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Impact of land use and geological conditions on selected physical soil properties in relation to the earthworm abundance and biomass along an altitudinal gradient in Slovakia

Abstract: The aim of the study was to analyse the impact of land use and altitudinal gradient including geological conditions on selected soil physical properties with subsequent effect on earthworms as important soil organisms. The research was conducted at three study sites (Očová – OC, Tajov – TA, Liptovská Teplička – LT) situated in the different climatic and natural conditions of Slovakia each with 3 plots differing in land use (arable land - AL, permanent grasslands – PG, forest land – FL). During 2014 over two periods, we measured soil penetration resistance (PR) with total depth of the measurement (DP) and soil moisture (SM). Earthworms were hand sorted counted and weighed. We found out high variability of measured parameters conditioned by time, space (altitudinal gradient) and land use. PR values of all measurements ranged from 0.19 to 5.00 MPa, DP values from 0.02 to 0.80 m and soil moisture from 2 to 50%. Paired samples test confirmed differences between different land use types mainly between AL and FL plots. There were confirmed significant differences between three ecological gradients in all observed properties with one exception. Correlations among observed variables under different altitudinal gradients and land use types were found. The earthworm density and biomass was significantly higher in permanent grasslands compared to forest and arable land. In arable land, the earthworm density and biomass negatively correlated with the penetration resistance and positively with the depth of the total measurements. In permanent grasslands earthworm biomass positively correlated with soil moisture.

Keywords: Penetration resistance, soil moisture, soil depth, land use change, earthworms

INTRODUCTION

Natural conditions and land use has permanent influence on soil properties and vegetation cover (Dupouey et al. 2002). Any change can affect the aboveground and belowground part of ecosystems including soil. The duration and land use type determines the soil physical and chemical properties with subsequent effect on soil biota. A large part of European land is currently devoted to agricultural activities (Vliet et al. 2015). Twenty-five per cent of Europe´s land is covered by arable land and permanent crops, 17% by pastures and mixed mosaics and 35% by forests (European Environment Agency 2010). Similarly, about 50% of the present Slovak land territory is agricultural land even though Slovakia is a predominantly mountainous country situated in the western Carpathian arch. Only a small part of Eastern Slovakia belongs to the eastern Carpathian region and the west-southern and east-southern part to the Panonian lowland. Communities vary from thermophilous in southern parts of the country, to mountainous in the higher altitude. Mountain regions cover more than 55% of the total land territory. The climate is temperate. Thus most of the Slovak territory should be covered by forest. The dominant rocks include sedimentary formations, but with granite and metamorphite mountain cores. Among the causes of landscape change are urbanization, agricultural intensification, land abandonment and forest expansion, international commerce and trade, new demands of land for nature conservation and development of renewable energy uses (Plieninger and Bieling 2012). Nowadays, land abandonment is becoming a serious trend in Slovakia, Poland and other parts of Europe accelerated by the retirement of the older generation of farmers and the significant migration of young people to urban areas (Kanianska et al. 2014, Bucala-Hrabia 2017).

Land use changes driven by intensification of agriculture over the past century have resulted in widespread deterioration of many soil properties influencing abundance and diversity of soil biota. Soil compaction is a physical form of soil degradation that alters soil structure, limits water and air infiltration and reduces root penetration in the soil. The consequences of soil compaction are still underestimated (Nawaz et al. 2013). Soil compaction has direct effects on physical soil properties and can be measured by penetration resistance. Soil compaction is mostly affected by water content, bulk density, soil texture

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and porosity. Soil susceptibility to compaction is the probability that soil becomes compacted when exposed to compaction risk. It can be low, medium, high and very high in dependence of soil properties and the set of external factors like, e.g. climate, soil use, etc. (Houšková and Montanarella 2008). Soil compaction influences soil productivity (Mueller et al. 2010) often resulting in yield reduction of most crops and decrease of soil fauna diversity and abundance. Earthworms are very sensitive to physical soil parameters thus they are used as good bioindicators of microclimate and physical status of soil. Soil compaction in cultivated lands affects mostly the upper layer of soil but so-called subsoil compaction is also observed. Subsoil compaction is a serious problem because it is expensive and difficult to alleviate and it has been acknowledged as a serious form of soil degradation by the European Union (Jones et al. 2003). There are about 200 000 hectares of compacted agricultural soils and about 500 000 hectares potentially compacted agricultural soils in Slovakia (Kobza 2014).

Earthworms are exposed to a range of natural and human induced disturbances including land use and management. Assessment of this impact is difficult and an integrated approach of the evaluation of abiotic and biotic parameters is required. Because of the abovementioned, the objective of this research was to analyse of the impact of land use type and altitudinal gradient on the soil physical properties related to soil compaction having an impact on the earthworm abundance and biomass.

STUDY AREA

The research was conducted at three study sites, situated in the different climatic and natural conditions of Slovakia, each with 3 plots differing in land use (arable land – AL, permanent grasslands – PG, forest land – FL) and altitudinal gradient. Očová study site (OC) is situated in Poľana Mountain from 418 to 422 m a.s.l. with Haplic Planosol developed on polygenic sediments. Tajov study site (TA) is situated at Kremnica Mountain from 580 to 595 m a.s.l. with Haplic Cambisol developed on slope deposits. Liptovská Teplička study site (LT) is situated in Low Tatras Mountain from 931 to 950 m a.s.l. with Rendzic Leptosol developed on dolomitic limestones (Fig. 1, Table 1, 2, and 3) (MESR, 2002).

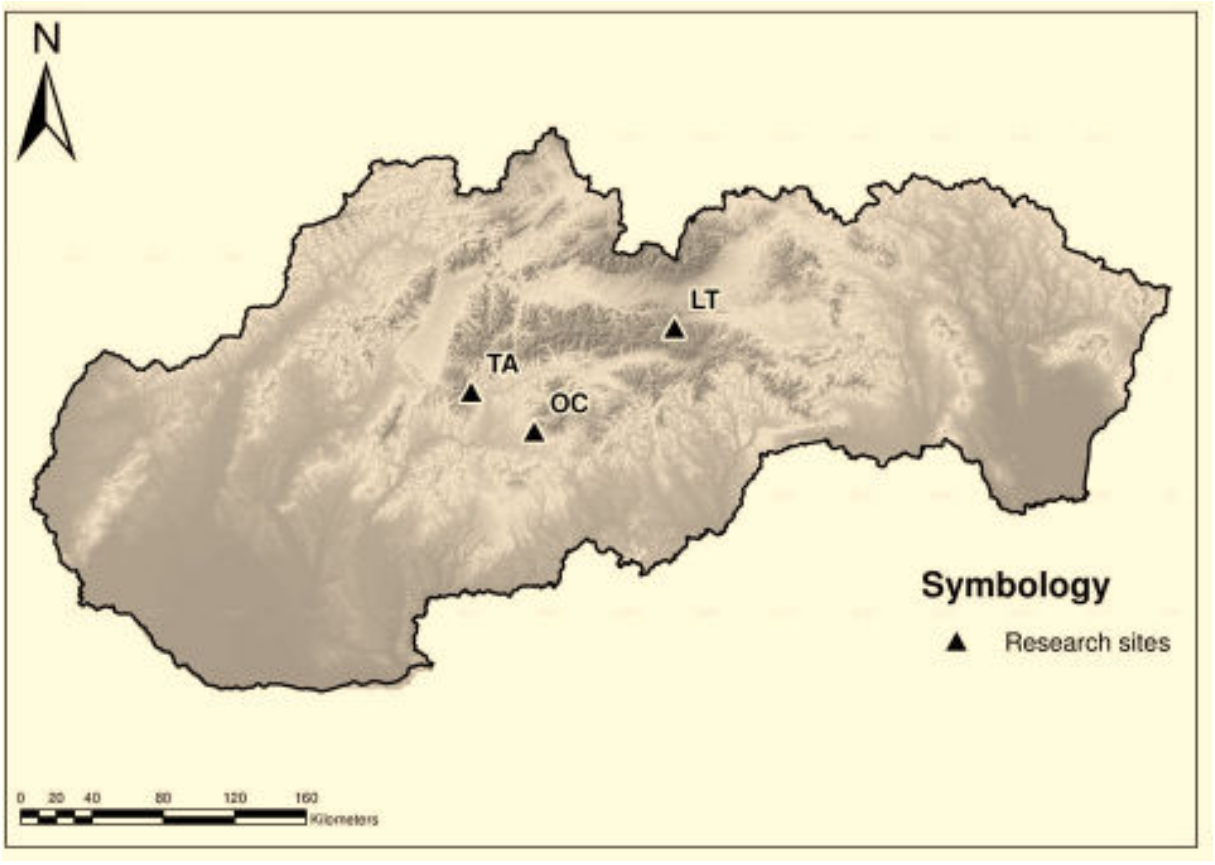

FIGURE 1. Location of the study sites in Slovakia. Abbreviations: OC – Očová, TA – Tajov, LT – Liptovská Teplička

TABLE 1. Geographic characteristics and land management at 3 study site under different land use

Study site	Geographical location	Soil type	Substrate	Soil texture	Altitude – AL (m)	Land management
OC	Poľ ana Mountain	Haplic Planosol	Polygenic sediments	Loamy	AL-418 PG-420 FL-422	AL-intensive farming PG-meadow
TA	Kremnica Mountain	Haplic Cambisol	Slope deposits	Loamy	AL-595 PG-597 FL-580	AL-extensive farming PG-sheep pasture
LT	Low Tatras	Rendzic Leptosol	Dolomitic limestone	Loamy	AL-950 PG-931 FL-945	AL-organic farming PG-meadow

Abbreviations: OC – Očová, TA – Tajov, LT – Liptovská Teplička, AL – Arable land, PG – Permanent grasslands, FL – Forest land.

TABLE 2. Climatic characteristics from the meterological stations nearest to the 3 study sites (according to Slovak Hydrometeorological Institute)

Study site	Meteorological station	Long-term average air temperature (°C)	Long-term average rainfall (mm)
OC	Vígľ aš	7.7	669
TA	Banská Bystrica	8.1	795
LT	Poprad	6.2	950

Abbreviations: OC – Očová, TA – Tajov, LT – Liptovská Teplička.

TABLE 3. Soil chemical properties at 3 study sites under different land use

Study site	Land use	pH_{KCl}	TOC	Nt	P	K	Mg
		($g \cdot kg^{-1}$)			($mg \cdot kg^{-1}$)		
OC	AL	4.90	17.27	1.86	13.88	171.75	602.25
	PG	6.24	51.81	6.09	223.01	329.74	632.49
	FL	3.89	65.75	3.84	2.76	171.75	759.30
TA	AL	4.84	15.45	1.62	33.56	221.90	127.36
	PG	4.19	42.30	4.14	0.52	136.22	631.80
	FL	5.06	145.44	7.38	13.49	329.74	717.57
LT	AL	6.70	34.50	3.05	38.23	199.36	949.12
	PG	6.94	51.30	5.16	3.82	300.33	1233.15
	FL	7.12	30.00	4.21	11.09	119.22	1273.57

Abbreviations: OC – Očová, TA – Tajov, LT – Liptovská Teplička, TOC – Total organic carbon, N_t – Total nitrogen, P – Available phosphorus, K – Available potassium, Mg – Available magnesium.

METHODS

During 2014 over two periods (summer – beginning of June, autumn – end of September, and beginning of October), we measured penetration resistance of soil (PR) total depth of the penetration resistance measurement (DP), and soil moisture (SM) at each study sites and plots in 10 replications. Soil moisture level (SM) was measured at 0.05 m depth by soil moisture sensor (ThetaProbe) in the soil moisture volume percentage by measuring the changes in the dielectric constant. Penetration resistance (PR) was measured with an electronic penetrometer (Eijkelkamp Penetrologger) with a cone diameter of 1 cm^2 and a 60° top angle cone with the maximum operational depth of 0.80 m. Cone resistance was recorded in MPa per 0.00–0.80, and sub sequently recalculated per layers of 0.00–0.20, and 0.20–0.80 m with the aim of observing the differences in penetration resistance in upper soil layer and subsoil. The measurement gives a continuous record of the penetration resistance of the cone with depth (DP – total depth of the penetration resistance measurement). Some areas were so dry, compacted or shallow that the probe couldn´t be inserted to the depth of 0.80 m. Soil and substrate conditions play here an important role.

At each study site and plots, earthworms were hand sorted from seven soil monoliths (35 cm×35 cm ×20 cm) placed in line in 3 m distance. The earthworms were counted and collected. Earthworms from deeper soil layers were expelled by 1.5 L of 0.2% formalin. The collected earthworms were weighed. The earthworm density and biomass from soil monoliths were recalculated per square meter.

We used a paired samples test to examine the differences in physical properties between the three land use types (arable land, permanent grasslands and forest land) and the three altitudinal gradients. Correlation analyses were conducted using the Spearman correlation coefficients to identify relationships between earthworms and selected physical soil properties. All analyses were performed with the statistical software PASW Statistics (version 18.0).

RESULTS AND DISCUSSION

We found out high variability of measured parameters determined by time, space (altitudinal gradient) and land use types. Penetration resistance values of all measurements ranged from 0.19 to 5.00 MPa, depth of penetration measurement from 0.02 to 0.80 m, and soil moisture from 2 to 50% (Table 4, 5, and 6).

The penetration resistance of all depth, at all study sites and in all different land use types was higher in summer compared to autumn aspect when

TABLE 4. Descriptive statistics for the penetration resistance (MPa)

Land use type	AL			PG			FL		
Depth	0–0.80	0–0.20	0.20–0.80	0–0.80	0–0.20	0.20–0.80	0–0.80	0–0.20	0.20–0.80
Očová – summer aspect									
Mean	4.68	3.73	5.00	4.23	2.81	4.78	4.34	3.17	4.81
Minimum	4.19	1.78	5.00	1.68	0.60	2.06	2.15	1.51	2.39
Maximum	4.90	4.61	5.00	4.78	4.13	5.00	4.77	4.10	5.00
S.D.	0.20	0.79	0.00	0.88	1.21	0.91	0.74	0.71	0.81
Očová – autumn aspect									
Mean	2.73	1.41	3.20	1.71	1.19	1.91	3.19	1.22	3.89
Minimum	1.88	0.95	1.90	1.47	0.83	1.58	1.63	0.89	1.90
Maximum	3.96	1.94	4.80	2.09	1.48	2.39	4.33	2.33	5.00
S.D.	0.77	0.26	1.04	0.20	0.18	0.24	0.85	0.40	1.08
Tajov – summer aspect									
Mean	4.15	2.52	4.74	4.68	3.72	5.00	4.64	3.55	5.00
Minimum	3.28	0.55	3.90	4.42	2.68	5.00	4.25	1.98	5.00
Maximum	4.87	4.48	5.00	4.82	4.26	5.00	4.89	4.57	5.00
S.D.	0.62	1.53	0.40	0.11	0.43	0.00	0.21	0.86	0.00
Tajov – autumn aspect									
Mean	3.08	1.41	3.68	3.91	2.15	4.55	3.45	2.05	3.98
Minimum	1.57	0.58	1.77	2.28	1.23	2.39	1.41	0.82	1.63
Maximum	4.60	3.42	5.00	4.65	3.60	5.00	4.82	4.28	5.00
S.D.	1.13	0.93	1.33	0.66	0.61	0.82	1.31	1.10	1.48
Liptovská Teplička – summer aspect									
Mean	3.94	1.71	4.73	4.25	2.05	5.00	4.28	2.26	5.00
Minimum	3.41	0.83	4.17	3.75	0.66	4.80	3.75	0.87	4.73
Maximum	4.52	3.09	5.00	4.59	3.37	5.00	4.66	3.63	5.00
S.D.	0.34	0.61	0.32	0.23	0.79	0.08	0.28	0.89	0.12
Liptovská Teplička – autumn aspect									
Mean	3.37	0.62	4.30	3.93	1.49	4.79	4.02	1.42	4.96
Minimum	2.79	0.19	3.65	3.22	0.50	4.12	3.50	0.50	4.51
Maximum	4.02	1.10	5.00	4.39	2.55	5.00	4.42	2.68	5.00
S.D.	0.39	0.31	0.46	0.41	0.81	0.33	0.30	0.74	0.22

Abbreviations: AL – Arable land, PG – Permanent grasslands, FL – Forest land, – S.D. Standard deviation.

soil moisture content was higher. This confirmed that soil compaction is mostly affected by water content (Nawaz et al. 2013). The degree of compaction significantly depends also on soil texture (Gomez et al. 2001, Hettiaratchi 1987) that is loamy at all three study sites. Loamy soils are moderately susceptible to soil compaction. At LT study site, the highest PR 0–0.8 values were recorded in forest land and the lowest in arable land with organic farming. Similarly, at TA study site the lowest PR 0–0.8 values were recorded in arable land, but the highest in permanent grasslands. On the contrary, at OC study site, PR 0–0.8 values in permanent grasslands were the lowest. The variable situation was also in PR values of top soil (PR0–0.20) and sub soil (PR0.20–0.80). The most compacted sub soil was in summer, at OC study site in arable land and at TA and LT study sites in forest land and permanent grasslands (Table 4). Thus could be observed the influence of soil types on soil susceptibility to compaction. According to Houšková and Montanarella (2008), Planosol (in OC) is soil type with high, Cambisol (in TA) with medium, and Leptosol (in LT) with low susceptibility to compaction.

The lowest variability in the depth of penetration resistance measurements was observed between three different land use types at LT study site. The soil (Rendzic Leptosol) was developed on dolomitic limestone, which determined its shallowness and skeletness. The deepest values were measured at OC study site in permanent grasslands (0.78 m), at TA and LT study sites in arable lands (0.45 and 0.30 m) (Table 5).

TABLE 5. Descriptive statistics for the depth of penetration resistance measurement (m)

Study site	OC			TA			LT		
Land use	AL	PG	FL	AL	PG	FL	AL	PG	FL
Summer aspect									
Mean	0.06	0.15	0.14	0.18	0.06	0.07	0.24	0.14	0.14
Minimum	0.02	0.04	0.04	0.03	0.04	0.02	0.11	0.08	0.06
Maximum	0.16	0.63	0.68	0.36	0.11	0.15	0.34	0.23	0.25
S.D.	0.04	0.17	0.18	0.13	0.02	0.04	0.08	0.04	0.06
Autumn aspect									
Mean	0.58	0.78	0.41	0.45	0.29	0.36	0.30	0.21	0.18
Minimum	0.25	0.70	0.13	0.07	0.08	0.03	0.17	0.12	0.11
Maximum	0.80	0.80	0.79	0.80	0.80	0.80	0.38	0.36	0.28
S.D.	0.21	0.03	0.22	0.29	0.20	0.31	0.06	0.08	0.06

Abbreviations: OC – Očová, TA – Tajov, LT – Liptovská Teplička, AL – Arable land, PG – Permanent grasslands, FL – Forest land, S.D. – Standard deviation.

TABLE 6. Descriptive statistics for the soil moisture in % by volume

Study site	OC			TA			LT		
Land use	AL	PG	FL	AL	PG	FL	AL	PG	FL
Summer aspect									
Mean	13.40	24.00	10.90	13.40	13.70	11.00	27.30	26.50	11.20
Minimum	4.00	18.00	6.00	7.00	9.00	2.00	21.00	20.00	7.00
Maximum	22.00	29.00	15.00	18.00	19.00	15.00	33.00	35.00	17.00
S.D.	6.20	3.66	2.59	3.14	2.90	3.90	3.44	5.02	3.54
Autumn aspect									
Mean	35.20	39.90	36.90	38.60	40.90	33.40	19.80	46.00	31.00
Minimum	28.00	35.00	27.00	28.00	33.00	21.00	6.00	41.00	18.00
Maximum	40.00	47.00	43.00	46.00	46.00	43.00	27.00	50.00	49.00
S.D.	3.43	4.21	4.01	4.54	4.46	6.76	6.60	2.61	9.79

Abbreviations: OC – Očová, TA – Tajov, LT – Liptovská Teplička, AL – Arable land, PG – Permanent grasslands, FL – Forest land, S.D. – Standard deviation.

The higher soil moisture values were measured in autumn compared to summer. The highest soil moisture content among all study sites and in all different land use types was measured in permanent grasslands. On the other hand, the lowest soil moisture content values were measured in forest land (Table 6). The positive influence of grasslands on soil water holding capacity was confirmed. Vegetation type has a significant influence on soil moisture dynamics (Chen et al. 2008) and can mediate the soil moisture response to precipitation and change the spatial distribution of soil moisture (Vivoni et al. 2008).

The paired samples test on differences between three different land use types (AL, PG and FL plots) confirmed statistical significant differences between AL and FL plots in several observed soil physical properties (PR, PR20, PR20–80, DP). Between AL and PG as well as PG and FL plots statistical significant difference was observed only in soil moisture. From the altitudinal gradient point of view, significant differences in all observed properties with the exception of penetration resistance measured in 0–0.2 m depth were proved between OC and LT as well as TA and LT study sites. There were found no statistical differences only between OC and TA, with study sties differing only about 170 m at altitude. There were confirmed significant differences between three ecological gradients in all observed properties with the exception of penetration resistance measured in 0–0.2 m depth (Table 7).

This trend is consistent with a number of worldwide studies that have examined the impact of altitudinal gradient and land use on abiotic and biotic soil properties (e.g. Bojko and Kabala 2016; Bucala et al. 2015, Taguas et al. 2015, Trabaquini et al. 2015, Zhao et al. 2015). Correlations among the variables under different altitudinal gradient and land use type are presented in Table 8.

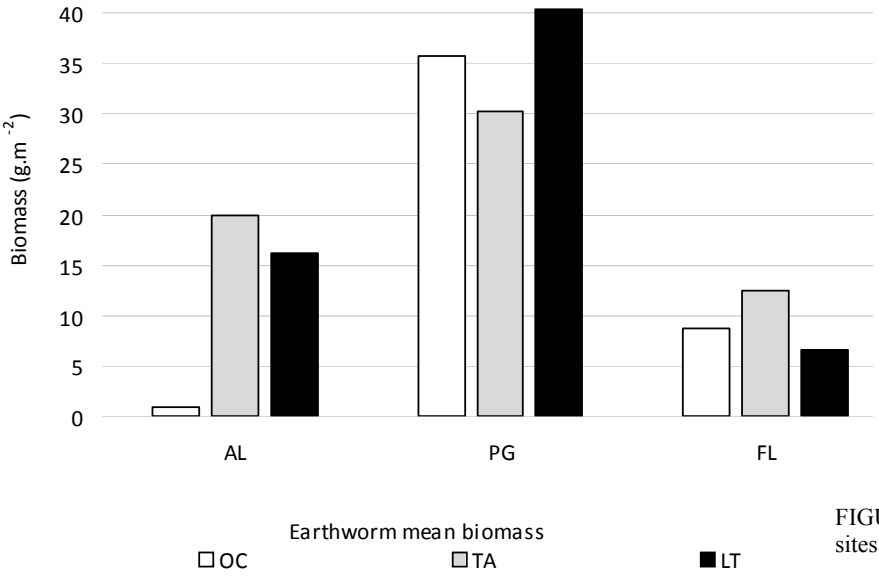

FIGURE 2. Earthworm number at 3 study sites under different land use type (ind·m^{-2})

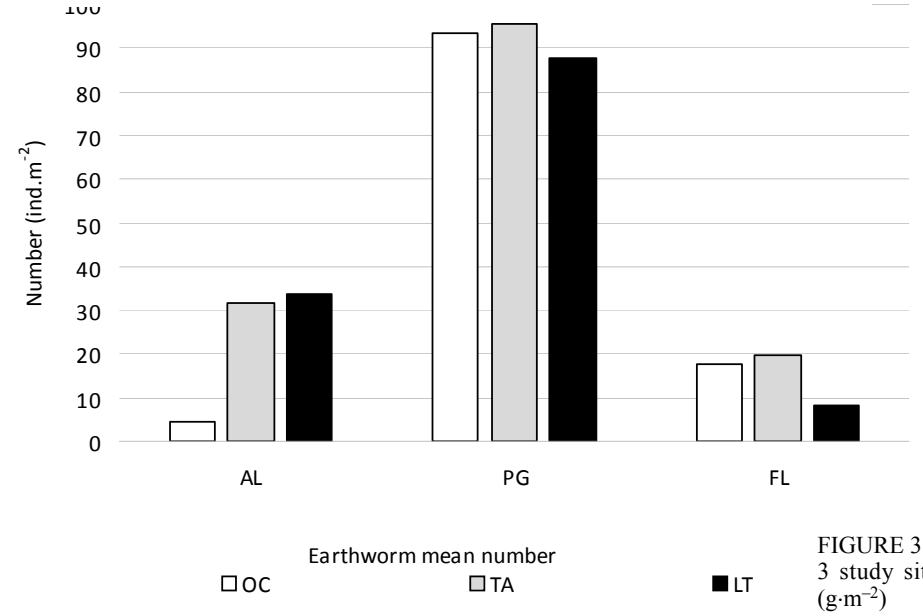

FIGURE 3. Earthworm fresh body biomass at 3 study sites under different land use type (g·m^{-2})

TABLE 7. Paired samples test on differences between 3 different land use types and 3 different altitudinal gradients of selected soil physical properties (n=60)

Compared properties										
Compared pair	PR		PR20		PR20–80		DP		SM	
	t	p	t	p	t	p	t	p	t	p
AL – PG	-0.899	0.372	-2.000	0.050	-0.457	0.649	0.913	0.365	-4.908	**0.000**
AL – FL	-2.468	**0.017**	-2.394	**0.020**	-2.238	**0.029**	2.561	**0.013**	1.620	0.111
PG – FL	-1.423	0.160	-0.293	0.770	-1.534	0.130	1.633	0.108	8.560	**0.000**
OC – TA	-0.560	0.124	-0.357	0.722	-1.848	0.070	1.591	0.117	0.395	0.694
OC – LT	-5.441	**0.000**	1.767	0.082	-6.455	**0.000**	6.307	**0.000**	4.653	**0.000**
TA – LT	-3.761	**0.000**	1.026	0.309	-4.705	**0.000**	4.903	**0.000**	3.921	**0.000**

t – test value, significant at $p \leq 0.05$.

Abbreviations: PR – Penetration resistance in the depth of 0–0.80 m, PR20 – Penetration resistance in the depth of 0–0.20 m, PR20–80 – Penetration resistance in the depth of 0.20–0.80 m, DP – Depth of penetration resistance measurement, SM – Soil moisture in the depth of 0.05 m, AL – Arable land, PG – Permanent grasslands, FL – Forest land, OC – Očová, TA – Tajov, LT – Liptovská Teplička.

TABLE 8. Spearman's correlation coefficients for penetration resistance in different depth, depth of penetration resistance measurement and soil moisture under 3 different land use types and 3 different altitudinal gradients (n=60)

	PR	PR20	PR20–80	PR	PR20	PR20–80	PR	PR20	PR20–80
Land use	AL			PG			FL		
DP	**-0.990****	**-0.714****	**-0.971****	**-0.984****	**-0.889****	**-0.859****	**-0.994****	**-0.951****	**-0.811****
SM	**-0.454****	0.132	**-0.429****	**-0.601****	**-0.557****	**-0.487****	**-0.548****	**-0.523****	**-0.413****
Altitudinal gradient	OC			TA			LT		
DP	**-0.977****	**-0.512****	**-0.969****	**-0.985****	**-0.746****	**-0.968****	**-0.975****	**-0.877****	**-0.911****
SM	**-0.475****	-0.432**	**-0.417****	0.154	0.233	0.135	0.041	0.060	0.100

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level.

Abbreviations: PR – Penetration resistance in the depth of 0–0.80 m, PR20 – Penetration resistance in the depth of 0–0.20 m, PR20–80 Penetration resistance in the depth of 0.20–0.80 m, DP – Depth of penetration resistance measurement, SM – Soil moisture in the depth of 0.05 m, AL – Arable land, PG – Permanent grasslands, FL – Forest land, OC – Očová, TA – Tajov, LT – Liptovská Teplička.

Significant negative correlation rate was measured between penetration resistance and depth of the measurement under all different altitudinal gradients and land use types. Moreover penetration resistance negatively correlated with soil moisture under all land use types and at OC study site. There were two exceptions, TA and LT study sites.

As our results confirmed natural characteristics determined by elevation including land use types with applied specific management have strong effect on abiotic soil properties. And soil biota is subsequently affected by abiotic soil properties.

The lowest mean number of earthworms was found in intensively managed arable land at OC study site (4.66 ind·m^{-2}) and the highest in permanent grasslands used for sheep grazing at TA study site (95.63 ind·m^{-2}) (Fig. 2). Among three different land use types, the highest earthworm density was measured in permanent grasslands at all three study sites followed by arable land at LT (with organic farming) and TA and by forest land at OC study site. The same trend was observed in case of earthworm biomass. The lowest mean fresh body biomass of earthworms was found in arable land at OC study site (0.82 g·m^{-2}) and the highest in permanent grasslands at LT study site (40.35 g·m^{-2}) (Fig. 3).

The correlation analysis between earthworm characteristics and soil physical properties under different land use and altitudinal gradient is reported in Table 9.

In arable land the earthworm density and biomass negatively correlated with the penetration resistance and positively with the depth of the total measurements. This negative effect of soil compaction on earthworms is consistent with other studies that have shown mechanical loosening to be a source of earthworm mortality (Smith et al. 2008, Ernst and Emmerling 2009; Vogel et al. 2017). In permanent grasslands, earthworm biomass positively correlated with the soil moisture. Soil moisture is considered, apart from food supply, to be a key environmental factor for earthworm activity, growth and reproduction (Perreault and Whalen 2006) and high soil moisture content could contribute to higher earthworm biomass (Tian et al. 2000). From the altitudinal gradient point of view, the earthworm density and biomass negatively correlated with the depth of the measurement and positively with the soil moisture at TA study site. At

TABLE 9. Spearman´ s correlation coefficients for earthworm density, biomass and soil physical properties

	ED	EB	ED	EB	ED	EB
Land use	AL		PG		FL	
PR20	**-0.478***	**-0.579****	-0.154	-0.093	-0.286	-0.251
DP	**0.446***	**0.588****	0.182	0.168	0.309	0.328
SM	0.295	0.263	0.263	**0.440***	0.155	0.244
Altitudinal gradient	OC		TA		LT	
PR20	-0.224	-0.305	0.331	0.404	-0.062	-0.027
DP	0.313	0.384	**-0.563****	**-0.586****	-0.260	-0.291
SM	**0.557****	0.411	**0.544***	**0.497***	0.189	0.238

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level

Abbreviations: ED – Earthworm density, EB – earthworm biomass, PR20 – Penetration resistance in the depth of – -0.20 m, DP – Depth of penetration resistance measurement, SM – soil moisture in the depth of 0.05 m, AL – Arable land, PG – Permanent grasslands, FL – Forest land, OC – Očová, TA – Tajov, LT – Liptovská Teplička.

OC study site the earthworm density positively correlated with the soil moisture. At LT study site in shallow Rendzic Leptosol no correlations were recorded. The abundance of the earthworms is determined also by geological substrate. Substrate determines soil texture and grain´s size and shape. Earthworms prefer fine particles. Coarse particles from dolomitic limestone in LT can be negative factor for earthworms either because the abrasive action of such grains that damages earthworm skin or because this soil retains less water (Laossi et al. 2010).

CONCLUSIONS

The results confirmed the big impact of land use, altitudinal gradient, soil type, texture and geological substrate and on selected physical properties. In the current period of rapid land use changes, this points also to their big impact on soil organisms. We found out high variability of measured physical parameters conditioned by time, space (altitudinal gradient) and land use. Penetration resistance of all depth, at all study sites and in all different land use types was higher in summer compared to autumn aspect when soil moisture content was higher. The highest soil moisture content among all study sites and in all different land use types was measured in permanent grasslands. On the other hand, the lowest soil moisture content values were measured in forest land. The most compacted sub soil was in summer, at OC study site in arable land and at TA and LT study sites in forest land and permanent grasslands. The lowest variability in the depth of penetration resistance measurements was observed between three different land use types at LT study site with shallow Rendzic Leptosol with the low susceptibility to compaction. Paired samples test confirmed differences between different land use types, mainly between AL and FL plots. Between three ecological gradients significant differences were confirmed in all observed properties with one exception. Correlations among observed variables under different altitudinal gradients and land use types were found. The earthworm density and biomass was significantly higher in permanent grasslands compared to forest and arable land. In arable land, earthworm density and biomass negatively correlated with the penetration resistance and positively with the depth of the total measurements. In permanent grasslands earthworm biomass positively correlated with the soil moisture. Permanent grasslands have positive effect on earthworm populations. Loss of soil fauna in arable lands is connected with intensification. Our results confirmed that in addition to natural conditions land use has a significant impact on soil physical and biological properties, which should be taken into account in landscape planning and management.

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