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The organic matter content and pH of forest soils in the Brodnica Forest Division

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Abstract: The study was conducted in the Górzno and Czarny Bryńsk Forest, ranges which belong to the Brodnica Forest District. Brunic Arenosol (Dystric) soils predominate in the Brodnica Forest Division (over 77% of the total area). The aim of this study was to analyze the granulometric composition, the organic matter content and pH values in H_2O and KCl at three genetic horizons of soils (A – humus, B – *sideric* and C – parent material) within the crown extension of four tree species: English oak, European beech, Scots pine and Norway spruce. Silt and clay had a significantly higher share of A-horizon compared with B and C horizons. Soil samples collected under the crowns of Norway spruces were characterized by a significantly higher percentage of sand and a significantly lower percentage of silt than soil samples collected under beech and pine trees. In the analyzed soil horizons, pH values increased significantly with depth regardless of tree species. Tree species had a significant effect on the pH of the analyzed soils and the organic matter content of A horizon. Soil samples collected under the crowns of Norway spruces had significantly lower pH values than those collected under pine trees. Soil samples collected under the crowns of Norway spruces had significantly higher organic matter content than those collected under oak trees. There was a very high negative correlation between organic matter content and the values of pH measured in 1 M KCl, and a high negative correlation between organic matter content and the values of pH measured in H_2O suspension.

Keywords: soil, pH, organic matter, tree species

INTRODUCTION

In natural habitat conditions, the distribution of various tree species depends on the physical, chemical and biological properties of the soil, which in turn are shaped by vegetation, including forest, as well as the climate and water conditions (Scull, Harman, 2004; Osman, 2013; Encina-Domínguez et al., 2018). Soil provides living conditions in forest ecosystems, while the climate in small areas does not play such an important role in the formation of habitats (Brożek, 2011). Even in small areas, forest soils are characterised by a high variability of chemical properties, especially in the outer layers. Apart from vegetation, they are influenced by many factors, including granulometric composition, topographical relief and human activity (Schöning et al., 2006; Borůvka et al., 2007; Šamonil et al., 2011). One of the most important chemical properties of forest soils is the pH. During their long life, even single trees can affect and change the soil pH. Plant roots transport nutrients and secrete organic acids that determine the physicochemical and chemical properties of soils. Root mass and materials built up on the soil surface undergo decomposition, enriching the pool of organic matter. The micro-scale pH variability is predominantly determined by the distribution of organic carbon in the soil (Gruba et al., 2009). Humus, as one of the most important soil substrates, determines its sorption properties and due to gradually decomposition, providing plants with the necessary nutrients. From this layer, humic substances, mainly fulvic acids, are leached to lower soil levels, where they accumulate in the form of complex compounds with iron and aluminium (Kalbitz et al., 2000). As Bieniek (2013) reports, according to the World Reference Base (WRB, 2015), in outwash plains (i.e. sandurs), regardless of their utilisation, there are mainly typical rusty soils and rusty soils with features of podsolization – Brunic Arenosol (Dystric) as well as Albic Brunic Arenosol (Dystric). The main feature of the rusting process is the formation of immobile complex compounds of organic substances and sesquioxides. Research on rusty soils outside of young glacial areas also concerns areas of older glaciations (Janowska, 2001), dunes (Bednarek, 1991) and mountain areas (Marzec, Kabała, 2008). These soils are characterised by an acidic pH, high content of mobile aluminium, low abundance of nutrients and unfavourable physical properties resulting from high

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percent of sand fraction. Rusty soils are of little use as arable land; however, they create valuable forest areas. Thus, learning about their properties is very important. Humus, which is a binder in sandy soils, reduces the displacement of the clay fraction deeper into the profile. Because their litterfall is acidic and possesses a low nutrient content, the presence of trees may aggravate the soil acidification process. This applies mainly to conifers, but also occurs under beech stands (Augusto et al., 2002; Gruba, 2009). The species composition of forest communities affects the physicochemical and chemical properties of soils in their surface layers. Compared to litterfall from deciduous trees, litterfall originating from conifers contains less nitrogen, phosphorus, calcium and potassium, and indicates greater acidification. This is often a result of forest management consisting of planting conifers in place of deciduous trees and creating mixed stands, many examples of which can be found in the area of north-central Poland, where beech and spruce-pine-beech forests are in each other's vicinity (Jonczak, 2012).

The aim of the study was to determine the current condition of the soil environment within the crown range of four tree species: European beech (*Fagus sylvatica* L.), English oak (*Quercus robur* L.), Scotch pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* L.) in the habitat of fresh mixed forests. An analysis of the granulometric composition and organic matter content was conducted. Additionally, the pH values of rusty soil samples obtained from three genetic levels (topsoil [humus], rusty and bedrock) within the range of the crowns of four tree species were determined.

MATERIALS AND METHODS

The research was conducted in the Górzno and Czarny Bryńsk forest ranges near the city of Górzno in north-central Poland (Figure 1). These forests belong to the Brodnica forest district, which is a part of the Regional Directorate of State Forests in Toruń. The research area is located in the Górzno-Lidzbark Landscape Park, which covers three voivodeships: Kujawsko-Pomorskie, Warmińsko-Mazurskie and Mazowieckie. Its total area is equal to 27764.3 ha (website http://www.parki.kujawsko-pomorskie.pl).

The forests of Brodnica are dominated by stands with a predominant share of pine, which covers 84% of the area. Another species is English oak growing on over 5% of the area. The habitats of fresh mixed forests are predominant in the area of the Górzno and Czarny Bryńsk forest districts, where the research was conducted. In the forest district, typical rusty soils cover more than 77% of the area, followed by luvisols on 8% of the area. The soil cover also includes cambisols, podsolic soils and chernozems (website http://www.brodnica.torun.lasy.gov.pl). The research area is located within the outwash plain, made of sands and glacial gravels. The thickness of these sediments on the entire outwash plain exceeds 1 meter (Niewiarowski, Wysota, 1995 a, b; Sobiech, Wysota 2014).

The research was conducted on typical rusty soils (Polish... 2019), defined as Brunic Arenosol (Dystric) according to the World Reference Base (WRB, 2015). Due to the entirely different physical and chemical properties of organic and mineral deposits, organic (O) levels, i.e. mainly forest litter, were not included in the study. For laboratory tests, samples were taken from three genetic horizons: topsoil (A), rusty (Bv) and bedrock (C). The soil samples were taken from 33 profiles (Table 1). The soil surfaces beneath four tree species were selected for the study: European beech (3 trees – 9 soil profiles), English oak (2 trees – 6 soil profiles), Scotch pine (3 trees – 9 soil profiles) and Norway spruce (3 trees – 9 soil profiles). The age of the trees, determined on the basis of the diameter at breast height, was approximately 80 years. The selected trees were characterised by an average crown size under given conditions. The studied sites were free of understory, the trees grew in a tight formation, which resulted in slight undergrowth covering the soil. At every collection point, the level of forest litter was removed. In order to determine the morphological features of the typical rusty soil profile, excavations to a depth of 200 cm were made. The excavations, from which

Table 1. Description of the investigated material.

Tree species	Genetic horizons					
	A – humus horizon		Bv – *sideric* horizon		C – parent material	
	number of samples	thickness [cm]	number of samples	thickness [cm]	number of samples	thickness [cm]
Beech 9 profiles	9	11–19	9	71–95	9	85–107
Oak 6 profiles	6	13–27	6	43–75	6	56–98
Pine 9 profiles	9	8–32	9	54–115	9	62–129
Spruce 9 profiles	9	10–31	9	58–97	9	83–109

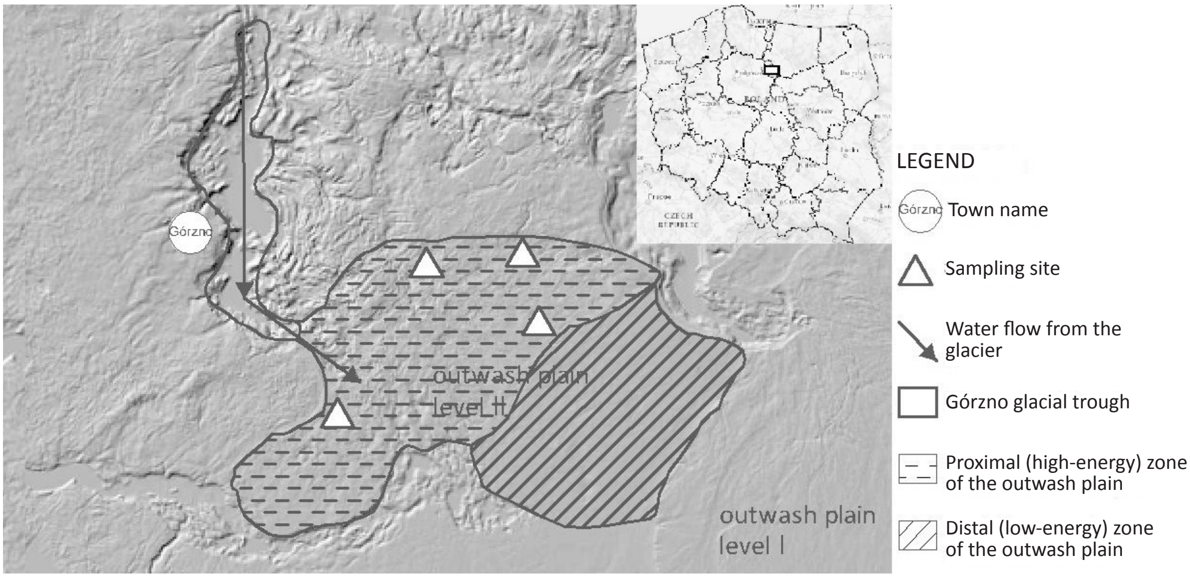


Figure 1. Location of the Brodnica Forest District and soil sampling sites.
Source: own study based on [website http://www.bdl.lasy.gov.pl; www.geoportal.gov.pl]

the soil samples from beneath each tree were taken, were spaced at the following distances from the trunk: 1 meter, 2 meters and 1 meter beyond the border of the crown.

The analyses of the soil samples were conducted in the laboratories of the Department of Agricultural Chemistry and Environmental Protection as well as the Department of Soil Science and Land Reclamation of the University of Warmia and Mazury in Olsztyn. In air-dried samples, the graining was determined by the Bouyoucos-Casagrande areometric method in Prószyński's modification. The granulometric groups and subgroups of the analysed samples were determined according to the applicable criteria of the Soil Science Society of Poland (Particle size distribution..., 2009). The organic matter content was determined by combustion of the samples at 550°C. The pH values in distilled H_2O and 1 M KCl dm^{-3} were determined by a potentiometric method using a pH meter (Panak, 1997). The mean pH values were calculated according to Gruba et al. (2010).

Analysis of the statistical data

The results of soil sample analyses were statistically evaluated using the STATISTICA 10 software (StatSoft 2010). A two-way ANOVA model with three replications was used. The first-order experimental factor was the tree species (4 species), and the second-order factor – the genetic level of the soil (3 levels). Differences between the averages at the level of $P < 0.05$ were assessed using the Tukey's range test. The least significant difference was established at $P < 0.05$. Moreover, the Pearson correlation coefficients were calculated for the pH in distilled H_2O and KCl and the content of organic matter.

RESULTS AND DISCUSSION

In the Brodnica forest district, the percentage content of granulometric fractions in rusty soils in the three tested horizons (topsoil, rusty and bedrock) was typical for forest soils (Table 2). Significantly more clay and silt fractions were determined in the topsoil horizons (A) than in the lower horizons – rusty (Bv) and bedrock (C). The thickness of the topsoil horizons ranged from 8 to 32 cm (Table 1). The Bv and C horizons were of similar graining (Table 2). The level of rusting varied in thickness, ranging from 43 to 115 cm (Table 1). Unequivocally the lowest Bv thickness was found under the oak (on average 59 cm). This horizon predominantly consisted of loose sands with a very low clay fraction content (on average 0.72%) (Table 2). The bedrocks of the studied soils were fluvioglacial – sander sands with the graining of loose sands. Their clay fraction content was on average 0.6%. The bedrock horizon thickness ranged from 56 to 129 cm (Table 1). Sandy soil graining determined their aero-hygro properties. Based on the field studies and assessment of morphological features, it was determined that the soils were permeable, periodically or permanently too dry, and the groundwater level was below the depth of 200 cm. The graining of the genetic levels was characteristic of rusty soils (Brożek, Zwydak, 2010).

The properties of forest soils, both physical and chemical, stem from a number of environmental factors. These include the origin of parent rocks, location in the relief, climate and vegetation, mainly trees. Considering the studied tree species, it was found that the soil collected in the vicinity of spruce trees was characterised by a significantly higher percentage of the sand fraction (2–0.05 mm), which

Table 2. Granulometric composition of forest soils and pH values in H_2O and 1 M KCl subject to genetic horizon and tree species.

Percentage of granulometric fraction [Ø mm]	Genetic horizons (G)			Tree species (D)				SE	P-value		
	A	Bv	C	beech	oak	pine	spruce		D	G	D×G
2–0.05	83.17 a	97.44 b	97.32 b	90.94 a	92.40 ab	91.48 a	95.67 b	0.872	0.006	0.000	0.370
0.05–0.002	11.36 a	1.84 b	2.08 b	6.43 a	5.12 ab	5.86 a	2.97 b	0.590	0.005	0.000	0.483
<0.002	5.47 a	0.72 b	0.60 b	2.64 a	2.48 a	2.66 a	1.36 b	0.301	0.039	0.000	0.216
pH_{H20}	4.01 a	4.61 b	5.09 c	4.59 ab	4.51 ab	4.74 a	4.44 b	0.054	0.001	0.000	0.333
pH_{KCl}	3.82 a	4.43 b	4.73 c	4.34 ab	4.30 ab	4.43 a	4.23 b	0.045	0.011	0.000	0.372

Legend: A – humus horizons of rusty soils, Bv – *sideric* horizon, C – parent material.
Different small letters in rows (a. b) denote significant differences at P<0.05 within experimental factors (genetic horizon, tree species); SEM – standard error of the mean.

was 95.67%, and significantly lower silt (0.05–0.002 mm) than the soil in the vicinity of beeches or pines (Table 2). Additionally, this soil was characterised by the lowest share of the clay fraction < 0.002 mm, on average 1.36%, in relation to the remaining tree stands (beech, oak and pine), which was confirmed statistically. Soils containing more coarse grain size fractions with a small share of the clay fraction are characterised by lower sorption capacity.

The soil pH is the basic and most easily measurable parameter describing the physicochemical properties of the soil. In woodland areas, particularly in forests and mixed forests, soil acidification is natural and beneficial for the stand renewal process. Over 90% of the area of Poland is covered by soils made of sedimentary rocks, mainly loose crumb rocks, which are poor in alkaline components. This is mainly the result of fluvioglacial (sander) morphogenesis and sedimentation of its typical sandy sediments. Such graining of the soils makes them susceptible to washing. The pH of typical rusty soils of the Brodnica forest district was acidic or strongly acidic (Table 2). The statistical analysis of the results revealed significant differences in the pH values in the genetic horizons of these soils. In the studied profiles, the soil pH values significantly increased with depth, regardless of the type of tree. The average pH values in 1 M KCl in dm^3 were: 3.82 in the topsoil level, 4.43 in the rusty level and 4.73 in the bedrock. Correspondingly higher values were found in distilled water (pH = 4.01 – A, 4.61 – Bv and 5.09 – C). A similar tendency was established by Jonczak and Sztabowski (2017) in the fresh mixed coniferous forest habitat because the pH values of rusty soils determined by the researchers measured in distilled H_2O increased with the depth in profiles from 3.5 in the topsoil layer to 5.8 in the mineral horizons. This phenomenon was explained by the influence of washed water management and shallowly located groundwater up to approximately 1.5 meters.

When studying current characteristics of rusty soils in the Brodnica forest district, a significant influence of tree species on the soil pH was found (Table 2). In the soil collected from the environment of spruce trees, significantly lower average pH values were recorded in the entire profile (4.44 in distilled H_2O and 4.23 in 1 M KCl) than in the soil collected under pine trees (4.74 in H_2O and 4.43 in KCl). In contrast, the locations under oak and beech had comparable mean pH values in the entire profile both in H_2O (4.51 and 4.59, respectively) and KCl (4.30 and 4.34, respectively). In the studies by Wacławowicz et al. (2017), the highest pH values were recorded in the soil under beech tree crown. According to Gruba et al. (2009), differences in the pH values can be observed even in small areas, i.e. up to 4 m^2, and increasing the area to 25, 100 and 400 m^2 had no effect on the value of the coefficient of variation. Some authors report that a slight depression of the pH develops around tree trunks (up to about 1 meter), particularly near pine and spruce (Gruba et al., 2009).

In soils poor in clay minerals, the amount of organic matter determines their sorption properties and pH (Janowska 2001). The conducted analysis of simple correlation shows a very high negative correlation between the content of organic matter and the pH value in 1 M KCl ($r = -0.726$) and a high correlation in distilled H_2O ($r = -0.544$), which is demonstrated in Figure 2. The obtained relation is similar to the results of Gruba et al. (2009). The negative correlation between the content of organic matter in the soil and its pH is not only a result of the synthesis of humic acids, but is mainly a consequence of the exchange reaction between alkaline cations and hydrogen (Gruba, 2009). Augusto et al. (2003) and Hagen-Thorn et al. (2004) report that the pH values of forest soil depend on the types of growing trees; however, the greatest variation occurs in its organic layers (0–10 cm), in which organic matter accumulates. In own research, the content of organic matter in the topsoil layers ranged from 1.16% to 6.26%.

The statistical analysis reveals that the average amount of organic matter was influenced by the type of trees (Figure 3). The highest average amount of organic matter, i.e. 3.53%, was obtained in the soil in the environment of spruce trees. It was 31% higher than that in the soil in the environment of English oaks. In the locations of beech and pine trees, the average organic matter content was rela-

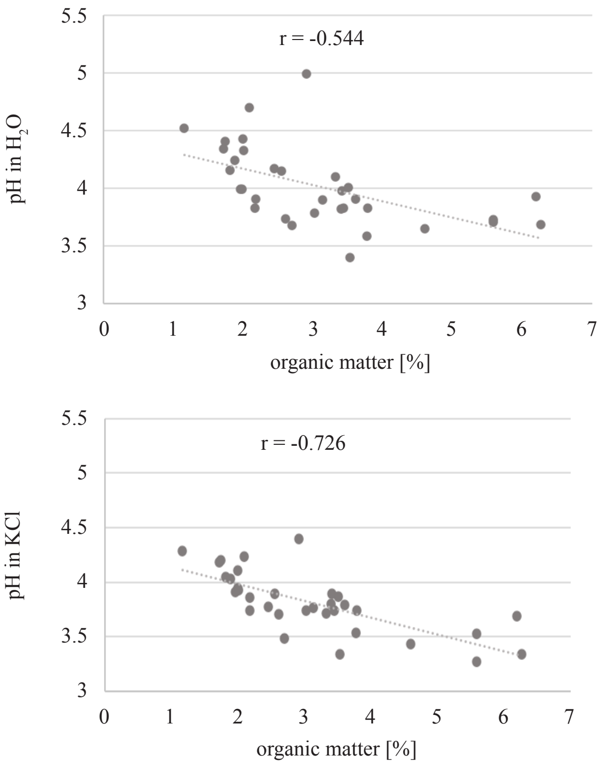
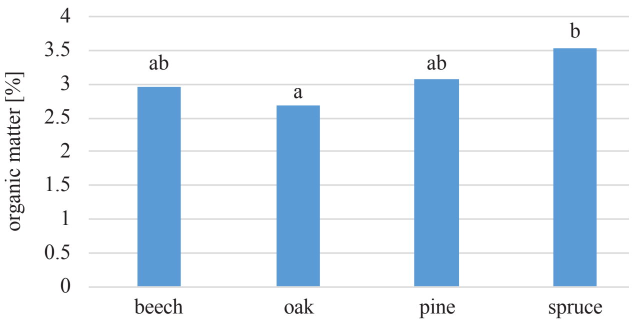


Figure 2. Correlations between organic matter content and pH values in H_2O and 1 M KCl in the (A) humus horizons of forest soils.



a, b – significant differences at $P<0.05$

Figure 3. Average organic matter content subject to tree species.

tively similar and amounted to approximately 3%. In forest ecosystems, the main source of organic matter is plant litter, which depends, among others, on the type of trees that grow in the forest (Wacławowicz et al., 2017). In rusty soils near forests, the amount of organic matter is usually several times higher than in arable soils used for farming (Bieniek, 2013).

CONCLUSIONS

1. In the Brodnica forest district, the granulometric composition of rusty soils in the three examined layers (topsoil, rusty and bedrock) is characteristic of the type of soil used as forest land. Significantly more clay and silt fractions are present in the topsoil layers than in the lower layers – rusty and bedrock.
2. The pH of the rusty soils under the studied tree stands was acidic and strongly acidic. The pH values in the studied profiles significantly increased with depth, regardless of the tree type, which can be explained by their fluvioglacial origin and susceptibility to washing of sandy bedrock.
3. It was found that the pH of the soil and the content of organic matter in the topsoil layer differed depending on the trees, as significantly lower pH values were recorded in the soil collected from the environment of spruce trees than in the soil collected under pines. A significantly higher average amount of organic matter in the soil of the topsoil layer was found in the locations of spruce trees than under oak trees.
4. A very high negative correlation was determined between the amount of organic matter and the pH value in 1 M KCl, and a high correlation was established in distilled H_2O.

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