struktura, dynamika i właściwości opadu roślinnego w 110-letnim drzewostanie bukowym z domieszką sosny i świerka. *Sylwan*, 155(11): 760-768.

Jonczak J. 2012. Wpływ domieszki sosny i świerka w drzewostanie bukowym na intensywność wypłukiwania węgla, żelaza i glinu z poziomu organicznego i próchnicznego gleb bielicowo-rdzawych, *Leśne Prace Badawcze*, 73(2): 143-151.

Jonczak J. 2013. Dynamics, structure and properties of plant litterfall in a 120-year old beech stand in Middle Pomerania between 2007-2010. *Soil Science Annual*, 64(1): 9-14.

Jonczak J. 2014. Rozkład liści buka w 120 letnim drzewostanie na obszarze Pomorza Środkowego. *Sylwan*, 158: 621-629.

Jonczak J., Czarnecki A. 2008. Risk assessment for biomass plantations planning on marginal soils as an effect of increasing frequency of weather extreme events. *Ecological Questions*, 9: 113-118.

Jonczak J., Mackiewicz K. 2012. Influence of pine and spruce admixture in European beech stand on some properties of organic and humic horizons of Dystric Arenosols and the intensity of biological turnover. *Polish Journal of Soil Science*, 45(2): 221-233.

Jonczak J., Parzych A. 2012. 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. *Journal of Forest Science*, 58(6): 278-286.

Jonczak J., Parzych A. 2014. The content of heavy metals in the soil and litterfall in a beech-pine-spruce stand in northern Poland. *Archives of Environmental Protection*, 40(4): 67-77.

Jonczak J., Parzych A., Sobisz Z. 2012. Gleby i flora wykrocisk w zespole *Empetro-nigri pinetum ericetosum* Słowińskiego Parku Narodowego, *Słupskie Prace Geograficzne*, 9: 33-42.

Kalbitz K., Wennrich R. 1998. Mobilization of heavy metals and arsenic in polluted wetland soils and its dependence on dissolved organic matter. *The Science of the Total Environment*, 209: 27-39.

Kowalkowski A. 2002. Wskaźniki ekochemicznego stanu gleb leśnych zagrożonych przez zakwaszenie. *Regionalny Monitoring Środowiska Przyrodniczego*, 3: 31-43.

Kowalkowski A. 2006. Die Bedeutung periglariärer Prozesse für die Bodenbeurteilung bei der Naturraumerkundeng. *Archiv für Naturschutz und Landschaftsforschung*, 45(3/4): 161-180.

Matsumoto H. 2000. Cell biology of aluminum toxicity and tolerance in higher plants. *International Review of Cytology*, 200: 1-47.

Matuszkiewicz J.M., Kowalska A., Solon J., Degórski M., Kozłowska A., Roo-Zielińska E., Zawiska I., Wolski J. 2013. Long-term evolution models of post-agricultural forests. IGiPZ PAN, Warszawa: ss. 320.

Moskal S. 1954. Glin ruchomy w glebach kwaśnych i metody jego oznaczania. *Roczniki Gleboznawcze*, 3: 154-174.

Norman S.A., Schaetzl R.J., Small T.W. 1995. Effects of slope angle on mass movement by tree uprooting, *Geomorphology*, 14: 19-27.

Ostrowska A., Porębska K., Borzyszkowski J., Król H., Gawliński S. 2001. Właściwości gleb leśnych i metody ich oznaczania. Dział Wydawnictw IOŚ, Warszawa: ss. 107.

Parker D.R., Bertsch P.M. 1992. Formation of the “Al_{13}” tridecameric polycation under diverse synthesis conditions. *Environ. Sci. Technol*, 26: 914-921.

Parzych A. 2011. Contents of nitrogen and phosphorus compounds in groundwaters of selected forest associations in Słowiński National Park. *Archives of Environmental Protection*, 37(4): 95-105.

Peterson, C.J., Carson, W.P., McCarthy, B.C., Pickett, S.T.A. 1990. Microsite variation and soil dynamics within newly created treefall pits and mounds, *Oikos*, 58 (1): 39-46.

Pokojska U. 1986. Rola próchnicy w kształtowaniu odczynu, właściwości buforowych i pojemności jonowymiennej gleb leśnych. Roczniki Gleboznawcze 37(2-3): 240-263.

Pokojska U. 1994. Nowe poglądy na toksyczność różnych form glinu. *Roczniki Gleboznawcze*, 45(1/2): 109-117.

Prescott C.E., Kabzems R., Ząbek L.M. 1999. Effects of fertilization on decomposition rate of Populus tremuloides foliar litter in a boreal forest. *Canadian Journal of Forest Research*, 29: 393-397.

PTG. 2009. Klasyfikacja uziarnienia gleb i utworów mineralnych – PTG 2008. *Roczniki Gleboznawcze*, 60(2): 5-17.

Ryan P.R., Delhaize E. 2010. The convergent evolution of aluminum resistance in plants exploits a convenient currency. *Functional Plant Biology*, 37: 275-284.

Ryan P.R., Kinraide T.B., Kochian L.V. 1994. $A1^{3+}$-Ca^{2+} interactions in aluminum rhizotoxicity. I. Inhibition of root growth is not caused by reduction of calcium uptake. *Planta*, 192: 98-103.

Stachurski A., Zimka J.R. 1975. Leaf fall and rate of litter decay in some forest habitats. *Ekologia Polska*, 23(1): 103-108.

Tablot J. M., Yelle D. J., Nowick J., Treseder K. K. 2012. Litter decay rates are determined by lignin chemistry. *Biogeochemistry*, 108: 279-295.

Tonon G., Sohi S., Francioso O., Ferrari E., Montecchio D., Gioacchini P., Ciavatta C., Panzacchi P., Powlson D. 2010. Effect of soil pH on the chemical composition of organic matter in physically separated soil fractions in two broadleaf woodland sites at Rothamsted, UK. *European Journal of Soil Science*, 61: 970-979.

Trojanowski J., Parzych A. 2011. Properties of forest soils under *Vaccinio uliginosi-Betuletum pubescentis* and *Empetro nigri -Pinetum* in the Słowiński National Park. *Baltic Coastal Zone*, 15: 69-83.

Van der Heijden M.G.A., Bardgett R.D., van Straalen N.M. 2008. The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. *Ecology Letters*, 11: 296-310.

Vardar F., Ünal M. 2007. Aluminum toxicity and resistance in higher plants. *Advances in Molecular Biology*, 1: 1-12.

Wang A.S., Angle J.S., Chaney R.L., Delorme T.A., McIntosh M. 2006. Changes in soil biological activities under reduced soil pH during *Thlaspi caerulescens* phytoextraction. *Soil Biology and Biochemistry*, 38: 1451–1461.

Yano Y., Lajtha K., Sollins P., Caldwell C.A. 2004. Chemical and seasonal controls on the dynamics of dissolved organic matter in a coniferous old-growth stand in the Pacific Northwest, USA. *Biogeochemistry*, 71: 197–223.

Authors’ contribution

J.J. – conducted field studies, performed laboratory analysis besides the content of nitrogen, wrote the manuscript

A.P. – conducted field studies, performed analysis of nitrogen content