Spatial and Vertical Distribution of Soil Physico-Chemical Properties and the Content of Heavy Metals in the Pedosphere in Poland[1]

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Abstract

The lithological and petrographical characteristics of soil pedogenesis was determined, and the spatial and vertical distribution of some soil physico-chemical properties (including heavy metal content) were studied along two transects in Poland. The genetic horizon for 22 soil profiles were described for particle size and petrographic composition, quartz grain abrasion, transformation of organic substance, carbon and nitrogen characteristics, base saturation, exchangeable cations, and acidity. The results showed that the morphogenesis of parent rock in all studied profiles is characterized by the glaciofluvial sedimentation of fine sands. All research plots were situated on valley terraces or outwash planes connected with glaciofluvial accumulation of redeposited, polygenetic sand formation. Soils belonged to three subtypes of Spodosols (podsolic class). All soil profiles were characterized by a very acid reaction (pH 3.0-4.5 in horizon A), and the degree of acidity corresponded to soil type. All other defined physico-chemical properties indicated that soils had low nutrient status. Mineral-humus layers of most of the soils were characterized by a high carbon:nitrogen ratio (from 10.6 to 53.7). This suggests limited biological activity of the soils and slow humification and mineralization rates. Overlying humus has three distinct subtypes (mor, moder/mor, mor/moder). In all soils the ratio of humic acids to fulvic acids was less than one, with the highest content of fulvic forms in humus compounds. Total exchangeable cations averaged 2.5 meq per 100 g of soil from the mineral-humus horizon and 0.5 meq per 100 g of soil in the parent rock. The degree that the sorption complex was saturated with base cations was also very low (less than 10 percent). Heavy metal spatial distribution in studied soils was not distinguished by region, but by local pollution sources or by natural concentration in the soil.

Introduction

Pine forest ecosystems with associated podzolic soils are very common in central and eastern Europe. For example, in Poland the potential natural plant association of coniferous communities (*Vaccinio-Piceetea*) occupies about 25.3 percent of the total area of the country (Matuszkiewicz 1991). Similarly, the same area of Poland is characterized by podzolic soils (Spodosols). The highest concentration of podzolic soils (39.7 percent) is in the central Polish lowland (Prusinkiewicz and others 1980). All the study plots of both the climatic and Silesian transects in Poland (Breymeyer, this volume) are located on podzolic soils. Research was done in 22 soil profiles (Breymeyer and others 1995, Breymeyer 1996).

This study determined the geographical differentiation of lithological and petrographical conditions of the pedogenesis of soils and analyzed the spatial and vertical distribution of some soil physico-chemical properties, including the content of heavy metals.

Methods

Base soil profiles and diagnostic excavations were done at study areas selected in accordance with the concept of the research. The basis for pedological research was the diagnosis of the different genetic horizons of 22 soil profiles on two research transects. For each profile, soil material was collected for analysis from different genetic horizons. A series of determinations were carried out concerning the morpholithogenic properties of the soil substratum (Degorski 1994a, b; Degorski [In press a]), the overlying humus and the organic matter in the mineral-humus layers (Degorski and Jefriemow [In press]), the physico-chemical properties of soils

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(Degorski 1995a, b; Degorski [In press b]), and the heavy metal content of the soils (Gworek and Degorski [In press]) by using standard soil science methods. Differences and similarities between the morpholithological features of the study sites were analyzed, as well as the physico-chemical features causing the breakdown of heavy metals and trace elements. Euclidean distance and Ward's method (Batko and Moraczewski, 1987) were used. Trace elements and heavy metals (Zn, Mn, Fe, Pb, Ni, Cr, and Cu) were determined using extraction with 20 percent HCl, after the combustion of organic matter at a temperature of 480 °C. Concentrations of these elements were determined by atomic adsorption spectrophotometry (AAS). An accumulation index was calculated from the data for all mineral-humus (A), eluvial (E) and illuvial (I) horizons. The accumulation index was calculated as the ratio of the content of a given element in the genetic horizon and in the parent rock, giving an indication of exogenic origin in the surface layers of the soil (Gworek 1985).

Results

Physico-Chemical Characteristics of the Soils

All of the soils studied were developed in redeposited, polygenic sandy formations that accumulated in the Pleistocene and Holocene. These differed only in the age of sedimentation, which is associated with the late Pleistocene (*fig. 1*).

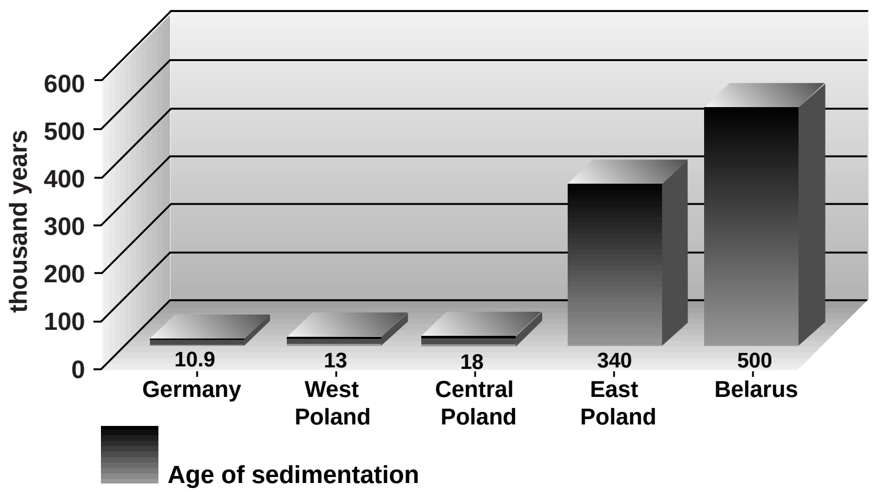


Figure 1 — Age of last sedimentation for soil substratum.

The studied habitats of pine forests and mixed pine forests developed on formations of river accumulation terraces or glaciofluvial forms (Degorski [In press a]). All of the studied soil samples were loose and poor-clay sands of moderate or varied grain size and with clear features of presorting, as well as limited contents of skeletal fractions (over 1 mm). The surface layers of soils located on terrace areas (e.g., K092, K098, KB001, and S126) were characterized by increased proportions in their mechanical composition of silty and dusty fractions. This was caused by an increase in deflational processes that took place in these areas in periglacial periods. The fluvial character of the sediments and their limited surface aeolization was confirmed by granulometric indices calculated on the basis of their mechanical composition (Degorski [In press a]). Cumulative curves characterizing the fluvial material and constructed on Phi probability plots (Program Analiza Uziarnienia 2.0 - Mechanical Composition 2.0) depart clearly from the log-normal distribution. This characterizes a leptokurtic breakdown (GSP 1.5-1.9) because curves for sands with features scattering over a considerable interval resemble straight lines and have a distribution close to the mesokurtic (GSP 1.3-1.4) (*fig. 2*). All of the studied soils are Spodosols. Morphological features and chemical criteria allow for their inclusion within three subtypes: podsols, rusty podsols, and podsolic rusty.

All of the profiles studied are characterized by very acid reactions. For the mineral-humus layers, pH values ranged from 3.0 to 4.5, with the degree of differentiation corresponding to the type of soil (*fig. 3*). In addition to acidic reactions, other analyzed physico-chemical properties of the soils also indicate low nutrient status. Total exchangeable cations (V) amounted on average to 0.5 meq per 100 g of soil in the mineral-humus layer. The degree of saturation of sorption complexes with base cations is very low in the mineral-humus horizons and around 20 percent in the parent rock (*fig. 4*). All of the soils studied on both transects are also characterized by very broad ratios of organic carbon (C) to total nitrogen (N). The C:N ratio in mineral-humus horizons amounts to values of about 10.6 to 53.7, indicating very limited biological activity of the soil and slow processes of humification and mineralization (*fig. 5*).

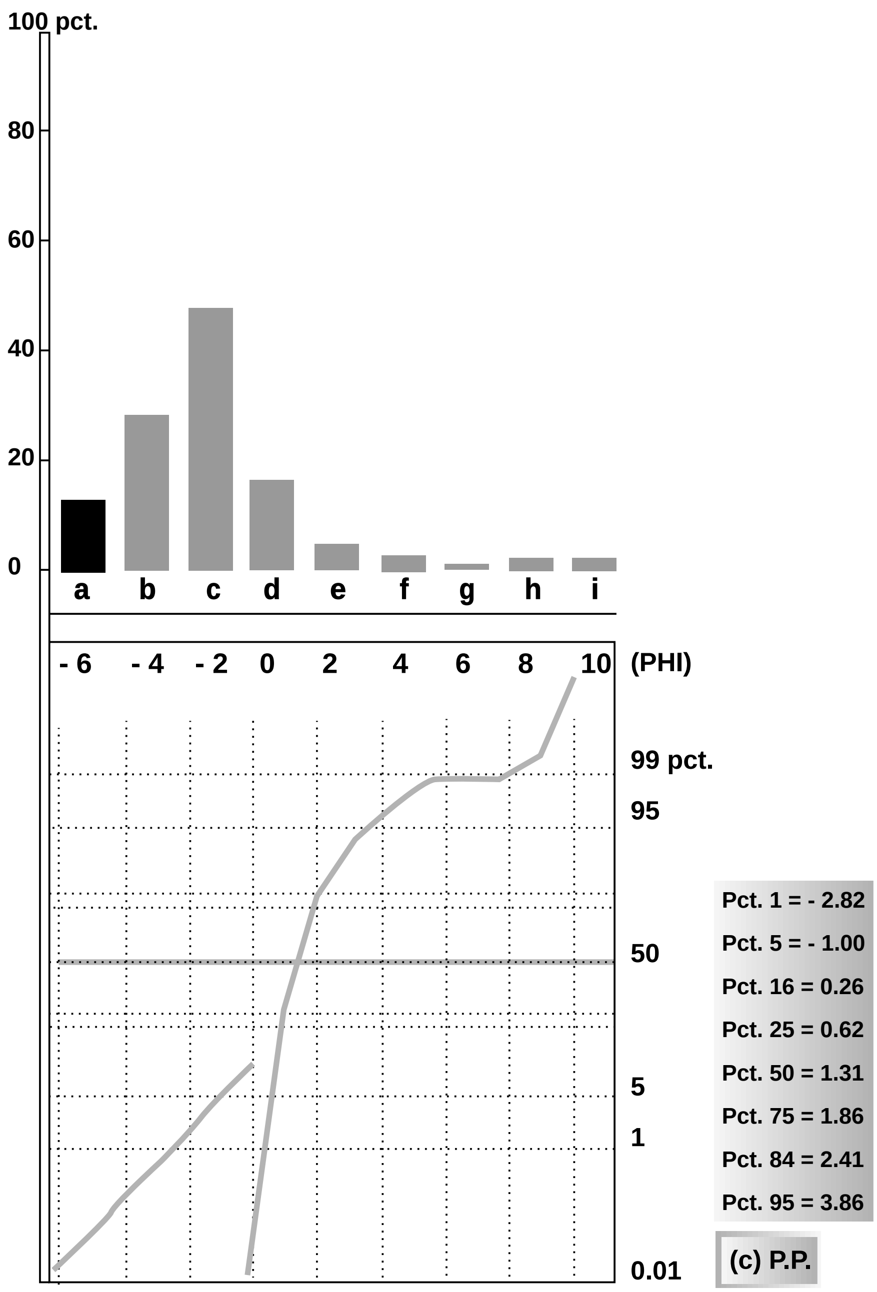
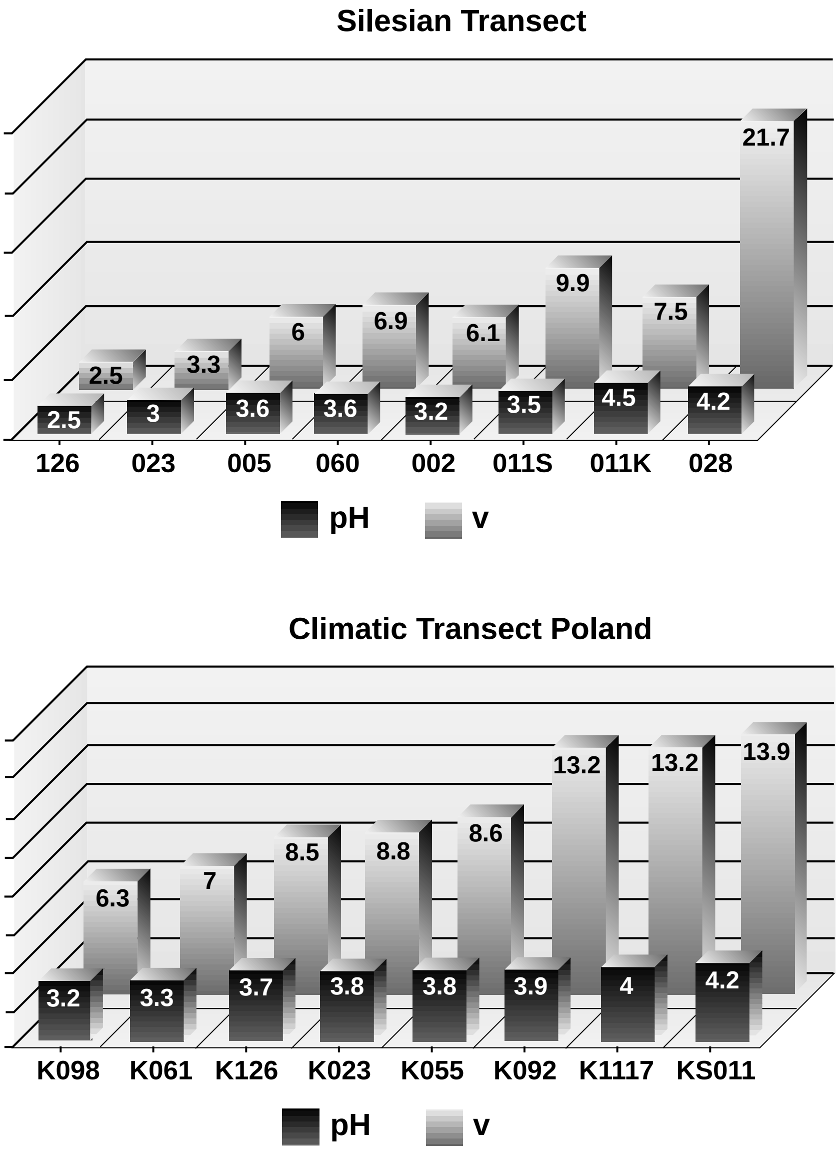


Figure 2 — Soil texture characteristics defined for research site KS011, horizon-B. a - i = particle size fractions:
a = stones and gravel (over 1 mm);
b = coarse sand (0.5 - 1 mm);
c = medium sand (0.25 - 0.5 mm);
d = fine sand (0.1 - 0.25 mm);
e = very fine sand (0.05 - 0.1 mm);
f = coarser silt (0.02 - 0.05 mm);
g = silt (0.005 - 0.02 mm);
h = fine silt (0.002 - 0.005 mm);
i = colloidal clay (below 0.002);
perc. = percentile.

Figure 3 — Relationship between pH and base saturation (V) on two transects.



Analysis of organic matter also pointed to the poverty of the studied soils and slow processes of humification. The ratio of humic to fulvic acids is less than 1 in all the studied soils, indicating humus of the first type in the Kononowa classification (1968), i.e., that with a low degree of condensation of aromatic ring compounds (Degorski 1994a, b; Degorski 1995a, b). On the basis of statistical analysis of the results for physico-chemical properties, properties of organic matter, humus type and properties of the substrate, the studied soils may be divided into three subgroups differing from one another in a statistically significant way (*figs. 6, 7*). These groups are linked with the genetic type of the soil (podsols, rusty podsols, or podsolic rusty), with the type of the overlying humus (mor, moder/mor, mor/moder), and with the mean characteristics of physico-chemical properties.

The first group includes podsol soils with mor-type humus and the lowest pH values (3.0-3.5). These are characterized by the lowest rates of mineralization and humification (the greatest thickness of overlying humus and the widest ratio for humic to fulvic acids). The second group are rusty podsol soils, with moder/mor type humus of lesser thickness and with better sorption properties. The third group are rusty with poorly-marked processes of leaching (a lack of a clear eluvial horizon). The overlying humus is of the mor/moder or moder types and has the least thickness and the highest rate of mineralization and humification of organic compounds (the narrowest C:N ratio). The low carbon content together with the high

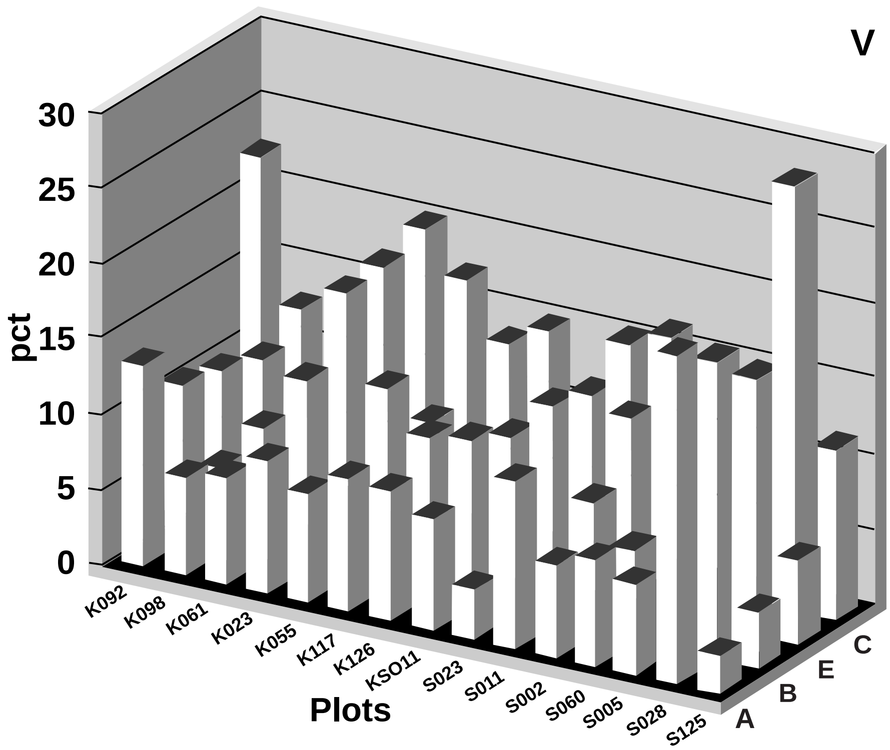


Figure 4 — Percent base saturation for whole soil horizons (A, E, B, C) and research plots.

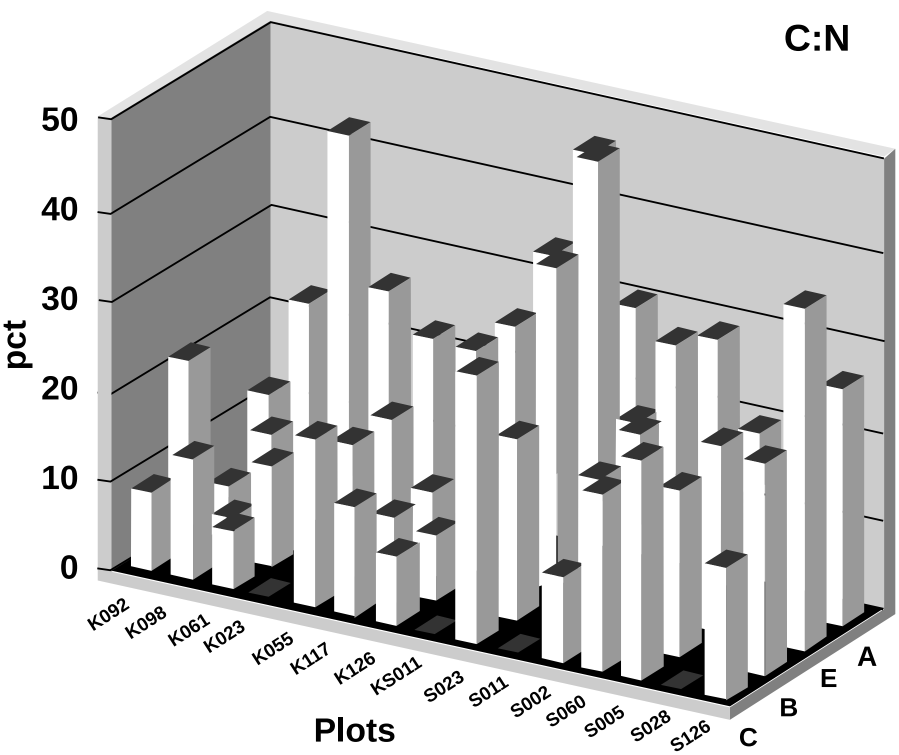


Figure 5 — C:N ratio in soils for each soil horizon.

degree of humification and the greater content of humates and humic acids (the narrowest Ch:Cf ratio) all indicate soils with significantly more advanced evolution of organic matter. The sorption properties of this group of soils are also the best among those studied. The degree of saturation of the sorption complex with base cations increases from 10-20 percent in the mineral-humus layers to about 30 percent in the parent rock, while the reaction (pH) varies from about 4 to 4.5 in the mineral-humus horizons (*fig. 7*).

The Breakdown of Heavy Metals and Trace Elements

There is no statistically-significant basis for claims regarding geographical-scale variation in contents of heavy metals and trace elements along the two transects. The only differences observed were in relation to regional distributions. The increase in the contamination of a soil with some element is most often caused by some local source of pollutant emissions. A good example of this situation is the spatial distribution of the lead content in soils along the two transects (*fig. 8*). The highest level of lead was recorded at point S028 at Klucze near Olkusz. This is traditionally

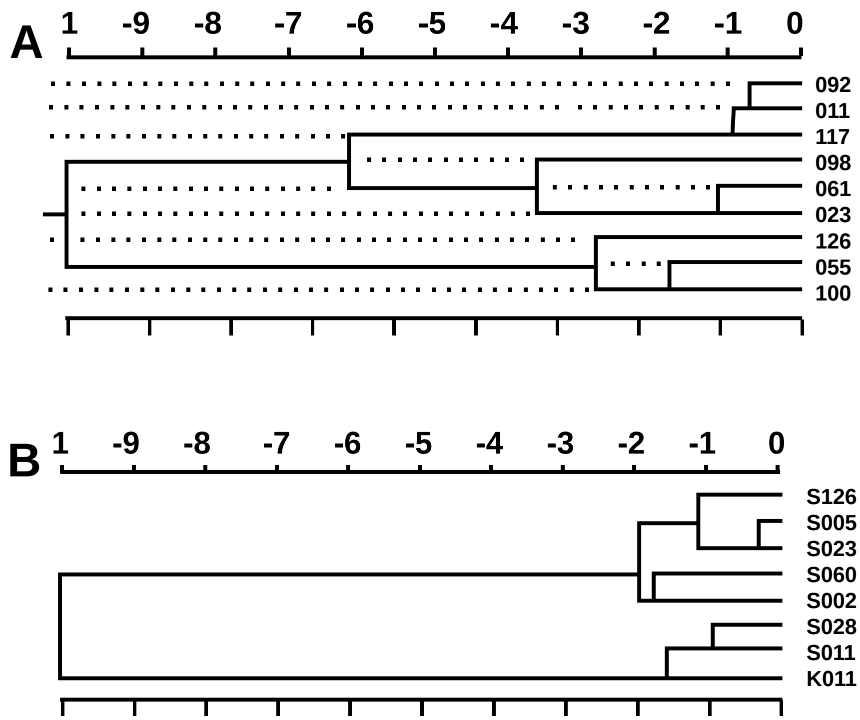


Figure 6 — Similarity of the soil properties of two transects (Euclidean distance/Ward's Method) (Batko and Moraczewski 1990). a = climatic transect, b = Silesian transect.

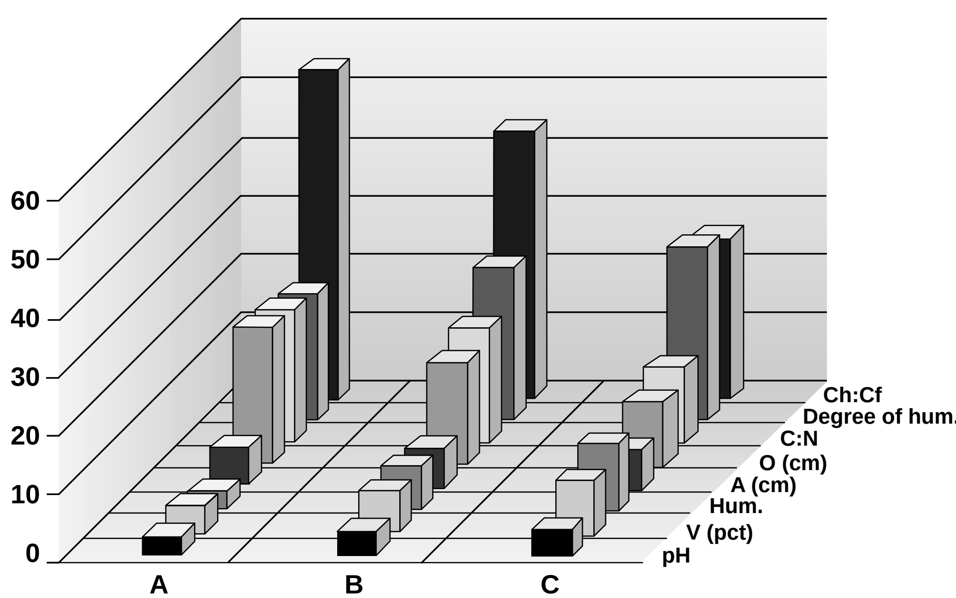


Figure 7 — Selected physical and chemical properties of the mineral-humic horizon defined for selected soil groups, pH = acidity determined in H_2O; V = saturation degree of the sorption complex with cations of basic character in percent; Hum = contents of humines; A = thickness of the A horizon in cm; O = thickness of the O horizon in cm; SH = humification degree in percent; Ch:Cf = the ratio of humine to fulvic acids x 100 percent. A = podzolic soil, B = rusty-podzolic soil, C = rusty soil

and remains a region in which zinc and lead ores are extracted and processed. The contents of lead in the remaining points analyzed were linked to both the location of industries and transportation routes.

The indices of accumulation defined for all of the studied soils confirmed ideas concerning the spatial distribution of the contents of heavy metals and trace elements in the profiles. The greatest concentration occurs in the levels of overlying humus (O) and of the accumulation-humus horizon (A). The highest values for the index were attained for lead (to about 15 times the content of this element in the parent rock) and manganese (to about 8 times the content) (*fig. 9*). The distribution of concentrations of heavy metals in the upper layers of the soil differed from those of the chemical background in the parent rock, indicating specific geographical relationships. The content of zinc is clearly higher in Upper Silesia in connection with the concentration of industry in this region. In contrast, the contents of nickel, iron, and chromium were clearly greater in the mineral-humus horizons of western Poland. The higher content of these three elements in the soils of the western part of the country may point to the transfer of pollution from western Europe, which evidently has an impact on the heavy metal contamination of the soils in this part of Poland. Such a finding is in accordance with the dominant wind direction in Poland (westerly and north-westerly).

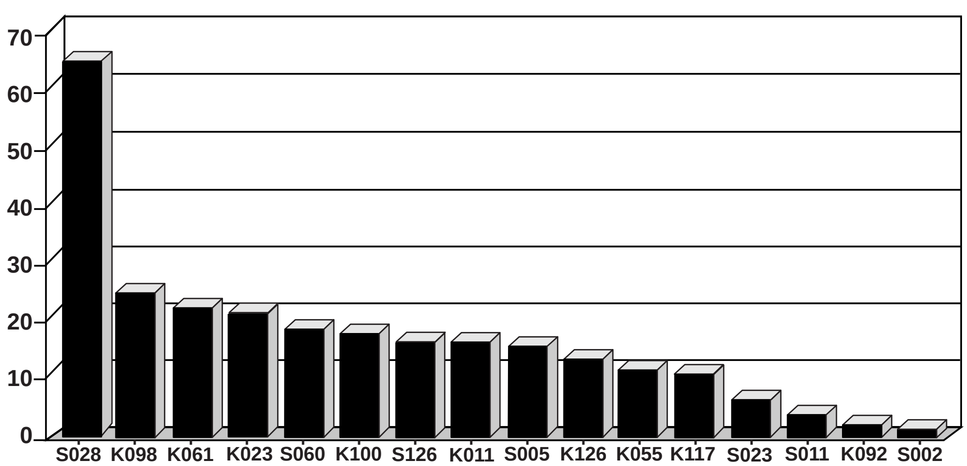
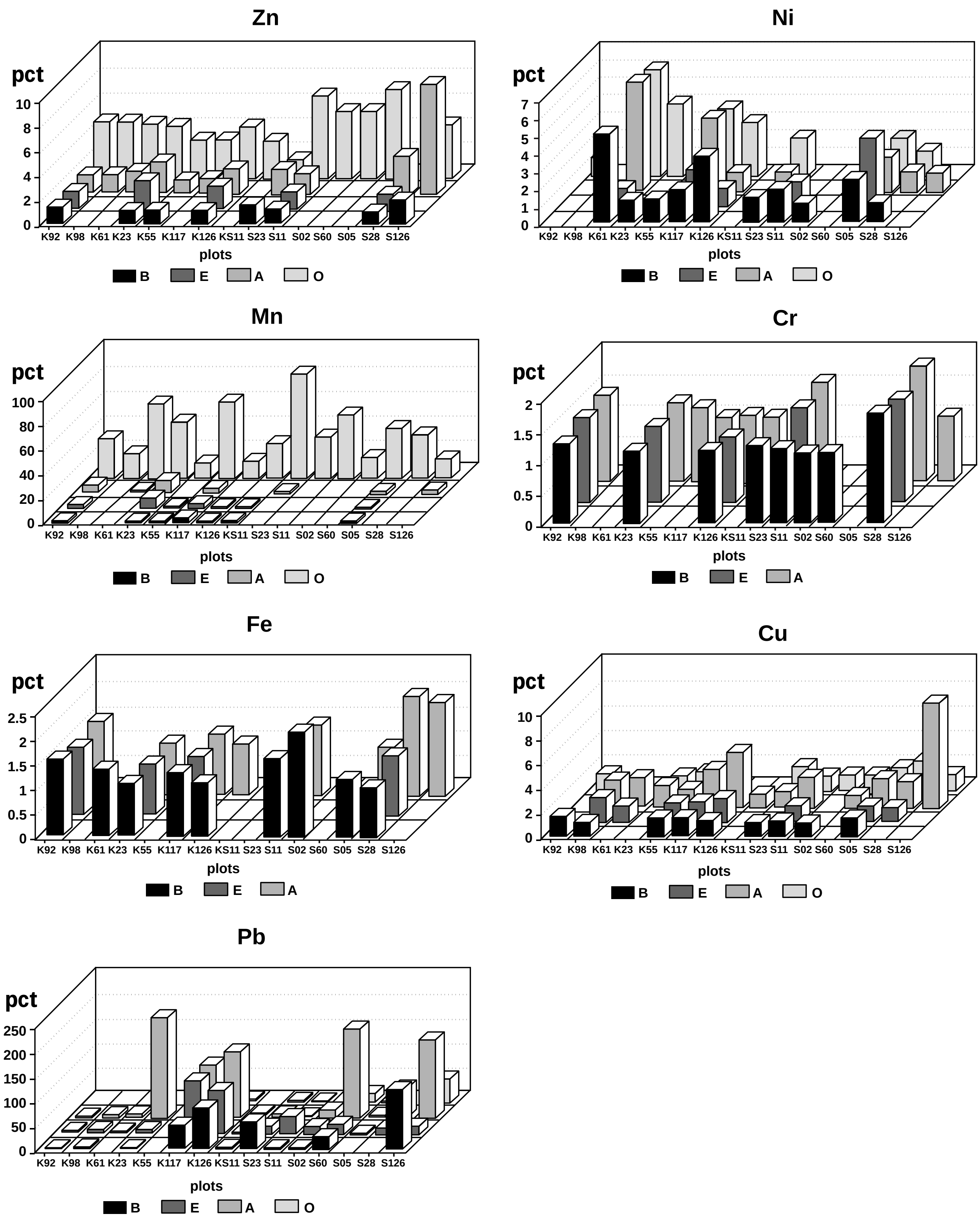


Figure 8 — Spatial variability of lead distribution on two research transects. Bars are showing Pb mg/1000 g of soil.

Conclusion

All of the research sites were linked morphogenetically with the accumulation of redeposited, polygenetic sand formations that occurred in the Pleistocene. Soils on both transects belong to three subtypes of Spodosols: podsolic, rusty podsolic, and rusty. All of the studied profiles were characterized by high acidity (pH of 2.5 to 4.5) and a degree of variation in this feature that corresponds to soil type. All other defined physico-chemical properties were also indicative of the fact that soils were of low nutrient status. Many of the soils were characterized by mineral-humus layers with a high C:N ratio (ranging from 10.6 to 53.7). This attests to the low nutrient cycling rates of the soils and the slowness of the processes of humification and mineralization. The lowest values of humic acids and humines were determined in podsolic soil, suggesting that mineralization rates are lowest in these soils.

Figure 9 — Accumulation index of heavy metals and trace elements.



Acknowledgments

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