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Comparison of earthworm populations in arable and grassland fields in the Outer Western Carpathians, South Poland

Agnieszka Józefowska[1], Anna Miechówka[1] & Jan Frouz[2]

[1] *Department of Soil Science and Soil Protection, Agriculture and Economy Faculty, University of Agriculture in Krakow, Al. Mickiewicza 21, 30-120 Krakow, Poland; e-mail: a.jozefowska@ur.krakow.pl*

[2] *Institute for Environmental Studies, Faculty of Science, Charles University in Prague, José Martího 407/2, CZ 6200 Prague 6, Czech Republic*

Abstract: The impact of different geographical regions (Silesian Foothills, region 1 and Mały Beskids, region 2), and method of soil use (arable field and grassland) on the main soil properties and biological activity was studied. Earthworm biomass, density and diversity, as well as dehydrogenase activity, were analysed. Significant soil physical and chemical properties were more affected by regions, whereas the type of land use had a greater impact on the biological properties. The mean earthworm density was 213 ind. m^{-2} and 241 ind. m^{-2} in grassland, and 50 ind. m^{-2} and 120 ind. m^{-2} in arable field, in region 1 and 2, respectively. Eight earthworm species were recorded, and fewer species were recorded in arable field (1–4) than in grassland (6–7). The Silesian Foothills are a new habitat for the occurrence of the species*Fitzingeria platyura depressa*. A high earthworm density was accompanied by high microbial activity, and dehydrogenase activity was lower in the soil of arable field than in grassland soil.

Key words: earthworms; arable and grassland fields; population characteristics; *Fitzingeria platyura depressa*

Introduction

Soil tillage affects soil biological diversity, mainly due to mechanical damage, reduction in crop diversity and the loss of an insulating layer of vegetation. This leads to a decreased food supply, especially of organic matter in arable fields (Edwards & Bohlen 1996; van Eekeren et al. 2008; Postma-Blaauw et al. 2012). The reduction in biological diversity might also reduce the availability of ecosystem services (de Vries et al. 2013). Indicators can demonstrate the state and trends of soil conditions; for example, earthworms, nematodes and microorganisms are common bioindicators (Brookes 1995; Paoletti 1999; Bongers & Ferris 1999). Another group of indicators, especially of soil pollution, are soil enzymes (Dick et al. 1996; Ciarkowska et al. 2014). These indicators should support environmental decision-making, which is linked to soil functions and ecosystem services (Pulleman et al. 2012). Mountain agricultural regions in South Poland consist of a characteristic mosaic of fields, where arable fields are interspersed with grasslands. The conversion of arable field to grassland is popular in marginal regions such as mountains (Gormsen et al. 2004), because crops are unprofitable and are treated more as an element of traditional farming, and not as a method of earning profit. The Common Agricultural Policy of the European Union favours the creation and/or maintenance of green areas (according to Rural Development Programmes 2014–2020), which is another reason why, nowadays, grassland is more common than arable field in mountain regions.

We have studied the differences between arable field and grassland in two regions of the Outer Western Carpathians, to explain the potential benefit of maintaining grassland for some soil types in mountain regions. Many publications exist concerning the transformation of arable field into grassland (e.g., Gormsen et al. 2004; van Eekeren et al. 2008; Postma-Blaauw et al. 2012). However, we do not focus on changes resulting from this transformation, but on a comparison of adjacent soils that are used differently. The study aimed to obtain information regarding whether soil that is used in two different ways (arable field and grassland) in two different regions, vary in their soil biological activity, as expressed by dehydrogenase activity and biomass, and in the density and diversity of earthworms. In addition, we assessed the relationships between biological activity and selected physical, chemical and physicochemical properties.

Material and methods

Site description

The study was carried out in two geographic regions of the Carpathians: the Silesian Foothills (region 1) and Mały Beskids (region 2). Soils from the first region (region 1) were formed from loess-like carbonateless material. The bedrock for the second group of soil was Carpathian flysch deposit (region 2). Soils of the Silesian Foothills were classified according to WRB (2014), as Gleyic or Haplic Retisols. The soils of Mały Beskids were classified as Haplic or Stagnic Cambisols. All sites were located in lower mountain regions at an altitude of 320–545 m a.s.l., on a moderately warm

Table 1. Location and the characteristics of the investigated sites.

Region	Site	Coordinates (the border between A and G)	Altitude (a.s.l.)	The way of use*	Soil type**
1 (Silesian Foothills)	1	49°50′17″ N	320	A	Gleyic Retisol (Eutric, Siltic)
		19°14′18″ E		G	Gleyic Retisol (Anthric, Epidystric, Siltic)
	2	49°50′41″ N	363	A	Gleyic Retisol (Eutric, Siltic)
		19°18′41″ E		G	Gleyic Retisol (Eutric, Siltic)
	3	49°51′20″ N	339	A	Haplic Retisol (Eutric, Siltic, Ruptic)
		19°23′36″ E		G	Haplic Retisol (Eutric, Siltic, Ruptic)
2 (Mały Beskids)	4	49°49′36″ N	389	A	Stagnic Cambisol (Eutric, Ruptic)
		19°29′53″ E		G	Stagnic Cambisol (Eutric, Ruptic)
	5	49°46′50″ N	446	A	Haplic Cambisol (Epidystric, Ruptic)
		19°29′56″ E		G	Haplic Cambisol(Eutric, Ruptic)
	6	49°43′56″ N	545	A	Stagnic Cambisol (Eutric, Ruptic)
		19°23′40″ E		G	Stagnic Cambisol (Eutric)

Explanations: * A – arable field; G – grassland; ** according to WRB 2014.

climate floor (Table 1). The studied arable field in both regions was dominated by the cultivation of cereals (a typical crop rotation is corn or potatoes/wheat/wheat). The investigated grasslands were mostly mowed once or twice per year and occasionally supported by grazing cattle. Both arable field and grassland land use were extensive, which is typical of these Carpathian regions.

Soil sampling and laboratory analysis

A total of 12 soil pits (two regions, with three sites in each region and two land use patterns at each site) were investigated in August after the harvest. Soil pits were arranged in pairs on the neighbouring arable fields (A) and grasslands (G), to eliminate the influence of soil-forming factors other than land use.

Each of the 12 soil pits was excavated for description and sampling. Soil samples from 0–0.3 m layers were taken for analysis. The number and type of samples depended on the specific analysis.

Close to each soil pit, fresh material was collected randomly with three replications to determine dehydrogenase activity using the method of Casida et al. (1964).

The bulk density was measured in intact soils, using a Kopecky cylinder (100 cm^3 volume), in three replicates (Blake & Hartge 1986), and water field capacity (WFC) and wilting point (WP) were determined based on curves of the soil water retention capacity (pF curves), using a porous plate in pressure chambers (Eijkelkamp's apparatus) (Klute & Driksen 1986).

Soil samples collected from the soil pit were dried and sieved through a 2-mm sieve, and the following properties were analysed: particle size distribution by the Casagrande-Proszynski aerometer method, and soil pH in H_2O using potentiometry (1.0 : 2.5 soil : water ratio). The conventional Kjeldahl method was used to estimate the total soil nitrogen content. The total organic carbon content in the soil samples was determined by dry combustion (Euro Thermoglas TOC-TN 1200). The density of the solid phase was determined by using pycnometry (Blake & Hartge 1986).

Earthworm sampling and identification

The abundance, biomass and species diversity of Lumbricidae were determined in each of the 12 study locations. Close to the soil pit, five replicate soil samples of 0.25 × 0.25 m and 0.2 m depth, were taken randomly from the surface. Earthworms from the soil samples collected in this way were sorted using the hand-sorting method. Earthworms from deeper soil layers were expelled by the formalin method, with three applications at 10–15 min intervals (4–5 L per quadrat in total of a 0.3% formaldehyde solution in water) via the sampling holes at the base (based on Schmidt 2001). Earthworms were collected in plastic containers and rinsed with cold tap water. In the laboratory, worms were cleaned, counted and weighed with an electronic balance, and then killed and preserved initially in 4% formaldehyde. Earthworms were identified mainly by external characteristics using the keys of Kasprzak (1986), Plisko (1973) and Pižl (2002) and the Lumbricidae spp. were assigned to ecological groups (based on Lee 1985; Edwards & Bohlen 1996; Römbke et al. 2005). All juvenile earthworms from *Lumbricus* spp. were included in the anecic group.

Statistical evaluation

The effects of location (region) and land use on earthworm abundance and density, and selected soil biological, chemical, physical and physicochemical properties, were determined by ANOVA. Before analysis, earthworm data were $\log(n + 1)$-transformed. Linear correlations were used to evaluate correlations between the investigated parameters. All statistical analyses were carried out with the package Statistica 10 (StatSoft, Inc.). The earthworm community structure in individual sites was analysed using Redundancy analysis (RDA). Ordinations were calculated with CANOCO 5.0.

Results

Soil chemical, physical and physico-chemical properties

The particle size composition of the investigated soils is depicted in Table 2. Soils from region 1 were characterised by a more silty texture (silt loam) than soils from region 2 (mainly loam). Significant variation in the sand and silt content of soils of different regions was observed (Table 2).

The water content of soil, the water field capacity and total soil porosity were higher in grassland soil than in arable soils, but the differences were not significant (Table 2). The bulk density and wilting point was lower in grassland soil than in arable soil (Table 2). The particle density in all of the investigated soils was comparable.

Table 2. Physical properties of investigated grassland (G) and arable field (A) soil in 0.0–0.3-m layers (means ± SD).

			Region 1		Region 2		F (*P*)	F (*P*)
			G	A	G	A	Region	Land use
Soil texture	Sand	%	15 ± 2	16 ± 1	40 ± 7	44 ± 7	60.45 (0.000)	n.s.
	Silt		71 ± 6	67 ± 6	52 ± 5	39 ± 6	36.91 (0.000)	n.s.
	Clay		14 ± 5	18 ± 5	8 ± 2	17 ± 3	n.s.	n.s.
Particle density		$mg\ m^{-3}$	2.5 ± 0.0	2.6 ± 0.0	2.6 ± 0.0	2.6 ± 0.0	n.s.	n.s.
Bulk density			1.4 ± 0.1	1.4 ± 0.0	1.3 ± 0.1	1.5 ± 0.1	n.s.	n.s.
Water content of soil		%	25.6 ± 1.1	24.8 ± 0.7	26.6 ± 6.4	21.1 ± 2.2	n.s.	n.s.
Water field capacity			27.7 ± 2.3	25.3 ± 0.2	27.3 ± 5.1	22.4 ± 2.0	n.s.	n.s.
Wilting point			10.9 ± 1.2	11.4 ± 1.3	10.0 ± 0.9	12.0 ± 3.7	n.s.	n.s.
Total porosity			46.2 ± 2.9	44.5 ± 0.8	47.8 ± 3.7	42.4 ± 2.8	n.s.	n.s.

Explanations: The two columns on the right indicate the statistical significance ($P < 0.05$). n.s. – non significant.

Table 3. Chemical and biological properties of investigated grassland (G) and arable field (A) soil in 0.0–0.3-m layers (means ± SD).

	Region 1		Region 2		F (*P*)	F (*P*)
	G	A	G	A	Region	Land use
pH H_2O	4.9 ± 0.3	5.1 ± 0.0	6.2 ± 0.6	5.6 ± 0.2	15.00 (0.005)*	n.s.
TOC (total organic carbon) ($g\ kg^{-1}$)	15.4 ± 2.9	11.2 ± 0.4	14.2 ± 3.0	12.5 ± 0.2	n.s.	n.s.
TN (total nitrogen) ($g\ kg^{-1}$)	1.6 ± 0.2	1.2 ± 0.2	1.5 ± 0.3	1.2 ± 0.2	n.s.	n.s.
Dehydrogenase activity (μg TPF $g^{-1}h^{-1}$)	3.4 ± 1.1	1.0 ± 0.5	4.0 ± 1.5	2.9 ± 0.6	n.s.	6.11 (0.039)*

Explanations: The two columns on the right indicate the statistical significance ($P < 0.05$). n.s. – non significant.

Table 4. Biomass, density and ecological groups of earthworms (means ± SD) in grassland (G) and arable field (A) in two regions.

		Region 1		Region 2		F (*P*)	F (*P*)
		G	A	G	A	Region	Land use
Total biomass	($g\ m^{-2}$)	73.4 ± 29.9	5.4 ± 1.7	92.7 ± 28.1	18.9 ± 18.5	n.s.	28.30 (0.001)
Epigeic		2.9 ± 0.1	0	2.4 ± 1.0	1.1 ± 1.1	n.s.	27.01 (0.001)
Endogeic		42.8 ± 17.2	5.4 ± 1.7	40.2 ± 11.5	17.7 ± 17.4	n.s.	6.97 (0.030)
Anecic		27.7 ± 21.3	0	50.1 ± 30.1	0	n.s.	173.50 (0.000)
Total density	(individuals m^{-2})	213 ± 65	50 ± 14	241 ± 53	120 ± 91	n.s.	15.05 (0.005)
Epigeic		32 ± 18	0	25 ± 11	5 ± 4	n.s.	21.76 (0.002)
Endogeic		15 ± 81	50 ± 14	184 ± 51	115 ± 89	n.s.	13.86 (0.000)
Anecic		23 ± 6	0	33 ± 21	0	n.s.	90.64 (0.000)

Explanations: The two columns on the right indicate the statistical significance ($P < 0.05$). n.s. – non significant.

The chemical properties of soils under different land use and from each region are shown in Table 3. The pH varied from very acid to slightly acid. Soils from region 1 were more acid than those from region 2 (Table 3). The mean organic carbon (TOC) contents of the studied soils ranged from 11.2–15.4 $g\ kg^{-1}$. The content of organic carbon in grassland soil was higher than in analagous layers in arable soil, but the differences were not significant (Table 3). The soil total nitrogen (TN) content ranged from 1.2–1.6 $g\ kg^{-1}$ (Table 3). The TN content, similar to the TOC content, was higher in grassland than in arable soil (Table 3).

Dehydrogenase activity

The mean dehydrogenase activity in the topsoil ranged from 1.02 μg $TPFg^{-1}\ h^{-1}$ in arable soil from region 1, to 3.97 μg $TPFg^{-1}\ h^{-1}$ in grassland soil from region 2 (Table 3). The dehydrogenase activity of grassland soil from region 1 was over three times higher than that in analogous soil layers in arable field. In the second region, the difference between dehydrogenase activity in soil from grassland and arable field was similar but not very high; dehydrogenase activity was 1.4-fold higher in grassland than in arable soil, which was statistically significant (Table 3).

The mean microbial biomass ranged from 273.5 $mg\ kg^{-1}$ in arable soil from region 2, to 439.1 $mg\ kg^{-1}$ in grassland soil from the same region (Table 3) and did not differ significantly between regions and land-use type.

Earthworm density and biomass

Eight earthworm species were recorded: *Dendrobaena octaedra* (Savigny, 1826), *Lumbricus rubellus* (Hoffmeister, 1843), *L. castaneus* (Savigny, 1826), *Octolasion lacteum* (Örley, 1881), *Aporrectodea caliginosa* (Savigny,

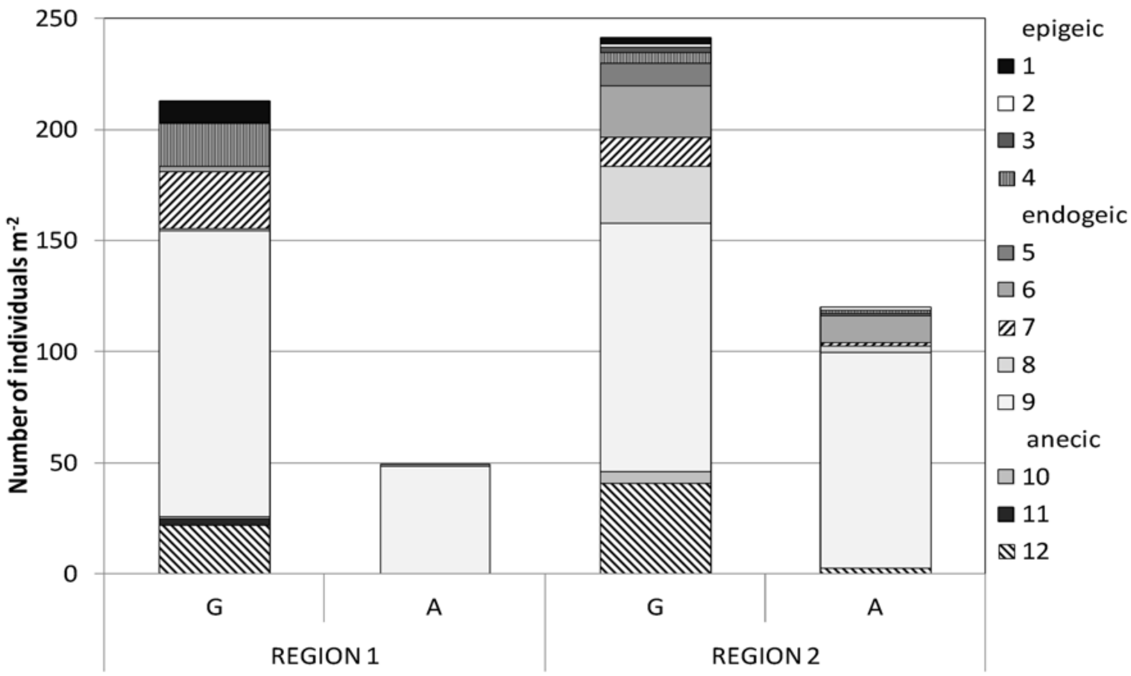

Fig. 1. Density of earthworms including the division into species in investigated soils. 1 – *Dendrobaena octaedra*, 2 – *Lumbricus rubellus*, 3 – *Lumbricus castaneus*, 4 – *Dendrobaena* juv., 5 – *Octolasion lacteum*, 6 – *Aporrectodea caliginosa*, 7 – *Aporrectodea rosea*, 8 – *Octolasion* juv., 9 – *Aporrectodea* juv., 10 – *Lumbricus terrestris*, 11 – *Fitzingeria platyura depressa*, 12 – *Lumbricus* juv.

1826), *A. rosea* (Savigny, 1826), *L. terrestris* (L., 1758), and *Fitzingeria platyura depressa* (Rosa, 1893). These species did not occur in all study locations. Higher species diversity was noted in grassland soils than in arable field soils. In region 1 six species were found in grassland, whereas only one species in arable field (Fig. 1). In addition, *Fitzingeria platyura depressa* was recorded at two sites in grassland soils of region 1. The most abundant species was *A. rosea*, followed by *D. octaedra* (Fig. 1). Grassland from region 1 had a mean earthworm density of 213 individuals m^{-2}, and a biomass of 73.4 g m^{-2}, and earthworms from all three ecological groups were collected (Table 4). In arable field from this region, only one endogeic species, *A. caliginosa*, was recorded. The mean earthworm density at these locations was 50 individuals m^{-2}, and the biomass was 5.4 g m^{-2}.

In region 2, the species diversity was higher in grassland soils (seven species) than in arable field soils (four species). Mean earthworm density for grassland and arable soils from region 2 were 241 and 120 individuals m^{-2}, respectively, and the biomass was 92.7 g m^{-2} and 18.9 g m^{-2}, respectively. In both the grassland and arable soils, the most abundant species was *A. caliginosa. Octolasion lacteum* was found in region 2, but not in region 1 (Fig. 1). In grassland from region 2, similar like in region 1, earthworms from all three ecological groups were present (Table 4). In arable field from this region, mainly endogeic species and several epigeic species were recorded.

Relationship between earthworm frequency, soil properties and land use type

The linear correlation coefficients between the number and biomass of earthworm ecological groups and some measured soil properties are given in Table 5. The frequency of epigeic and anecic earthworms and biomass were correlated with the organic C content. Earthworm number and biomass from both ecological groups were also positively correlated with dehydrogenase activity. Additionally, the abundance of epigeic and anecic earthworms was negatively correlated with clay content. Dehydrogenase activity was also correlated with clay content. The frequency of anecic earthworms and biomass were positively correlated with the water field capacity and total soil porosity.

The results of Redundancy Analysis (RDA) (Fig. 2) explained 53% of the data variability, showing two principal axes that regulated the community of earthworms; the first axis represented 44% and the second axis, 9%, of the data variability, and the model was significant at $P < 0.002$ (Monte Carlo permutation test). Tillage, no-tillage and sand content were also the only significant parameters ($P < 0.05$) by forward selection in RDA. All earthworm species prefer no tillage sites, *L. rubellus, O. lacteum* and *A. caliginosa* prefer a higher sand content, whereas *D. octaedra* prefers soils with a lower sand content.

Discussion

Soils in mountain regions are characterised by a high diversity, because of the variability in the parent material from which they are produced. Skiba (2008) suggested that the fragmentary characteristic of the soil cover in Carpathian soil is connected to the lithological features of the bedrock and to intense morphogenetic processes. As shown in the research presented here, soil formed

Table 5. Pearson's correlation matrix of soil properties and biological activity of soil.

	ADh	Ecological group/no. of earthworm individuals m^{-2}				Ecological group/earthworm biomass ($g\ m^{-2}$)			
		Epigeic	Endogeic	Anecic	Total	Epigeic	Endogeic	Anecic	Total
Sand	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Silt	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Clay	–0.569*	–0.579*	n.s.	–0.528*	n.s.	n.s.	n.s.	n.s.	n.s.
Water content	n.s.	n.s.	n.s.	0.541*	n.s.	n.s.	n.s.	n.s.	n.s.
Particle density	n.s.	–0.574*	–0.671*	–0.540*	–0.696*	–0.782**	–0.721**	–0.513*	–0.708*
Bulk density	–0.622*	n.s.	n.s.	–0.692*	n.s.	n.s.	n.s.	–0.595*	n.s.
Water field capacity	n.s.	n.s.	n.s.	0.633*	n.s.	n.s.	n.s.	0.534*	n.s.
Wilting point	n.s.	–0.535*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Total porosity	0.581*	n.s.	n.s.	0.629*	n.s.	n.s.	n.s.	0.533*	n.s.
pH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TOC	0.678*	0.561*	n.s.	0.550*	n.s.	0.548*	n.s.	0.500*	n.s.
TN	n.s.	n.s.	n.s.	0.588*	n.s.	n.s.	n.s.	0.552*	n.s.
ADh		0.711**	n.s.	0.647*	n.s.	0.663*	n.s.	0.625*	0.553*

Explanations: * $P < 0.05$, **$P < 0.01$, n.s. – non significant.

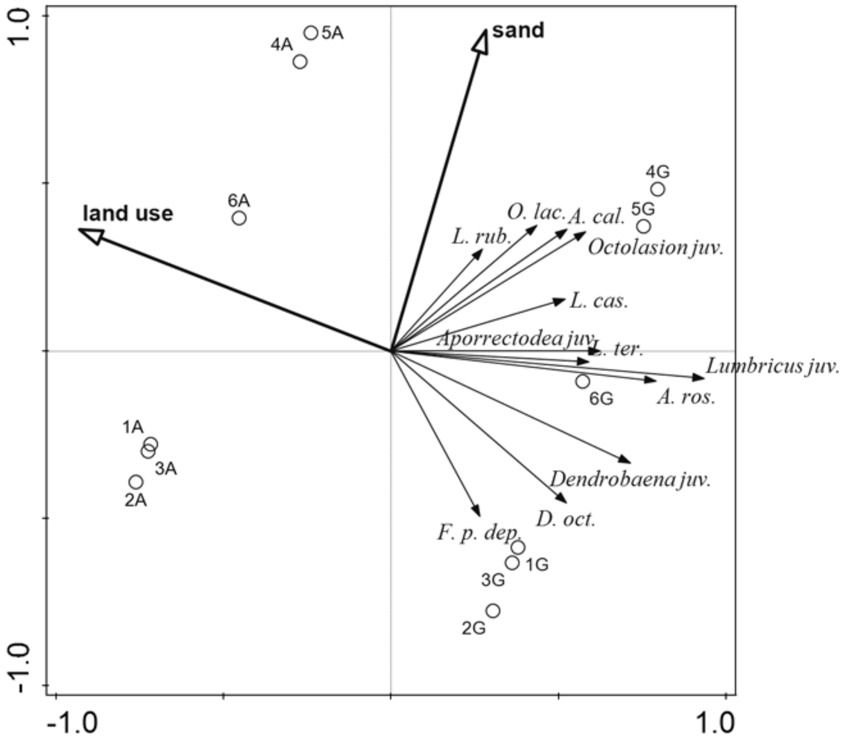

Fig. 2. RDA ordination of earthworm communities in the investigated soils. *D. oct. – Dendrobaena octaedra, L. rub. – Lumbricus rubellus, L. cas. – Lumbricus castaneus, O. lac. – Octolasion lacteum, A. cal. – Aporrectodea caliginosa, A. ros. – Aporrectodea rosea, L. ter. – Lumbricus terrestris, F. p. dep. – Fitzingeria platyura depressa.* For 1A, 1G, see Table 1.

from the loess-like carbonateless material possesses different chemical and physical properties to soil created from Carpathian flysch deposits. Differences between these two groups of soils, such as texture and pH value, imply that the soil biological properties also differ. Ivask et al. (2008) claims that the type of soil is important regarding the influence of the type of use on soil biological properties, and observed that earthworms prefer Calcaric Cambisols more than Calcaric Regosols or Stagnic Luvisols, which have a lower TOC content and pH. However, statistical analysis of our data showed that the difference between dehydrogenase activity and the presence of earthworms in these two soil groups was not significant. This suggests that soil physical and chemical properties were more affected by region, whereas the type of land use had a greater impact on biological properties. We presume that we can predict the biological activity of soil based on land use, which is important in terms of ecology (de Vries et al. 2013).

Crucial factors that influenced the diversity of soil biological activity were the methods of land use. Our results correspond to those of Pelosi et al. (2014) who suggested that soil type and climate had only a small effect on earthworm community compared with soil tillage intensity. In both investigated regions, the number of earthworms was higher in grassland soil than in arable field. Grassland soil from region 1 contained approximately four times more earthworms than arable soils from the same region. In the second region, the number of earthworms in grassland soil was twice as high as in that from arable field. Additionally, fewer species were present in soil from arable field than from grassland. One reason for these differences might be the impact of tillage on earthworms. An extensive body of literature exists on the effect of tillage practice on earthworm activity (e.g., Kladivko 2001; Edwards 2004; Brito-Vega et al. 2009) and Ouellet et al. (2008) noted that tillage reduced earthworm numbers, mainly via the physical destruction of earthworms and their habitat.

Almost all earthworm species recorded during this study are common and have been recorded by many authors (Pižl & Stary 2001; Csuzdi et al. 2011) during studies of the soil in this part of the Carpathians. As part of research concerning the effect of mountain meadow management on soil fauna, Pižl & Stary (2001) identified five earthworm species that are common in Carpathian grasslands: *D. octaedra, L. rubellus, A. caliginosa, A. rosea* and *O. lacteum.* Besides the same species as listed above two more species were noted: *L. castaneus* and *F. platyura depressa.* According to Römbke et al. (2005),*L. castaneus* is a common species in agricultural soil, especially in meadows. Only one species, *F. platyura depressa,* which has the northern border of its occurrence in the Carpathian Mountains (Kasprzak 1989) is an interesting species, because until now, it was only recorded in the Pieniny and Sudety Foothill in Polish territory, mainly in forest soils (Kasprzak 1986; Plisko 1973). Other subspecies of this species, *F. platyura platyura* and *F. platyura montana*, are more common in the southern part of Poland (Rożen 1982; Kostecka & Skoczeń 1993). According to the available literature, the Silesian Foothills represent a new habitat for the occurrence of *F. platyura depressa.*

The density and biomass of earthworms belonging to different ecological groups show that arable soils did not support earthworms from the anecic group. Worms from the epigeic group were present in small numbers only in arable soils from region 2. This agrees with data from Gormsen et al. (2004) who noted a decrease in density of anecic species such as *L. terrestris* and *A. longa,* and of epigeic species such as *L. rubellus* in arable field, compared with grassland. Endogeic species were present in arable soils; according to Pelosi et al. (2014), worms such as *A. icterica, A. caliginosa* and *A. rosea* might benefit from crop-residue incorporation. However, our research indicates that endogeic species are less sensitive than other groups, but ploughing does affect their populations. In grassland soils, all three ecological groups of earthworms were observed which have been previously noted (Pižl & Stary 2001; Edwards 2004).

The effect of land use on the earthworm community is modified by interactions with soil environmental properties. The results here show that the number of earthworms increased together with the increase in the organic carbon content. This relationship confirms the positive correlation between the TOC content and biomass and the abundance of the epigeic and anecic earthworm groups (Table 5). Data confirm that epigeic and anecic earthworms prefer habitats with a higher organic matter content than species of the endogeic group (Lee 1985; Monroy et al. 2006). This study shows that the number of epigeic and anecic earthworms negatively affects the size of the clay fraction, which reflects a significant negative correlation between the density of earthworms from these groups and the content of the fraction $\o < 0.002$ mm (Table 5). An extensive body of literature exists on the effects of pH on earthworms (Edwards & Bohlen 1996; Curry 2004). In this study, soil pH did not affect the number of earthworms. This might be because the soil pH ranged from 4.9 to 6.2 and deviated slightly from the optimum range defined by Curry (2004) for European species of earthworms, which is 5.0–7.4.

The high biomass of earthworms was correlated with a high activity of dehydrogenases (Table 5): the density of epigeic and anecic earthworms, especially of those that feed on organic matter contained in the surface layer of the soil, was accompanied by a significantly higher activity of these enzymes. This confirms the view of many authors (Lee 1985; Edwards 2004; Curry 2004) that the main function of soil fauna, especially of earthworms, is to crush plant residues. Furthermore, earthworms mainly from the anecic group, draw plant residues into the soil, thereby contributing to the rapid multiplication of microorganisms, which directly affects the activity of dehydrogenases, which are an indicator of the intensity of metabolism of respiratory soil microorganisms (Brzezińska & Włodarczyk 2006). Therefore, without measuring the activity of microorganisms, it can be assumed that a high density of earthworms will be reflected by a high microbial activity in the soil.

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References

Blake G.R. & Hartge K.H. 1986. Particle density, Chapter 14, pp. 377–382. DOI: 10.2136/sssabookser5.1.2ed.c14. In: Klute A. (ed.), Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. 2nd ed. Series Agronomy, Number 9 (Part 1), SSSA Book Series 5, American Society of Agronomy, Madison, Wisconsin, USA, 1188 pp. ISBN-13: 978-0-89118-811-7, ISBN-10: 0-89118-811-8

Bongers T. & Ferris H. 1999. Nematode community structure as a bioindicator in environmental monitoring. Trends Ecol. Evol. **14 (6):** 224–228. DOI: doi:10.1016/S0169-5347(98)01583-3

Brito-Vega H., Espinosa-Victoria D., Fragoso C., Mendoza D., De la Cruz Landero N. & AldereteChavez A. 2009. Soil organic matter particle and presence of earthworm under different tillage systems. J. Biol. Sci. **9 (2):** 180–183. DOI: 10.3923/jbs.2009.180.183

Brookes P.C. 1995. The use of microbial parameters in monitoring soil pollution by heavy metals. Biol. Fertil. Soils **19 (4):** 269–279. DOI: 10.1007/BF00336094

Brzezińska M. & Włodarczyk T. 2006. Methods of soil catalase and dehydrogenase activity measurement, pp. 59–74. In: Russel S., Wyczółkowski A.I. & Bieganowski A. (eds), Selected Methodological Aspects of Soil Enzyme Activity Tests, IA PAS, Lublin. 74 pp. ISBN-10: 83-89969-70-X, ISBN-13: 978-83-89969-70-5

Casida L.E.J., Klein D.A. & Santoro T. 1964. Soil dehydrogenase activity. Soil Sci. **98 (6):** 371–376.

Ciarkowska K., Sołek-Podwika K. & Wieczorek J. 2014. Enzyme activity as an indicator of soil-rehabilitation processes at a zinc and lead ore mining and processing region. J. Environ. Manage. **132:** 250–256. DOI: 10.1016/j.jenvman.2013.10.022

Csuzdi C., Pop V. & Pop A. 2011. The earthworm fauna of the Carpathian Basin with new records and description of three new species (Oligochaeta: Lumbricidae). Zool. Anz. **250** (**1**): 2–18. DOI: 10.1016/j.jcz.2010.10.001

Curry J.P. 2004. Factors affecting the abundance of earthworms in soils, Chapter 6, pp. 91–113. In: Edwards C.A. (ed.), Earthworm Ecology, 2nd ed., CRC Press LLC, Boca Raton, 448 pp. ISBN: 0-8493-1819-X

de Vries F.T., Thébault E., Liiri M., Birkhofer K., Tsiafouli M.A., Bjørnlund L., Jørgensen H.B., Brady M.V., Christensen S., de Ruiter P.C., d'Hertefeldt T., Frouz J., Hedlund K., Hemerik L., Hol W.H.G., Hotes S., Mortimer S.R., Setälä H., Sgardelis S.P., Uteseny K., van der Putten W., Wolters V. & Bardgett R.D. 2013. Soil food web properties explain ecosystem services across European land use systems. Proc. Natl. Acad. Sci. USA **110 (35):** 14296–14301. DOI: 10.1073/pnas.1305198110

Dick R.P., Breakwell D.P. & Turco R. F. 1996. Soil enzyme activities and biodiversity measurements as integrative microbiological indicators, Chapter 15, pp. 247–271. DOI: 10.2136/sssaspecpub49.c15. In: Doran J.W. & Jones A.J. (eds), Methods for Assessing Soil Quality, Soil Science Society of America, Spec. Publ. 49, Madison, Wisconsin, 410 pp. ISBN: 0-89118-826-6

Edwards C.A. (ed.) 2004. Earthworm Ecology. CRC Press, Boca Raton, Fl, /456 pp. ISBN: 9780849318191

Edwards C.A. & Bohlen P.J. 1996. The Biology and Ecology of Earthworms. Publ. Chapman and Hall, London, 426 pp. ISBN: 0412561603, 9780412561603

Gormsen D., Hedlund K., Korthals G.W., Mortimer S.R., Pižl V., Smilauerova M. & Sugg E. 2004. Management of plant communities on set-aside land and its effects on earthworm communities. Eur. J. Soil Biol. **40 (3-4):** 123–128. DOI: 10.1016/j.ejsobi.2004.08.001

Ivask M., Kuu A., Meriste M., Truu J., Truu M. & Vaater V. 2008. Invertebrate communities (Annelida and epigeic fauna) in three types of Estonian cultivated soils. Eur. J. Soil Biol. **44 (5-6):** 532–540. DOI: 10.1016/j.ejsobi.2008.09.005

Kasprzak K. 1986. Skąposzczety glebowe III, Rodzina: Dżdżownice (Lumbricidae). Series: Klucze do oznaczania bezkręgowców Polski, tom 6. PAN, Warszawa, 187 pp. ISBN: 8301061677, 9788301061678

Kasprzak K. 1989. Zoogeography and habitat distribution of earthworms (Lumbricidae) and enchytraeids (Enchytraeidae) of the Carpathian Mountains (Poland). Misc. Zool. **13:** 37–44.

Kladivko E.J. 2001. Tillage system and soil ecology. Soil Till. Res. **61:** 61–76.

Klute A. & Dirksen C. 1986. Water retention. Laboratory methods, Chapter 26, pp. 635–662. DOI: 10.2136/sssabookser5.1.2ed.c26. In: Klute A. (ed.), Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods, 2nd ed., series Agronomy, Number 9 (Part **1**), SSSA Book Series 5, American Society of Agronomy, Madison, Wisconsin, USA, 1188 pp. ISBN-13: 978-0-89118-811-7, ISBN-10: 0-89118-811-8

Kostecka J. & Skoczeń S. 1993. Earthworm (Oligochaeta: Lumbricidae) populations in four types of beech wood *Fagetum carpaticum* in the Bieszczady National Park (south-eastern Poland). Part I. Species composition, diversity, dominance, frequency and associations. Acta Zool. Cracov. **36 (1):** 1–13. ISBN: 83-900337-8-X

Lee K.E. 1985. Earthworms their Ecology and Relationships With Soils and Land Use. Academic Press, Sydney, 411 pp. ISBN: 0124408605, 9780124408609

Monroy F., Aira M., Dominguez J. & Velando A., 2006. Seasonal population dynamics of *Eisenia fetida* (Savigny, 1826) (Oligochaeta, Lumbricidae) in the field. Compt. Rend. Biol. **329 (11):** 912–915. DOI: 10.1016/j.crvi.2006.08.001

Ouellet G., Lapen D.R., Topp E., Sawada M. & Edwards M. 2008. A heuristic model to predict earthworm biomass in agroecosystems based on selected management and soil properties. Appl. Soil Ecol. **39 (1):** 35–45. DOI: 10.1016/j.apsoil.2007.11.003

Paoletti M.G. 1999. The role of earthworms for assessment of sustainability and as bioindicators. Agr. Ecosyst. Environ. **74 (1-3):** 137–155. DOI: 10.1016/S0167-8809(99)00034-1

Pelosi C., Pey B., Hedde M., Caro G., Capowiez Y., Guernion M., Peigné J., Piron D., Bertrand M. & Cluzeau D. 2014. Reducing tillage in cultivated fields increases earthworm functional diversity. Appl. Soil Ecol. **83:** 79–87. DOI: 10.1016/j.apsoil.2013.10.005

Pižl V. 2002. Žížaly České republiky [Earthworms of the Czech Republic]. Monografické č. seriálu: Sborník přírodovědného klubu v Uherském Hradišti. Supplementum **9:** 154 pp. ISBN: 80-86485-04-8

Pižl V. & Stary J. 2001. The effects of mountains meadow management on soil fauna communities (on example of earthworms and oribatid mites). Silva Gabreta **7:** 87–96.

Plisko D.J. 1973. Lumbricidae — Dżdżownice (Annelida: Oligochaeta) Fauna Polski – Fauna Poloniae 1, PWN, Warszawa, 156 pp.

Postma-Blaauw M.B., de Goede R.G.M., Bloem J., Faber J.H. & Brussaard L. 2012. Agricultural intensification and de-intensification differentially affect taxonomic diversity of predatory mites, earthworms, enchytraeids, nematodes and bacteria. Appl. Soil Ecol. **57:** 39–49. DOI: 10.1016/j.apsoil.2012.02.011

Pulleman M., Creamer R., Hamer U., Helder J., Pelosi C., Pérés G. & Rutgers M. 2012. Soil biodiversity, biological indicators and soil ecosystem services-an overview of European approaches. Curr. Opin. Environ. Sustain. **4 (5):** 529–538. DOI: 10.1016/j.cosust.2012.10.009

Römbke J., Jänsch S. & Didden W. 2005. The use of earthworms in ecological soil classification and assessment concepts. Ecotoxicol. Environ. Safe. **62 (2):** 249–265. DOI: 10.1016/j.ecoenv.2005.03.027

Rożen A. 1982. The annual cycle in populations of earthworms (Lumbricidae, Oligochaeta) in three types of oak-hornbeam of the Niepolomicka Forest. I. Species composition, dominance, frequency and associations. Pedobiologia **23:** 199–208.

European Union's European Agricultural Fund 2015. The Rural Development Programme (RDP), 2014–2020. [Program Rozwoju Obszarów Wiejskich na lata 2014 – 2020 (PROW 2014-2020)] http://www.minrol.gov.pl/ (accessed 26.01.2015).

Schmidt O. 2001. Time limited hand sorting for long-term monitoring of Earthworm populations. Pedobiologia **45 (1):** 69–83. DOI: 10.1078/0031-4056-00069

Skiba S. 2008. Some problems of the soil classification of the Carpathian mountain soils. Gruntoznavstvo / Soil Science **9 (3-4):** 165–168.

van Eekeren N., Bommele L., Bloem J., Schouten T., Rutgers M., de Goede R., Reheul D. & Brussaard L. 2008. Soil biological quality after 36 years of ley-arable cropping, permanent grassland and permanent arable cropping. Appl. Soil Ecol. **40 (3):** 432–446. DOI: 10.1016/j.apsoil.2008.06.010

WRB 2014. World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. Update 2015. In: World Soil Resources Reports 106, FAO, 2014, 192 pp. ISBN: 978-92-5-108369-7

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