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# REGIONAL DIFFERENCES OF PODZOLIC SOIL PROPERTIES IN CENTRAL AND NORTHERN EUROPE

# PRZESTRZENNE ZRÓŻNICOWANIE WŁAŚCIWOŚCI GLEB BIELICOWYCH W ŚRODKOWEJ I PÓŁNOCNEJ EUROPIE

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*Abstract*: The aim of the paper is determine spatial differences of selected properties in podzolic soils of the central and northern Europe and subsequently to point to their regional differences. The work took in the area of the zonal occurrence of podzolic soils and carried out within Germany, Poland, Belarus, Lithuania, Latvia, Estonia and Finland, between longitudes 12°25' and 32°37' E and longitudes 50°10' and 69°44' N. The internal similarity of the soil units established on the basis of the statistical analysis of dissimilarity of their characteristics and of the grouping of soil profiles, allowed for the performance of geographical division of the podzolic soils into two zones, within which the regional sub-zones were thereafter determined.

*Abstrakt*: Celem artykułu jest określenie przestrzennego zróżnicowania właściwości gleb bielicowych w środkowej i północnej Europie, a następnie próba ich geograficznej regionalizacji. Badaniami objęto obszar strefowego występowania gleb bielicoziemnych i prowadzono je na terenie Niemiec, Polski, Białorusi, Litwy, Łotwy, Estonii i Finlandii, pomiędzy 12°25' a 32°37' E oraz pomiędzy 50°10' a 69°44' N. Na podstawie właściwości gleb określonych dla 39 obiektów modelowych, obliczono wzajemne podobieństwo pomiędzy nimi, wykorzystując do tego celu analizę skupień. Analiza ta posłużyła do wyznaczenia regionów o największym podobieństwie wewnętrznym, zaś statystycznie istotnie różniących się pomiędzy sobą. Stwierdzono również silny związek pomiędzy czynnikami pedogenicznymi a uzyskanym podziałem. Wydzielono dwie strefy i pięć podstref regionalnych.

*Key words*: podzolic soil, geographical regions, northern and central Europe.

*Słowa kluczowe*: gleby bielicowe, regiony geograficzne, północna i środkowa Europa.

## INTRODUCTION

While the share of the soil cover of the Boreal and sub-Boreal climatic and vegetation belt taken by podzolic soils is considerable (in Finland their share jumps up to more than 75% (Atlas of Finland 1986), and the documentation of the characteristics of such soils is rich [among other: Lundblad 1934, 1936a, b; Rode 1937; Ponomariewa 1964, 1969; McKeague et al. 1971; Prusinkiewicz 1972a, b; Mokma, Buurman 1982; Mokma 1991; Gustafsson et al. 1995, 1999; Lundström 2000a, b; Melkerud et al. 2000; Olsson, Melkerud 2000] there has so far been a lack of reported work of a subject matter that would indicate the spatial differentiation to the properties of podzolic soils on a supraregional scale, in such a way that there would be comprehensive treatment taking in analysis of many soil properties determined from material collected by a single author in line with uniform laboratory methods. Up to the present, pedosphere division was synthesis of many authors results [Volobujev 1973; Głazowska 1981; Buol et al.1989; Bednarek, Prusinkiewicz 1997].

In consequence, the basic aim of the work described here has been to determine the spatial differences of selected properties in podzolic soils of the central and northern Europe and subsequently to point to their regional differences. The results obtained on the spatial variability of podzolic soils from the point of view of differentiation in their properties has been related to the already-existing geographical divisions of the pedosphere.

## MATERIAL AND METHODS

The work took in the area of the zonal occurrence of podzolic soils, whose western and southern limits constitute the natural range of fresh pine forests belonging to the *Dicrano-Pinion* alliance, while the northern limits are set by the *Phyllodoco-Vaccinion* alliance [Bohn et al. 1996], and the eastern by the political boundary of Russia. The study was thus carried out within Germany, Poland, Belarus, Lithuania, Latvia, Estonia and Finland, between longitudes 12°25' and 32°37' E and longitudes 50°10' and 69°44' N. 418 soil pits were dug in podzolic and rusty podzolic soils across the study area, with 39 of the habitat features most typical of the studied geographical unit being selected for further analysis. Study was carried out in 13 geographical regions of Europe (Table 1).

The recognised influence of many endogenous and exogenous factors of the geographical environment on the spatial variation in soil cover ensured that the carrying-out of pedological research on the geographical scale required the adoption of a range of very precisely defined assumptions and criteria in the selection of sites. These required that a site:

(1) had an autogenic soil with an endo-percolative type of water regime,
(2) was located at an altitude of less than 300 m a.s.l.,
(3) had a flat surface with an inclination of less than 2°,
(4) had a permeable rocky material beneath,
(5) had sediments of a glaciofluvial character,
(6) supported a forest ecosystem with a prevalence of Scots pine in the tree stand,
(7) had minimum tree-stand ages of 80 years,

TABLE 1. Geographical localisation of the research soils

| Profil No | Localisation of research soil | | | | |
|---|---|---|---|---|---|
| | country | geographical region | plot | latitude N | longitude E |
| 1 | Finland | Lapland | Kevo | 69°44'46.48" | 27°01'20.78" |
| 2 | | | Kessi | 69°01'23.21" | 28°30'21.56" |
| 3 | | | Oulanka | 66°21'33.45" | 29°21'34.12" |
| 4 | | | Tennila | 66°56'23.45" | 25°56'21.34" |
| 5 | | Ostrobothnia | Muhos | 64°43'25.45" | 26°01'48.40" |
| 6 | | Finnish Lake District | Luopioinen | 61°32'34.28" | 24°48'35.44" |
| 7 | | | Lammi | 61°09'34.21" | 25°00'12.08" |
| 8 | | | Hattula | 61°11'45.38" | 24°50'12.34" |
| 9 | | | Vitsiola | 61°05'23.78" | 24°55'57.32" |
| 10 | | | Punkaharju | 61°39'41.64" | 29°16'54.88" |
| 11 | Estonia | Eastern Baltic Coastland | Tipu | 58°18'59.84" | 24°59'37.82" |
| 12 | Latvia | | Jaunjelgava | 56°37'22.24" | 24°53'16.61" |
| 13 | Lithuania | | Mincia | 55°25'50.32" | 26°01'05.70" |
| 14 | | | Strazdai | 55°08'31.45" | 26°09'46.12" |
| 15 | Poland | | Płaska | 53°52'27.92" | 23°18'30,14" |
| 16 | | Podlasie-Belarus' Uplands | Browsk | 52°53'19.32" | 23°37'10,05" |
| 17 | | Northern PreCarpathian Uplands | Józefów | 50°28'38.42" | 22°59'29.06" |
| 18 | Belarus | Podlasie-Belarus' Uplands | Baranowicze | 52°56'47.68" | 25°53'04.32" |
| 19 | | | Krasna Swoboda | 52°48'14.76" | 27°08'51.96" |
| 20 | | Berezina-Desna Lowland | Soligorsk | 52°52'24.54" | 28°25'49.66" |
| 21 | | | Bychow | 53°14'22.35" | 30°12'44.27" |
| 22 | | | Słowgorod | 53°25'28.43" | 31°06'47.80" |
| 23 | | | Chotimsk | 53°20'57.29" | 32°37'38.00" |
| 24 | | | Uzłogi | 53°20'53.58" | 32°35'54.04" |
| 25 | Germany | Western-Baltic Lakelands | Chrisdorf | 53°06'08.50" | 12°25'47.91" |
| 26 | Poland | Southern Baltic Lakelands | Namyślin | 52°39'41.36" | 14°32'11.47" |
| 27 | | | Gościm | 52°44'22.33" | 15°42'21.82" |
| 28 | | | Krucz | 52°47'17.81" | 16°26'13.96" |
| 29 | | | Bobrowniki | 52°48'50.93" | 19°00'44.18" |
| 30 | | | Skrwilno | 52°48'10.81" | 19°19'49.27" |
| 31 | | Central Polish Lowland | Glinojeck | 52°49'36.93" | 20°19'28.70" |
| 32 | | | Glinojeck | 52°38'08.32" | 22°16'57.40" |
| 33 | | | Brok | 52°40'36.50" | 21°42'37.45" |
| 34 | | | Nowe Miasto | 51°35'02.64" | 20°37'05.36" |
| 35 | | Central Małopolska Upland | Miedzierza | 51°06'28.38" | 20°25'06.86" |
| 36 | | Silesian-Cracovian Upland | Złoty Potok | 50°43'16.10" | 19°32'17.15" |
| 37 | | | Złoty Potok | 50°20'59.05" | 19°39'12.63" |
| 38 | | Central Polish Lowland | Tworóg | 50°34'56.20" | 18°44'21.35" |
| 39 | | | Kuźnia Raciborska | 50°10'58.78" | 18°20'35.18" |

(8) was not characterised by the direct impact of humankind on the ecosystem.

The soil properties being evaluated were: thickness of the soil layer, mineral composition, the abrasion of prepared quartz grains of diameter 0.5–1 mm; particle-size distribution; the density by volume (Go) in samples of undisturbed structure, the real density (Gw); temporary humidity (W), the field water capacity (PPW), the maximal capillary capacity (KPW max), the composition by fraction of humus in the organic and humus layers, lactic dehydrogenase activity in the organic and humus layers, organic carbon content ($C_{to}$), organic carbon after extraction with sodium pyrophosphate ($C_p$), the carbon stock (MC), reaction ($pH_{H2O}$ and $pH_{KCl}$), total nitrogen (N), nitrate-nitrogen ($N\text{-}NO_3^-$), ammonium-nitrogen ($N\text{-}NH_4^+$), total phosphorus ($P_o$), plant-available phosphorus ($P_a$), exchangeable cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$), hydrolytic acidity ($H_h$); exchangeable aluminium ($Al^{3+}$), exchangeable acidity ($H^+$, $Al^{3+}$), iron ($Fe_p$), aluminium ($Al_p$) carbon ($C_p$) associated in humus complexes with sesquioxides, in an extract of 0.1M sodium pyrophosphate, iron content extracted in 20 HCl ($Fe_t$), amorphous iron ($Fe_o$) and amorphous aluminium ($Al_o$), and free iron ($Fe_d$) in citrate extract with sodium dithionite. Also calculated were: total porosity (Po) as (Gw–Go)/Gw; air capacity (Pp) as Po–PPW; total exchangeable base cations (S) as the sum of determinations for $Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$; capacity of the sorption complex (T) as $H_h$ + S; degree of base saturation (V) as S/T x 100%; the index of soil elasticity (Ui), as $(\Sigma Ca^{2+}Mg^{2+})/T$; the content of silicate forms of iron ($Fe_{gk}$) as $Fe_z$–$Fe_d$; index of process activity as $Fe_o/Fe_d$, molar ratio between elements of iron-aluminium-humus complexes as $C_p(Al_p + Fe_p)$; content of amorphous iron and aluminium as $(Al_o + '' Fe_o)$; content of iron-aluminium-humus complexes as $(C_p + Al_p + Fe_p)$; index of illuviation $(\Sigma_B\, C_p Al_p Fe_p - \Sigma_A\, C_p Al_p Fe_p)$; index for the movement of amorphous iron and aluminium $(Al_o + 1/2Fe_o)Bh/(Al_o + 1/2Fe_o)Ees$ and index for the movement of free iron ($Fe_dBh/Fe_dEes$). More details of using method was described by the author in the other publication [Degórski 2002].

The obtained results on the soil properties of 39 objects (soil profiles) provided a basis for the determination of similarities between them, with cluster analysis being used for this purpose. Ward's method was used in grouping. On the basis of the determined data some soil geographical regions was created, which were characterized by the highest internal and the smallest external similarity of soil properties. For the each region, the average value and standard deviation of some properties for podzolic soil was determined.

## RESULTS AND DISCUSSION

### General characteristic of the soils

The pedons analysed belong to podzolic soils [Polish Soil Taxonomy 1989] and characterised by typical morphology for this type of soil. Then, in northern Finland the soil cover analysed is constituted by the illuvial-humus podzolic soil, while on the remaining study plots – by the proper podzolic soils, with varying thickness of the diagnostic horizon of spodic. All of them developed from the permeable and poor in nutrients sandy formations. Quartz is the main mineral in these rocks, its content ranging from 50% in northern Finland to roughly 97% in southern Poland. They are characterised by acid reaction (pH in $H_2O$ from 3.1 in humus horizon to 4.8–5.0 in parent material), low sorption capacity, low degree of base saturation (below 20%), broad C:N ratio (up to 15 in humus horizon), and domination of the fulvic acids in the fractional composition of humus. All of the soils considered fulfil also the criteria proposed by Mokma [1983] and WRB [1998], which are expressed through the indicators of: content of amorphous iron and aluminium in the enrichment layer, movement of the amorphous iron and aluminium, illuviation, content of the ferrous-aluminium-humus complexes, as well as of the immobile complexes, making it altogether possible to classify these soils into the taxonomic podzol type units. Detailed characteristic of studied soils are presented by the author in the monograph [Degórski 2002].

Among 53 of the studied properties of podzolic soils, some properties were diagnostic features of their differentiation, i.e. the ones pointing to statistically-significant relationships with geographical location. They were: (1) the thickness of the organic horizon, (2) the thickness of the soil solum, (3) the content of non-resistant minerals in the soil's heavy fraction, (4) the granulometric heterogeneity of the soil substratum, (5) the degree of abrasion of lithological material, (6) the temporary humidity deficit in relation to field capacity, (7) the ratio of the stock of soil at field capacity to the stock in a state of capillary water capacity, (8) the air capacity, (9) the stock of organic carbon, (10) the ratio of the humic to fulvic acid contents, (11) the degree of humification, (12) lactic dehydrogenase activity, (13) contents of total phosphorus and plant-available phosphorus, (14) the content of exchangeable aluminium, (15) the content of exchangeable hydrogen ions, (16) the exchangeable acidity, (17) the relations between forms of aluminium and iron. Spatial variability of those properties was decided about soil regional differen-tiation.

## Regional differentiation of the soils analysed

The internal similarity of the soil units analysed in the study, established on the basis of the statistical analysis of dissimilarity of their characteristics and of the grouping of soils, allowed for the performance of geographical division of the podzolic soils into two zones (I and II), within which the regional sub-zones were thereafter determined (Fig.1). The identified regional units are also characterised by the statistically significantly different edaphic properties of the habitats (Table 2).

The obtained regional division of the podzolic earth soils analysed is as follows:

**Zone I**: the podzolic earth soils of the pine and mixed forests of the vegetation formation of the mesophilous and hygro-mesophilous coniferous forests of the moderately cool climate. Sub-zones:

- The meso-Holocene and neo-Holocene illuvial-humus podzolic soils of the pine forests of the regional vegetation formation of the northern boreal coniferous forests, occurring in conditions of a strongly humid climate, with a significant domination of precipitation over evaporation, on the area featuring nowadays a very active soil development environment, where the soil substratum is constituted by the youngest eo-Holocene sediments (Lapland). These soils are characterised by low thickness and intensive washing and small water retention which is facilitated by the glacio-fluvial material, featuring high shares of the coarse sand grains and the gravel-and-stone fraction (Table 3). This material is characterised by the low

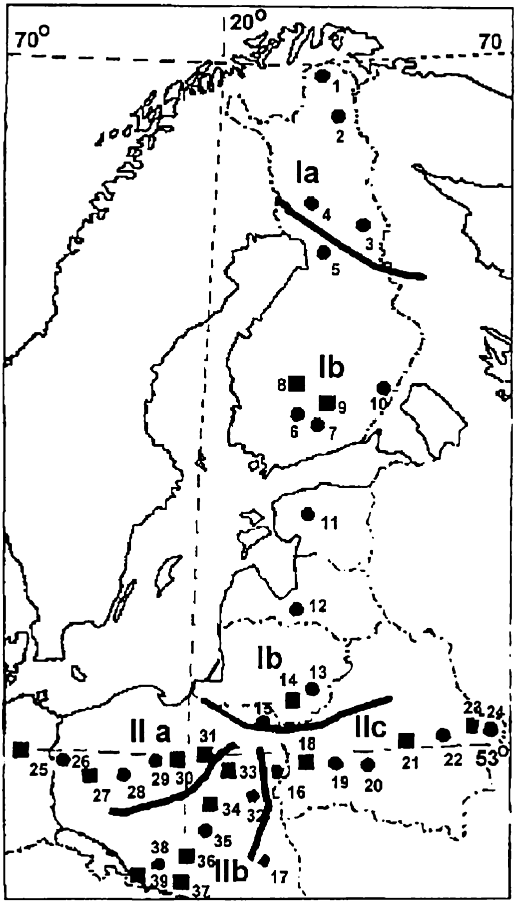


FIGURE 1. Geographical division of studied podzolic soils and location of research plots (square – rusty-podzolic soil, circle – podzolic soil): I. The Holocene and Late Vistulian-Holocene podzolic soils of pine and mixed/pine forests: Ia. Meso/neo Holocene soils in areas which the soil substrata are meso-Holocene or youngest eo-Holocene sediments, occurring today in conditions of a highly humid climate, Ib. Late Vistulian-Holocene podzolic soils, developed from eo-Holocene and Late Vistulian sediments, II. Pleistocene-Holocene podzolic soils of pine and mixed/pine forests of the vegetational formation of mesophilic deciduous and coniferous forests in the zone of warm-temperate climate: IIa. Plenivistulian-Holocene podzolic soils, developed from Plenivistulian sediments and occurring today in the conditions of a humid temperate climate, IIb. Neo-Pleistocene-Holocene podzolic soils, developed from sediments of the Warta stage of the Oder Glaciation, occurring today in conditions of a sufficiently humid climate, IIc. Meso- and neo-Pleistocene-Holocene podzolic soils of pine, developed from the sediments of the San II Glaciation and the pre-maximal and maximal stages of the Oder Glaciation, occurring today in conditions of a highly humid climate

quartz grain abrasion and non homogeneity, highest content of unresisting minerals and mean diameter of grain from the all studied soils. They are typically characterised by a significant accumulation of humus within the organic horizon and the increased biological activity in the upper part of the humus horizon in comparison with the organic horizon. The fractional composition of humus is dominated by the fulvic acids of Ist extraction (i.e., the ones associated with the mobile $R_2O_3$ forms), and the ratio of the fulvic to the humin acids is lower than 0.4. The ratio of total organic carbon to total nitrogen (C:N) is the highest among the soils analysed. Also, they are characterised by high exchange acidity. The ammonium form of nitrogen dominates, conducive to the development of pine ecosystems. The intensity of the processes of cryogenic weathering, both physical and chemical, accelerates the decomposition of aluminosilicates. These soils contain significant amounts of free iron ($Fe_d$) and of the amorphous forms of iron ($Fe_o$) as well as aluminium ($Al_o$), and contain the highest contents of the silicate forms of iron ($Fe_{gk}$). The process of podzolisation has a very intensive course, as confirmed by the very high values of the indicators of illuviation (determined according to the criteria of Mokma, [1983]), the contents of the ferrous-aluminium-humus complexes within the enrichment horizon ($C_p + Al_p + Fe_p$), the movement of the amorphous iron and aluminium ($Al_o + 1/2Fe_o$ within the layer B related to $Al_o + 1/2Fe_o$ within the layer E), and the movement of free iron ($Fe_d$ within the layer B related to $Fe_d$ within the layer E or AE) – Table 3.

TABLE 2. Some abiotic characteristics of the habitat obtained for the determined soil regions

| Zone | Sub-zone | Cs ka BP | AT °C | HI |
|---|---|---|---|---|
| I | a | 9.3 | 29.8 | 2.84 |
| | b | 14.0 | 25.0 | 1.84 |
| II | a | 20.0 | 20.0 | 1.30 |
| | b | 310.0 | 21.6 | 1.54 |
| | c | 400.0 | 25.2 | 1,70 |

CS – chronostratygraphy of the lithological material which is a substrate of studied soil AT – annual amplitude of mean value of monthly temperature, HI – values of Sielaninov higrothermal index determined for warmer half of the year (April – October)

- ♦ The Holocene podzolic soils of the pine and mixed forests, having developed from the sediments of the late Vistulian (Ostrobothnia, Finnish Lake District, Eastern Baltic Coastland), appearing nowadays in the conditions of the strongly humid climate, in the zone of the regional vegetation formation of the middle- and southern-boreal coniferous forests. In comparison with the soils of the northern boreal coniferous forests these ones are characterised by a bigger thickness and better physical properties. They also contain much more of the organic matter. The share of humic acids in the fractional composition of humus increases, although the ratio of the fulvic acids to the humic ones is still very low, ranging between 0.4 and 0.6. A warmer climate, when compared with that of Lapland, causes that the highest biological activity is displayed already by the organic horizon, in which the activity of the lactate dehydrogenase is higher than within the humus horizon. For the soil of this region the highest value of exchange acidity was determined (Table 3).

**Zone II**: Pleistocene-Holocene podzolic soils of pine and mixed/pine forests of the vegetational formation of mesophilic deciduous and coniferous forests in the zone of warm-temperate climate. Sub-zones:

- ♦ Late-Vistulian and Holocene podzolic soils of the pine and mixed forests, having developed from the Pleni-Vistulian sediments (the Western- and Southern-Baltic Lake Districts), occurring nowadays in conditions of the moderately humid climate in the lowland zone. Similarly as the soils of Lapland and of the Finnish Lake District, these soils are characterised by the highest contents of the amorphous forms of iron and aluminium, as well as a low share of the crystalline forms of Fe, which is an evidence of the young age of the soils considered. The slight degree of weathering of the soil material is confirmed also by the high share of the unresistant minerals in the mineral composition of the heavy fraction as well as a high share of the silicate form of iron ($Fe_{gk}$). These soils are characterised, too, by a very low share of the humic acids in the fractional composition of humus (Table 3).
- ♦ The Vistulian-Holocene podzolic soils of the pine and mixed forests, with the multiphase development cycle, having developed from the sediments of the Warta stage of the Odra glaciation (the Central Polish Lowlands, the Central Little Polish

TABLE 3. Regional differentiation of some soil properties determined for the podzolic soils

| Soil properties | Zone I | | | | Zone II | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | a | | b | | a | | b | | c | |
| | AV | ±SD | AV | ±SD | AV | ±SD | AV | ±SD | AV | ±SD |
| Thickness of O horizon [cm] | 8.1 | 0.9 | 5.4 | 0.6 | 4.5 | 0.4 | 5.1 | 0.5 | 5.6 | 0.6 |
| Thickness of soil solum [cm] | 23.5 | 4.6 | 47.7 | 9.1 | 63.1 | 2.7 | 66.1 | 4.1 | 77.1 | 4.1 |
| $Z_{PPW}/Z_{KPW}$ | 0.40 | 0.04 | 0.42 | 0.09 | 0.52 | 0.11 | 0.60 | 0.13 | 0.68 | 0.14 |
| Wo | 874 | 39 | 1066 | 70 | 1075 | 15 | 1130 | 72 | 1216 | 22.9 |
| Nm | 2.7 | 0.2 | 3.6 | 0.4 | 3.9 | 0.2 | 4.4 | 0.7 | 6.2 | 0.8 |
| MN in heavy fraction [%] | 88.5 | 1.2 | 76.0 | 11.3 | 54.5 | 5.8 | 32.2 | 8.1 | 10.4 | 2.4 |
| GSS [mm] | 0.69 | 0.19 | 0.45 | 0.20 | 0.32 | 0.13 | 0.38 | 0.08 | 0.30 | 0.04 |
| C:N in AEes | 38 | 4 | 25 | 6 | 28 | 10 | 27 | 3 | 20 | 7 |
| Ch:Cf in O/AEes | 0.35 | 0.02 | 0.45 | 0.06 | 0.46 | 0.17 | 0.56 | 0.04 | 0.68 | 0.04 |
| MC to the 1 m deep $[kg \cdot m^{-2}]$ | 20.0 | 1.5 | 17.4 | 3.3 | 13.9 | 4.6 | 14.7 | 2.3 | 16.3 | 3.3 |
| $H(H^+, Al^{3+})$ in AEes $[(cmol(+) \cdot kg^{-1}]$ | 4.05 | 0.22 | 5.72 | 1.60 | 3.29 | 0.83 | 3.70 | 1.22 | 2.74 | 0.42 |
| $H(H^+, Al^{3+})$ in Bh $[(cmol(+) \cdot kg^{-1}]$ | 3.32 | 0.17 | 4.42 | 1.71 | 3.45 | 1.67 | 2.21 | 0.89 | 0.94 | 0.59 |
| $Al_o$ in Bh $[g \cdot kg^{-1}]$ | 6.70 | 2.72 | 4.45 | 0.69 | 3.81 | 0.00 | 2.85 | 0.13 | 6.78 | 0.12 |
| $Fe_d$ in Bh $[g \cdot kg^{-}1]$ | 6.59 | 0.50 | 3.87 | 0.01 | 2.98 | 0.00 | 2.68 | 0.11 | 6.77 | 0.62 |
| $Fe_o/Fe_d$ in Bh | 0.70 | 0.08 | 0.49 | 0.09 | 0.70 | 0.00 | 0.63 | 0.08 | 0.36 | 0.04 |
| $C_p/(Al_p+Fe_p)$ in Bh | 16.4 | 4.3 | 9.1 | 1.5 | 8.2 | 0.0 | 6.6 | 0.7 | 7.3 | 0.1 |
| $Al_o+1/2Fe_o$ in Bh [%] | 0.83 | 0.32 | 0.53 | 0.09 | 0.49 | 0.00 | 0.38 | 0.07 | 0.59 | 0.24 |
| $C_p+Al_p+Fe_p$ in Bh [%] | 1.92 | 0.38 | 1.49 | 0.30 | 1.22 | 0.00 | 1.06 | 0.12 | 2.62 | 0.24 |
| $(C_p+Al_p+Fe_p)$Bh $-(C_p+Al_p+Fe_p)$AEes | 1.41 | 0.38 | 1.06 | 0.31 | 0.57 | 0.00 | 0.53 | 0.12 | 2.29 | 0.12 |
| $(Al_o+1/2Fe_o)$Bh/$(Al_o+1/2Fe_o)$Ees [%] | 16.9 | 3.3 | 5.6 | 0.4 | 4.0 | 0.0 | 4.5 | 1.2 | 9.3 | 0.6 |
| $Fe_d$ in Bh / $Fe_d$ in Ees | 22.2 | 5.4 | 5.6 | 0.6 | 2.7 | 0.0 | 4.2 | 0.2 | 12.4 | 6.2 |

AV – average values, SD – standard deviation, Wo – quartz grain abrasion index, Nm – non homogenous index, MN – unresistant minerals, MC – carbon stock, GSS – average grain diameter

Plateau, the Silesian-Cracovian Plateau), occurring nowadays in conditions of the sufficiently humid climate. The geographical transitory character of the area, on which the soils in question developed, influenced also their properties, whose values are intermediate between the ones characteristic for the areas with the oldest and the youngest soil covers (Table 3).

- The Pleistocene-Holocene podzolic soils of the pine and mixed forests of the multi-phase development cycle, having taken shape out of the sediments of the pre-maximum and maximum stages of the Odra glaciation (the Eastern-Baltic Lake District, the Podlasie-Belarus' Upland, the Berezina-Desna Lowland), appearing contemporarily in the conditions of a strongly humid climate, in the lowland zone of the regional form of the vegetation formation of the hemi-boreal and nemoral pine forests. In view of the longest period of influence exerted by the exogenous factors on the soil substratum, these soils are characterised by the best physical properties among all the soil units considered (Table 3). The highest fractions of dust and loam have been observed in the granulometric composition. These soils are also characterised by the highest content of the organic matter, which, together with the grain composition, results in the most advantageous porosity of these soils. In the eastern part of the sub-zone, similarly as in northern Scandinavia, higher biological activity is displayed by the upper part of the humus horizon, in comparison with the horizon O. Very much like in the soils of the other geographical units, the fractional composition of humus is dominated by the fulvic acids of the first extraction, but the ratio of the fulvic to humin acids is the highest and amounts in the podzolic soils to 0.6–0.7, while in the podzolic-rusty soils – to 0.9–1.0. The ratio of total organic carbon to total nitrogen (C:N) is the smallest in the zone considered, which is confirmed by the highest biological activity of these soils, as expressed by the activity of the lactate dehydrogenase. It amounts for the humus horizons of the podzolic and podzolic-rusty soils to 20, for the Bh enrichment sub-horizon – to 16, and for the BfeBv enrichment horizon – to 11, while the averages for all the podzolic soils are equal, respectively, for A – 27, for Bh – 28. These soils distinguish themselves also by the higher share of bivalent cations in the sorption complex, as well as by the degree of saturation of the sorption complex with the cations of base character. The increased share of the bivalent cations in these soils is largely due to the increase of the secondary loamy materials in comparison with the younger soils, having appeared in the other regional sub-zones. The long-term influence of the destruction factors on the soil substratum and the course of the pedogenic processes is not only seen through the texture properties of the sediments (like, in particular, the very small share of the little resistant minerals in the heavy fraction of the lithological material), but also through the physico-chemical properties of soils. This is best reflected by the chemical diagnostic indicators. The soils of this regional sub-zone are characterised by the highest value of the $Fe_d/Fe_t$ indicator, which confirms their strongest weathering (the highest share of the iron silicates turned into oxides), and by the lowest ratio of $Fe_o$ to $Fe_d$, being the evidence of the "old age" of the precipitated iron oxides and their crystallisation [Bednarek, Pokojska, 1996], despite the fact that the climatic conditions existing in the subzone considered are not conducive to such processes. The very long and intensive process of podzolisation, having taken place in these soil units, is confirmed by the highest value of the illuvation indicator ($\Sigma_B C_p Al_p Fe_p - \Sigma_A C_p Al_p Fe_p$), as well as by the indicator of content of the amorphous iron and aluminium ($Al_o + 1/2 Fe_o$ within the layer B related to $Al_o + 1/2Fe_o$ within the layer E or AE) – Table 3.

The here proposed division of the sites might constitute a complement to the existing geographic regionalisations of soils [Głazowska 1981; Buol et al. 1989; Bednarek, Prusinkiewicz 1997]. In comparison with those divisions, the here presented proposal for the geographic division of the podzolic soils merged into one the sub-zones of the middle and southern taiga. The differentiation of the soil properties analysed between these two sub-zones was not statistically significant. One of the main causes that could have an impact on the result obtained may have been associated with the fact that the spatial analysis of the soil cover was narrowed down to just forest soils. According to the Russian scholars the deforested areas of the southern taiga are very specifically characterised by the grassland-podzolic soils, whose physical and chemical properties are an essential taxonomic factor in the division of the podzolic soils of the non-permafrost zone of the taiga [Głazowska 1981; Bednarek, Prusinkiewicz 1997]. In the light of the soil systematics, kept to in Poland, these soils are closer to the fallow soils.

The here presented spatial differentiation of the soils analysed proposes also to divide up the zone of the podzolic earth soils within the belt of the moderate warm climate into the regional sub-zones. The spatial breakdown of this area thus obtained, resulting from the differentiated properties of soils, displaying statistical significance, finds also a confirmation in the currently accepted concept of the spatial differentiation of the physiological-ecological vegetation formations of Europe [Bohn et al. 1996], as well as in the variability of the morpho-lithological properties of the substratum, from which given soils developed.

## CONCLUSIONS

On the basis of presented study it is possible to conclude that the spatial variability to pedogenic factors and the properties of the pedons studied allowed for a determination of the geographical differences in podzolic soils within two zones and five regional sub-zones:

1. The Holocene and Late Vistulian-Holocene podzolic soils of pine and mixed/pine forests of the vegetation formation of mesophilic and hygromesophilic coniferous forests of the cool-temperate climate:

   – highly humid climate, in areas characterised today by a very active pedogenic environment in which the soil substratum are meso-Holocene or youngest eo-Holocene sediments,

   – Late Vistulian-Holocene podzolic and rusty-podzolic soils of pine and mixed/pine forests, developed from eo-Holocene and Late Vistulian sediments, occurring today in conditions of a highly humid climate.

2. Pleistocene-Holocene podzolic soils of pine and mixed/pine forests of the vegetational formation of mesophilic deciduous and coniferous forests in the zone of warm-temperate climate:

– Plenivistulian-Holocene podzolic and rusty-podzolic soils of pine and mixed/ pine forests, developed from Plenivistulian sediments and occurring today in the conditions of a humid temperate climate,

– Neo-Pleistocene-Holocene podzolic soils, developed from sediments of the Warta stage of the Oder Glaciation, occurring today in conditions of a sufficiently humid climate,

– Meso- and neo-Pleistocene-Holocene podzolicsoils of pine and mixed/pine forests, developed from the sediments of the San II Glaciation and the pre-maximal and maximal stages of the Oder Glaciation, occurring today in conditions of a highly humid climate.

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