

Community Structure of Lumbricidae in Permanent Grassland and Arable Land

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ABSTRACT

Lumbricidae play a key role in the soil environment as “the ecosystem engineers”. They participate in all the categories of services provided by ecosystems. In agricultural areas, the conventional intensive farming practices have led to a significant decline in the biological diversity of soils including earthworms. In this study, we attempted to characterize the community structure of earthworms in permanent grassland and arable land of the Didactic & Experimental Station of Rzeszów University in Krasne near Rzeszów. Similar densities of earthworms were observed in the grassland and in the arable land ($101.01 \pm 18.03 \text{ ind.} \cdot \text{m}^{-2}$ and $82.12 \pm 18.26 \text{ ind.} \cdot \text{m}^{-2}$, respectively) ($p > 0.05$) as well as a similar biomass of Lumbricidae ($77.72 \pm 15.30 \text{ g} \cdot \text{m}^{-2}$ and $54.34 \pm 11.72 \text{ g} \cdot \text{m}^{-2}$) ($p > 0.05$). In the research, 7 species of earthworms were found in the permanent grassland and 6 representatives of Lumbricidae were identified in the arable land. The identified earthworms represented all three main morpho-ecological groups. The density and biomass of epi-endogeic earthworm *L. rubellus* and the anecic species of *L. terrestris* were shown to be higher ($p < 0.05$) in the grassland as compared to the arable land. In order to protect Lumbricidae and to sustain the beneficial role of earthworms in an ecosystem, it is necessary to monitor the negative changes in populations of earthworm species attributed to various farming practices.

Keywords: earthworms, biodiversity, agricultural areas, dominance, frequency, Shannon-Wiener diversity index, dominance values of Berger-Parker

INTRODUCTION

The size and quality of arable crops are the benchmarks of soil fertility. Soil fertility is determined by the physical, chemical and biological properties of soil and by the soil organisms [Barrios et al. 2007]. Earthworms constitute a significant share of soil organisms and, owing to their activity in soil, are referred to as ‘ecosystem engineers’ [Jouquet et al. 2006]. Lumbricidae contribute to the development of specific soil properties by improving its structure and increasing the field capacity [Zangerlé et al. 2011, Schon et al. 2017]. They also influence the dynamics of the organic matter [Fonte et al. 2009, 2010, Amosse et al. 2015] by delivering and retaining nutrients necessary for the growth and development of plants [van Groenigen

et al. 2014, Manono 2016] as well as by regulating the size of pest populations [Bertrand et al. 2015]. Therefore, the activity of Lumbricidae in the soil environment has a positive influence on the production of food crops, energy crops, and fibre crops.

In agricultural areas, conventional intensive farming practices have led to a significant decline in the biological diversity of soils [Briones, Schmidt 2017]. Ploughing contributes to a reduction in the population size and diversity of species of earthworms, as it physically disturbs the environment of earthworms and causes mechanical damage to earthworms, especially epigeic and anecic ones. Mortality rates –e.g. due to the injury caused by field ploughing – are estimated at 50%. The extent of these negative effects may be much greater, depending on the type and frequency of cultivation

[Curry 2004, Capowiez et al. 2009, van Capelle et al. 2012]. Harvest is another factor which further exacerbates the exposure to stress factors across farming fields, as it involves the removal of vegetation which creates a specific micro-climate and provides shade for the soil surface. If the plant layer is removed, the soil moisture decreases, and earthworms are exposed to direct sunlight. Various studies conducted in agrocenoses also proved that the use of chemical plant protection agents reduced the population size and biomass of earthworms [Pelosi et al. 2013, Datta et al. 2016].

The objective of this paper was to determine the qualitative and quantitative structure of earthworms in the grassland and in the arable land of the Didactic & Experimental Station of Rzeszów University in Krasne near Rzeszów.

MATERIAL AND METHODS

The study was conducted at the Didactic & Experimental Station of Rzeszów University in Krasne in two growing seasons. Two ecosystems were selected for the analysis: permanent grassland (50 a) and arable land (5 ha) (Table 1), in both of which numerous samples were collected for the analysis.

The cultivation activities employed in the studied ecosystems were also examined. Five years before the start of the research, goat rue (*Galega orientalis* Lam.), orchard grass (*Dactylis glomerata* L.), false oat-grass (*Arrhenatherum elatius* L.), meadow fescue (*Festuca pratensis* Huds.), and red clover (*Trifolium pratense* L.) were planted in the grassland.

The arable land was planted with winter rye (variety: Dańkowskie Amber; Danko sp. z o.o.; 90 kg · ha⁻¹) (first research season) and barley (second research season) (variety Stratus; Strzelce

sp. z o.o.; 140 kg · ha⁻¹). Low doses of phosphorus and potassium fertilizers (70 kg P · ha⁻¹ and 70 kg K · ha⁻¹) and a nitrogen fertilizer (ammoniac saltpetre 34%; 30 kg N · ha⁻¹) were used before planting.

The soil temperature and moisture were measured 0–20 cm below the soil surface and at a lower level, alongside the air temperature measurements conducted at each research site. The soil moisture was determined using oven-drying method at 105°C [PN ISO 11465:1999]. Additionally, the soil samples were collected at each research site for tests of soil pH-KCl, organic carbon (based on the Tiurin approach with Nikitin's modification) [Nikitin, Fishman 1969], and absorbable forms of phosphorus, potassium and magnesium according to the Mehlich III method [Mehlich 1984].

The combined Zajonc method [1970] according to ISO [EN ISO 23611–1:2006] was the basic method for the earthworm search. The earthworms were searched manually by sorting 25×25×25 cm soil blocks. The earthworms were extracted from the deeper layers of the profile by slowly flooding a hole with 10 litres of 0.4% formalin solution. The samples were collected from April to October (first research season) and from April to November (second research season). According to the Zisci recommendations [1962], eight samples were collected each time at the research sites, randomly selected by tossing a metal frame.

The following indicators were applied to assess the communities of Lumbricidae:

- dominance (D), $D = na/n$, where na is the number of specimens of the species a in all tested samples, n is the number of specimens of the tested community of species in all samples,
- frequency (C), $C = q/Q$, where q is the number of samples in which the species a is present, Q is the number of samples in the study batch,

Table 1. Characteristics of Lumbricidae sampling sites in Krasne

Site	Soil type	Soil properties
Grassland N 50° 02' 53.9" E 022° 03' 16.8"	Brown earth of loess-origin, granulometric composition of ordinary dust, average agronomic category (soil of wheat, good complex, soil class IIIa)	Mean soil temperature (0–20 cm) 14.1 ± 3.4 °C; (< 20 cm) 13.9 ± 3.3 °C Mean soil moisture (0–20 cm) 19.9 ± 6.1 %; (< 20 cm) 19.8 ± 6.4 % pH in KCl 5.95; humus 1.91%; 11.1 mg P ₂ O ₅ /100g s.m.; 18 mg K ₂ O/100g s.m.; 2.6 mg Mg/100g s.m.
Arable land N 50° 03' 13.9" E 022° 05' 26.7"	Brown earth of loess-origin, granulometric composition of ordinary dust, average agronomic category (soil of wheat, good complex, soil class IIIa)	Mean soil temperature (0–20 cm) 13.9 ± 3.9 °C; (< 20 cm) 13.8 ± 3.9 °C Mean soil moisture 0–20 cm) 19.7 ± 6.2 %; (< 20cm) 19.1 ± 6.7 % pH in KCl 5.78; humus 1.52%; 9.3 mg P ₂ O ₅ /100g s.m.; 16 mg K ₂ O/100g s.m.; 2.1 mg Mg/100g s.m.

- Shannon-Wiener (H), $H = -\sum p_i \ln p_i$, where p_i is the number of specimens of a particular species vs population size of all organisms,
- Berger-Parker (d), $d = N_{Max} / N$, where N_{Max} is the maximum number of identified species, and N is the number of all specimens per sample.

The data were presented as mean \pm standard deviation (SD). The results were analysed statistically in STATISTICA v. 10 software, using t-student test or Mann-Whitney U test.

RESULTS

Seven species of earthworms were found in the permanent grassland and six representatives of Lumbricidae were identified in the arable land (Table 2). The earthworms identified represented all three main morpho-ecological groups (Table 2). In the grassland, the *epigeic* group was represented by two species: *D. rubidus tenuis* and *D. octaedra*. However, *D. rubidus tenuis* was the only *epigeic* species identified in the arable land. *L. rubellus*, an *epi-endogeic* earthworm, was found at both research sites. Three species of *endogeic* Lumbricidae: *A. caliginosa*, *A. rosea* and *O. lacteum* were identified in both grassland and arable land. *Anecic* earthworms – deep-burrowing earthworms – were represented by *L. terrestris* in both grassland and arable land.

A similar number of earthworms was observed in the grassland and in the arable land (101.01 ± 18.03 ind. \cdot m⁻² and 82.12 ± 18.26 ind. \cdot m⁻², respectively) ($p > 0.05$); the biomass of Lumbricidae was similar as well (77.72 ± 15.30 g \cdot m⁻² and 54.34 ± 11.72 g \cdot m⁻²) ($p > 0.05$). No significant differences between the studied habitats were found in terms of the Shannon biological diversity index (H) and the Berger-Parker dominance index (d) ($p > 0.05$) (Table 3).

The eudominant species of *A. caliginosa*, *A. rosea*, and *L. terrestris*, prevailed in the grassland communities. The dominants included *L. rubellus* and *O. lacteum*, while *D. octaedra* and *D. rubidus tenuis* were classified as subdominants. The eudominants in the arable land included two species: *A. caliginosa*, *A. rosea*, whereas the remaining species were classified as dominants (Table 4).

The highest prevalence (100%) was reported for *A. caliginosa*, *A. rosea* and *L. terrestris* in the grassland, and for *A. caliginosa* (100%) and *A. rosea* (87%) in the arable land (Table 4).

The density and biomass of *epi-endogeic* earthworm *L. rubellus* and the *anecic* species of *L. terrestris* were shown to be higher ($p < 0.05$) in the grassland as compared to the arable land (Table 4).

DISCUSSION

The earthworms found in the arable land in Krasne (6 species), were also confirmed to be present in the nearby grassland (7 species), forming a rich lumbricofauna. This is also evident from the similar values of the Shannon biological diversity index (H) and the Berger-Parker index (d) obtained for both habitats (Table 3). The diversity of earthworms found in the arable land in Krasne is superior to that observed in other studies of arable areas [Kostecka 1993, Makulec 2004, Smith et al. 2008], where only 1–2 species were found to be present. The richness of species living in the arable land in Krasne may be attributed to good planning and skillful use of land resources at the farm of the Rzeszów University. This includes low and average doses of mineral fertilization (<100 kg \cdot ha⁻¹) and an adequately planned crop rotation. These practices have a positive impact on soil fauna [Bengtsson et al. 2005]. Rescheduling the ploughing to summer (August of the first and second research season) could also contribute to the lesser negative impact of this

Table 2. Species structure of Lumbricidae from permanent grassland and arable land in Krasne

Species of earthworm	Permanent grassland	Arable land
<i>Dendrodrilus rubidus tenuis</i> (Savigny 1826) a	+	+
<i>Dendrobaena octaedra</i> (Savigny 1826) a	+	-
<i>Lumbricus rubellus</i> (Hoffmeister 1843) ab	+	+
<i>Aporrectodea caliginosa</i> (Savigny 1826) b	+	+
<i>Aporrectodea rosea</i> (Savigny 1826) b	+	+
<i>Octolasion lacteum</i> (Oerley 1881) b	+	+
<i>Lumbricus terrestris</i> (L. 1758) c	+	+
Number of species	7	6

a – epigeic earthworms, ab – epi-endogeic earthworms, b – endogeic earthworms, c – anecic earthworms

Table 3. Earthworm community characteristics in permanent grassland and in arable land in Krasne

Ecological parameters	Permanent grassland	Arable land
Earthworm density [ind. · m ⁻²]	101.01 ^a ± 18.03	82.12 ^a ± 18.26
Earthworm biomass [g · m ⁻²]	77.72 ^a ± 15.30	54.34 ^a ± 11.72
Shannon-Wiener diversity index (H)	0.6 ^a ± 0.18	0.57 ^a ± 0.16
Dominance values of Berger-Parker (d)	0.06 ^a ± 0.01	0.07 ^a ± 0.02

^a – statistically insignificant differences ($p > 0.05$)

Table 4. Earthworm population characteristics from permanent grassland (PG) and arable land (AL) in Krasne

Earthworm species		Dominance [%]	Frequency [%]	Density [ind. · m ⁻²]	Biomass [g · m ⁻²]
<i>D. rubidus tenuis</i>	PG	3.33; subdominant	26.67	4.75 ^a ±3.37	0.59 ^a ±0.43
	AL	5.41; dominant	33.33	5.25 ^a ±3.52	0.67 ^a ±0.47
<i>D. octaedra</i>	PG	3.67; subdominant	33.33	3.25±1.91	0.51±0.30
	AL	-	-	-	-
<i>L. rubellus</i>	PG	5.96; dominant	60.00	8.00 ^a ±5.91	3.28 ^a ±2.68
	AL	6.83; dominant	40.00	3.75 ^b ±3.09	1.83 ^b ±1.53
<i>A. caliginosa</i>	PG	45.12; eudominant	100.00	62.00 ^a ±25.81	30.32 ^a ±13.50
	AL	52.91; eudominant	100.00	49.5 ^a ±22.03	21.78 ^a ±10.47
<i>A. rosea</i>	PG	23.12; eudominant	100.00	19.50 ^a ±7.80	10.99 ^a ±4.67
	AL	18.83; eudominant	86.70	15.00 ^a ±9.93	6.81 ^a ±4.93
<i>O. lacteum</i>	PG	5.41; dominant	40.00	6.25 ^a ±2.88	3.63 ^a ±1.86
	AL	7.38; dominant	40.00	7.25 ^a ±3.96	3.97 ^a ±2.33
<i>L. terrestris</i>	PG	13.61; eudominant	100.00	15.50 ^a ±8.97	40.04 ^a ±25.80
	AL	8.88; dominant	60.00	6.25 ^b ±4.76	16.99 ^b ±13.99

^a – statistically insignificant differences ($p > 0.05$); ^b – statistically significant differences ($p < 0.05$)

agricultural practice on Lumbricidae. At this time of the year, the *anecic* species can usually be found in the deeper layers of soil, whereas the *endogeic* earthworms tend to enter the state of anabiosis (because of low water levels). Moreover, the vicinity of the grassland with a more stable habitat facilitates permanent migration of Lumbricidae from that ecosystem.

According to Coleman et al. [2004], the density of earthworm populations in grasslands of the moderate climate zone ranges from 50 to 200 specimens per m². The population size of Lumbricidae in the grassland in Krasne (101.01 ± 18.03 ind. · m⁻²) falls within this range. Kanianska et al. [2016] (120 ind. · m⁻²) report similar data collected in a permanent grassland area in Slovakia.

However, the data regarding biomass can be interpreted differently. In the 1980s, the volume of biomass in meadow and grassland soils in Poland was estimated at 300 g · m⁻² [Kasprzak 1986]. Kostecka [1992] reported a biomass of 122 g · m⁻² in the meadows in Rajske in the region of Subcarpathia (Podkarpacie). The most recent studies of Rožen et al. [2013] on the meadows in Silesian Beskids (Beskid Śląski) highlands revealed a biomass of 50–60 g · m⁻². The meadow in Krasne was found to contain a similarly low

level of biomass of 77.72 ± 15.30 g · m⁻² (Table 3). According to other studies, the arable land is characterised by lower density and biomass of Lumbricidae compared to the habitats not exposed to direct interference [Smith et al. 2008, Feijoo et al. 2011, Felten, Emmerling 2011]. This tendency has not been confirmed in the study conducted in Krasne. Similar populations of earthworms in terms of size and biomass levels were found in the arable land of rye and barley and in the grassland (Table 3). Kasprzak [1986] recorded a biomass of earthworms within the range of 20–150 g · m⁻² in arable lands in 1980s. Witkowski [1983] recorded a biomass of 4.1–5.3 g · m⁻² in the fields planted with cereals and potatoes, whereas Ryl [1984] recorded 4.7 g · m⁻² of biomass in the arable land of wheat. The present study in the arable land in Krasne revealed a biomass of more than 54.34 ± 11.72 g · m⁻² (Table 3). This may point at the involvement of many factors, both biotic and abiotic, but it can also be attributed to the aforementioned good practices of agrocenosis in Krasne.

The endogeic species *A. caliginosa* and *A. rosea* prevailed in the communities identified at both research sites in the Didactic & Experimental Station of the Rzeszów University. These are common eurytopic species tolerant to the agricultural

disturbances in soil. *A. caliginosa* was usually reported as the most abundant species in the arable land. This finding was confirmed by many authors [e.g. Ivask et al. 2007, Lapied et al. 2009, Lüscher et al. 2014, Kanianska et al. 2016].

The population and biomass of deep-burrowing earthworms of *L. terrestris* were found to be superior in the grassland compared to the arable land. This may be due to the fact that ploughing destroys the earthworm burrows and tunnels in the arable land, thus causing the earthworms of this species to use their energy resources to reconstruct the tunnels and for other life activities [Monroy 2006]. Ploughing also limits the availability of nutrients which are absorbed from the soil surface to the underground tunnels. Similar tendencies were described by Whalen [2004].

Epigeic earthworms of *D. octaedra* species present on the nearby meadow were found in the arable land. Epigeic earthworms are usually most exposed to farming practices which transform the surface layers of soil to a large extent. It is assumed that the epigeic species are more numerous in the environments not exposed to the agricultural interference [Haynes et al. 2002].

CONCLUSIONS

A similar large population and biomass of earthworms along with comparable values of the Shannon-Wiener biological diversity index and the Berger-Parker dominance index were identified in the permanent grassland and in the arable land of the Didactic & Experimental Station of the Rzeszów University in Krasne. Eudominant *A. caliginosa* and *A. rosea* prevailed in the community in the arable land. Another eudominant, *L. terrestris*, was also identified in the permanent grassland community.

1. Modern agriculture, apart from the profits derived from land cultivation, should aim at supporting the biological diversity of soil organisms. In order to protect Lumbricidae and to sustain the beneficial role of earthworms in an ecosystem, it is necessary to monitor the negative changes in the populations of earthworm species attributed to various farming practices.
2. Earthworms are a bio-indicator of the soil environment quality. The representatives of all three morpho-ecological groups were found in both ecosystems, which is indicative of good planning and skillful use of land resources at the farming facilities of the Rzeszów University.

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