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DEGRADATION PROCESSES IN DIFFERENTLY USED LOESS SOILS OF SOUTHERN POLAND

PROCESY DEGRADACJI W RÓŻNIE UŻYTKOWANYCH GLEBACH LESSOWYCH POŁUDNIOWEJ POLSKI

Abstract: The processes of soil degradation present a serious threat to ecosystem sustainability. The objectives of the work were: to estimate differences in microstructures of loess soils of agro-, meadow and deciduous forest ecosystems, and to evaluate the extent to which image analysis could be applied to measure changes in this property. The arable soil was characterized by a lower value of macroporosity and the image area occupied by organic matter aggregates while meadow soil with a high amount of organic matter and neutral soil reaction presented the highest share of large excrements attributed to earthworms. Results of this work confirm opinions that deep tillage compaction can reduce the biomass and diversity of most soil organisms while hay crops improves soil fertility and helps maintaining biodiversity. The image analysis protocols developed to quantify the soil features mostly affected by the way of soil use, resulted effectively in bringing out differences between those properties in analyzed soils.

Keywords: arable, meadow, forest, loess soils, aggregation, porosity, micromophometric analyses

The processes of soil degradation present a serious threat to biomass, crop yields and ecosystem sustainability. Therefore, they must be controlled and the main aim of land management should be the reduction of the environmental impact of agricultural practices [1–3]. A way to evaluate the impact of management practices on the soil environment is to quantify the accumulation and decomposition of organic matter, soil fauna activity, aggregation and porosity. Soil aggregation has a great influence on its physical characteristics. Well aggregated soils possess a larger pore space and a higher infiltration rate leading to enhanced microbial activity in comparison with poorly aggregated one. Aggregates are also thought to play an important role in the protection of soil organic matter. The preservation of soil organic matter is desirable for land use as it is a key component in nutrient cycling. Furthermore, the retention of organic C in

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soil is becoming more important since the rise in atmospheric CO_2 and global climate warming have become recent concerns [4, 5]. A decisive role in the formation and stability of macro- and microaggregates play the activity of earthworms and other soil fauna representatives by removing plant litter and other organic materials from the soil surface and their incorporation into soil aggregates. Much of the environmental damage in arable lands such as erosion or susceptibility to compaction originate from soil structure degradation, which can be quantified by measurements of pore space, size, shape and continuity [6, 7].

Soils derived from loess have generally high natural fertility and productivity. Fertility of loess soils depends upon their large available water capacities, good aeration, ease of cultivation and moderately large reserves of most mineral nutrients. Properties of loess soils contrast clearly with typical poor, acid sandy soils that cover the major part of Polish territory. Therefore, loess soils have been submitted to the excessive long-lasting agricultural practices, which together with often inappropriate agro-technological treatment have resulted in their degradation [8, 9].

The objectives of the work were: (i) to estimate differences in microstructures, porosity and faunal activity of loess soils of agro-, meadow and deciduous forest ecosystems, and (ii) to evaluate on thin sections the extent to which image analysis could be applied to measure changes in void space, structure and excrement features related to degradation processes.

Materials and methods

Studies were carried out on the southern part of Proszowice Plateau which belongs to Malopolska Upland (50^o 06′ N and 20^o 20′ E) in southern Poland. The area is situated at the altitude of 300 m a.s.l. and formed from Miocene deposits covered with loess originating from the Baltic glaciations. Mean annual temperature ranges from 7.5 to 8 ^{o}C and the growing season lasts 210–220 days [8].

Soil samples were collected in September 2007 from three areas representing arable, meadow and forest soils, classified according to WRB classification, as chernozems. All studied soils had texture of silt with the content of sand, silt and clay ranged between 9–11 %, 73–76 % and 13–15 %, respectively. On arable soils wheat was cultivated, meadow soil was covered with grassland community belonging to *Arrhenatheretalia* association, and the forest soil was overgrown with deciduous forest from *Querco-Fagetalia* association.

Soil samples were taken from every type of land use from three outcrops. They were sampled from 2 horizons: surface (0–25 cm) and subsurface (25–40 cm) to perform chemical analyses. From every site and every studied soil horizon undisturbed soil samples for micomorphometric analyses were also collected.

For chemical analyses soil samples were air dried and sieved through 2 mm mesh sieve. In samples prepared in this way pH in 0.01 mol · dm^{-3} $CaCl_2$ was measured potentiometrically, while organic carbon and total nitrogen with the use of automatic C and N analyzer: TOC-TN 1200 Thermo Euroglas apparatus.

Undisturbed soil samples (4 × 6 × 3 cm) were impregnated with Araldite resin under vacuum conditions, in Epovac apparatus and cut and grind to 40 μm thick slices. Observations of soil thin sections were conducted using Nicon Eclipse E400 POL polarizing microscope in light passing through parallel nicols, using magnifications of 20×. Three representative areas of each slide were subjected to micromorphometric analysis using Aphelion ADCIS S.A., Aai Inc programme. Every analyzed image was divided into areas occupied by pores, plant rests and organic aggregates by color thresholding. For identified features, data on percent area coverage and size parameters were extracted. The classification of excrements was based on descriptions found in Bullock et al [10].

All the analyses were performed in three replicates. The results were subjected to unifactor STATISTICA 8, ANOVA analysis and a posteriori Fisher's test was used to study a significance of differences between studied objects at significance level 0.05. Simple correlation coefficients (r) between selected soil properties were calculated. A significance of correlation coefficients was estimated with the use of t-Student test.

Results and discussion

The mean level of organic carbon in top horizons of arable soils was twofold lower than in respective horizons of meadow soils and 4.5-fold lower than in top horizons of forest soils (Table 1). According to Bronick and Lal [3], differences in organic carbon contents between cultivated soils and analogical soils of natural ecosystems can amount to 25–75 %. They result from the decrease of biomass returning to soil and the increase of mineralization rate related with changes of soil moisture. Additionally cultivated soils are much more susceptible to erosion and nutrients leaching than soils of natural ecosystems. Studied arable soils were characterized by a low C:N ratios (Table 1) which indicate more intensive humus mineralization in these soils than in meadow and forest ones. As a result of these processes a large amounts of organic carbon in form of CO_2 volatilize out of soil simultaneously decreasing carbon sequestration in the soil [3]. In all studied profiles pH values were higher in subsurface horizons than in surface ones (Table 1). It resulted from leaching of carbonates with rainfall water and enhanced additionally in arable soils by acidifying effect of chemical fertilizers and in forest soils by forest vegetation.

Table 1

Selected physico-chemical properties of upper horizons of studied soils

Soil use	Horizon	Depth of soil horizons [cm]	pH 0.01 mol · dm^{-3} $CaCl_2$	$C_{org.}$	$N_{tot.}$	C:N
				[g · kg^{-1}]		
Arable	A1	0–25	5.8	32.1	3.4	9.5
	A2	25–40	6.1	21.6	2.4	8.9
Meadow	M1	0–25	6.1	46.7	3.9	12.1
	M2	25–40	6.4	24.2	2.3	10.3
Forest	F1	0–25	5.6	65.7	4.2	15.7
	F2	25–40	5.9	9.5	0.8	11.9

As expected the lowest amounts of plant rests were found in both horizons of arable soils and the highest in the top horizon of forest soil (Fig. 1). The last fact is related with the type of forest vegetation rich in lignin and cellulose, characterized by the low rate of decomposition, which is considered a key factor in carbon turnover rates, enhancing aggregation. The amount of plant fragments reflects C:N ratio as both values express the intensity of mineralization processes going through in soils. Therefore, the higher value of C:N is in the studied soil the larger area of image is occupied by plants rests, with a simple correlation coefficient between discussed parameters amounted to 0.954 significant at $p \leq 0.001$. This high correlation between these amounts proves the usefulness of micromophometric methods for the good explanation of the discussed soil phenomena.

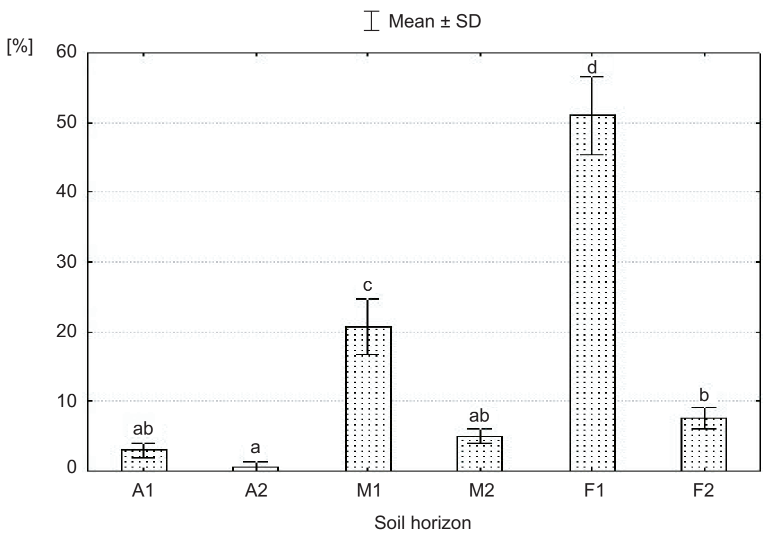

Fig. 1. Share of plants rests in the total image area in surface and subsurface horizons of studied soils (Indications of soil horizons are given in Table 1, the same letters above columns indicate a lack of statistically significant differences at the significance level ≤ 0.05)

Figure 2 shows the share of organic matter aggregates in the total image area of surface and subsurface horizons of studied arable, meadow and forest soils. It illustrates significant differences in this value between studied horizons. The largest image area occupied by organic matter aggregates was determined in the top horizon of meadow soil, a bit smaller in analogical horizon of forest soil and significantly smaller in horizons of arable soil. At the same time, it should be emphasized that the area occupied by aggregates was distinctly lower in subsurface horizon of arable soil than in top horizon of that soil. The fact indicates deterioration in the quality of soil structure, and in consequence reduction of soil functions. The organic particles area is associated with the content of organic carbon. Simple correlation coefficient (r) counted between soil aggregation area and the content of organic carbon amounted to 0.614 significant at $p \leq 0.001$.

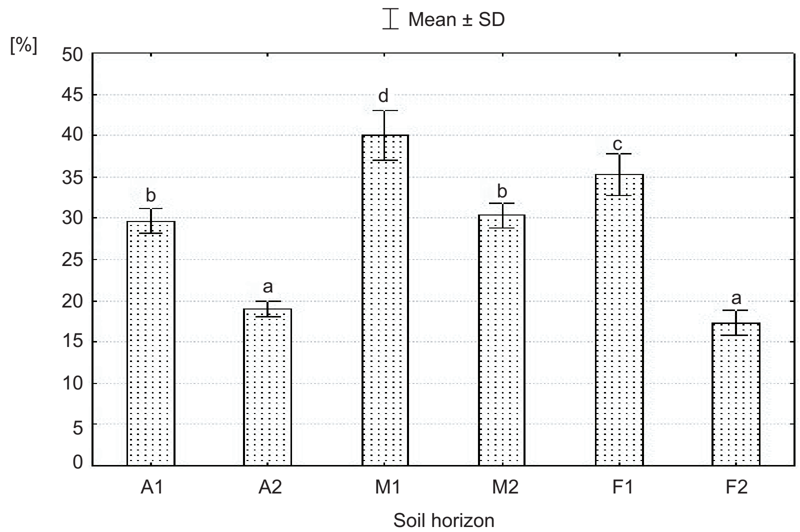

Fig. 2. Share of organic matter aggregates in the total image area in surface and subsurface horizons of studied soils (Explanations in Fig. 1)

The aggregates observed in thin sections were predominantly of faunal origin. According to thin section observations and considering size of aggregates related to their distinctive morphologies 3 classes of excrements were set: with the diameter less than 50 μm, between 50 and 300 μm and bigger than 300 μm. The smallest aggregates comprised three types: organic spheroids within root and plant fragments attributed to *Oribatid* mites, occurring mainly in top horizons of forest soils, irregular ellipsoids of amorphous organic material interpreted as derived from small *Collembola* species, occurring in all top horizons but prevailing in meadow soils and undifferentiated fused or aged excrements, found mostly in top horizons of arable soil. Among the medium large aggregates there were irregular spheroids of organic material attributed to *Enchytraeids*, found mostly in forest soils, *Collembola* excrements occurring in all studied soils and regular ellipsoids within plant fragments identified as *Diptera* larvae excrements, numerous in meadow soils. Aggregates of diameter larger than 300 μm were mainly of Earthworm's origin. They were in shape of mammilated organic or organic mineral excrement's or vermiform structure. They were present in all soils but with clear prevalence in meadow soil.

Figure 3 presents the percentage of aggregates of given size in the total aggregation. Results indicated that meadow soil with a high amount of organic matter and neutral soil reaction presented higher share of large excrements attributed to earthworms than forest or arable soils. Forest soils are generally attractive to earthworms only after some weathering and degradation of fresh deciduous litter by fungi and bacteria and in a small presence of earthworms numerous *Enchytraeids* aggregates were noticed there. Results of this work confirm also opinions of many authors [2–4, 11] that deep tillage compaction can reduce the biomass and diversity of most soil organisms while hay crops improves soil fertility and helps maintaining biodiversity. Intensification of

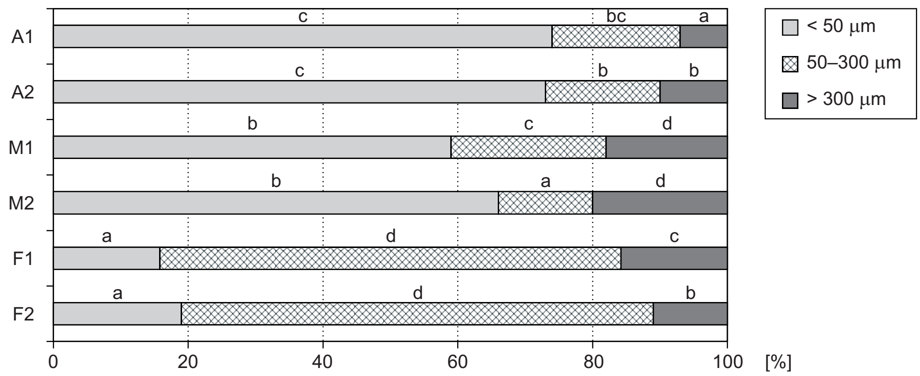

Fig. 3. Share of faunal aggregates with different diameters in the total aggregation in surface and subsurface horizons of studied soils (Explanations in Fig. 1)

cropping, annual tillage and other operations such as fertilization or pesticide use consistently affect populations of earthworms and other invertebrates. As a consequence they lead to modification of soil physical properties resulting in damage to soil structure.

The share of macropores (pores larger than 50 μm in diameter) in studied soil surface and subsurface horizons is presented in Fig. 4. Results show that according to the micromorphometric method [2], almost all studied soil horizons were moderately porous as they porosity ranges from 10 % to 25 %. Nevertheless statistically significant differences were calculated between their macroporosity. The highest value of macroporosity were determined in a top horizon of meadow soil and subsurface horizon of forest soil, while significantly lower values characterized the top horizon of arable soil.

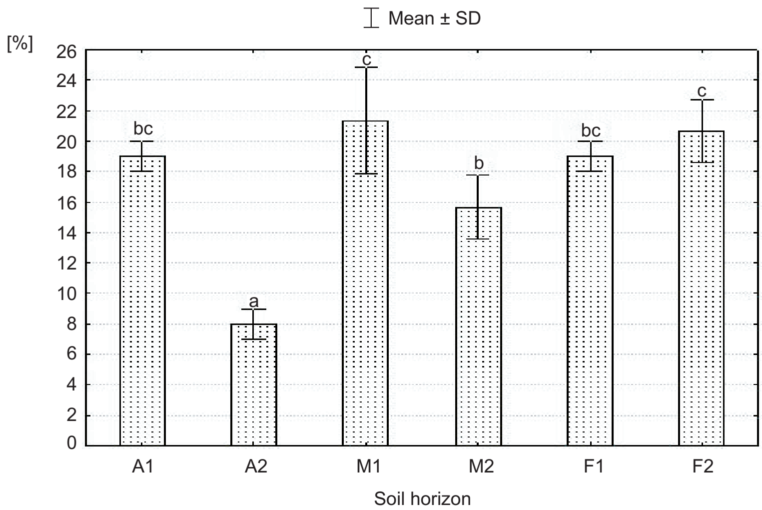

Fig. 4. Share of macroporosity in the total image area in surface and subsurface horizons of studied soils (Explanations in Fig. 1)

The lowest value of the total macroporosity (< 10 %), was found in the subsurface horizon of the arable soil which placed that soil layer among dense soils.

For a more detailed characterization of soil pores, pore size distribution was also counted with a special attention given to pores of diameter ranging from 50 to 500 μm (Fig. 5). This group of pores, according to Pagliai et al [2], is formed by transmission pores, which are important in soil–water–plant relationships and in maintaining good soil structure conditions. Therefore, damage to soil structure can be recognized by a decrease in the share of transmission pores. Figure 5 shows that shares of both transmission and large pores were significantly lower in studied horizons of arable soil than in horizons of meadow and forest soils. The highest shares of transmission pores were in both studied horizons of forest soil while the biggest part of large pores was determined in horizons of meadow soil. The results of this study validated that ploughing and other agricultural practices performed in arable soil induced decrease of porosity, in particular of the transmission and large pores. The negative aspects associated with this phenomenon could be the formation of ploughpan at the lower cultivation limit, which besides a reduction of water movement, may also hamper root growth.

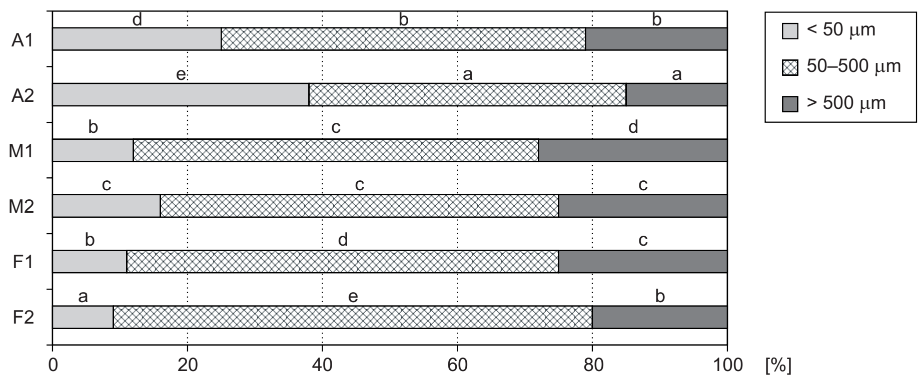

Fig. 5. Share of voids with different diameters in the total porosity in surface and subsurface horizons of studied soils (Explanations in Fig. 1)

Conclusions

1. Among forest, meadow and arable soils signs of degradation resulting from the use of soil and expressed by a decrease in soil organic matter content, porosity, aggregation and faunal activity were the most pronounced in the arable soil and the least in the meadow one.

2. Differences in soil properties between the three ways of soil use were not as distinct to be alarmed as the negative impact on soil structure exercised by agricultural practices was hampered by the beneficial effect of secondary carbonates which enhanced soil aggregation.

3. The image analysis protocols developed to quantify aggregation, void space and distribution, as the soil features mostly affected by the mode of soil use, resulted effective in bringing out differences between those properties in analyzed soils.

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PROCESY DEGRADACJI W GLEBACH LESSOWYCH W POŁUDNIOWEJ POLSCE

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Abstrakt: Procesy degradacji stanowią duże zagrożenie dla stabilności ekosystemów. Celami pracy było: ustalenie różnic w mikrostrukturze gleb lessowych ekosystemów uprawnych, łąkowych i lasów liściastych oraz określenie w jakim stopniu analiza obrazu może być stosowana do określania zmian tej właściwości. Gleba orna charakteryzowała się najniższą mikroporowatością i powierzchnią obrazu zajmowaną przez agregaty materii organicznej pochodzenia zwierzęcego, podczas gdy w glebie łąki, w której oznaczono dużą zawartość materii organicznej i obojętny odczyn, występował również największy udział dużych ekskrementów przypisywanych dżdżownicom. Rezultaty tej pracy potwierdzają opinie, że orka powodująca kompakcję gleby może redukować biomasę i różnorodność organizmów glebowych, podczas gdy użytkowanie łąkowe pomaga w utrzymaniu bioróżnorodności. Metody analizy obrazu stosowane do określania jakości właściwości gleb, modyfikowanych głównie poprzez sposób użytkowania okazały się skuteczne dla określenia różnic w tych właściwościach między analizowanymi glebami.

Słowa kluczowe: ekosystemy orne, łąkowe, lasów liściastych, gleby lessowe, agregatowość, porowatość, analizy mikromorfometryczne