PROCEEDINGS BOOK
12th ICEEE–2021
"Global Environmental Development & Sustainability: Research, Engineering & Management"
November 18 – 19, 2021 RKK – Óbuda University, Budapest, Hungary
ISBN: 978-963-449-256-6 **www.iceee.hu**

CONNECTION BETWEEN EARTHWORMS AND SOIL PARAMETERS

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Abstract *Earthworms play a determining role in forming soil organic matter, their presence is a good indicator of soils' biological activity and soil health. The main question of the research was if there was any effect of earthworms on soil characteristics, especially the organic matter content or vice versa. The investigated area was the Gödöllő Hillside. Ten sites were chosen, mainly in semi-natural areas. The earthworms were counted and soil samples were collected from 25×25×25 cm pits, 5 pits per site. Soil samples were analysed by a NIRsoil scanner device. Four earthworm species were found during the research: Aporrectodea rosea, Lumbricus terrestris, Lumbricus caliginosa and Eisena fetida. There were 4 sites characterized by sandy texture where no earthworms were present. The NIR device measured pH, humus, N, K, clay content and cation exchange capacity. There were significant connections between the number and the weight of adults and the soil parameters, and there was no significant connection in the case of the number of juvenile earthworms, however. Based on the medium strength of the correlation between the soil parameters and earthworm characteristics, we can conclude that more soil parameters have effects on earthworm numbers and weight than what was measured.*

Keywords *soil-earthworm relation, soil organic matter, soil texture, soil moisture, species richness*

INTRODUCTION

Perhaps none of the terrestrial animals are as important as earthworms [1]. Earthworms play an essential role in natural soil formation processes such as humus formation. Few animals play an important role in the history of topsoil [2]. In earlier articles of Salomé et al. (2010) earthworms are mentioned as having an important role in nature, whereby they play the role of „ecosystem-engineers" in natural soils [3-4]. Worldwide they can be divided into 23 families and within those families 700 genera and 7000 species [5]. Earthworms are greatly affected by environmental factors. Soil moisture content and temperature are perhaps the most important factors. They rest in winter due to the cold andin summer due to high temperatures [6]. An increase in precipitation has a negative effect on earthworm occurrences [7]. A large percentage of earthworms are found in the upper 20% of the soil [8]. Research suggests that some species can even survive for months in a 100% H_2O medium [9].
As a result of the mixing of the soil in forests, grains became more resistant to frost and their quality also improved [10]. Debris from withered leaves (they grind the plant food with small gravel grains via their intestinal tract) and the excrement of earthworms results in a rich, thick layer of humus [2]. However, if the soil is adequately saturated with organic matter, it will not feed on plant parts. Their ability to mix soil is determined by their nutritional requirements. Not only do they play an important

role in soil cultivation, but also in changing the chemical composition of the soil [6]. The less the soil is disturbed, the greater the positive effect it has on the presence of earthworms [11]. The size of the soil fractions is important in the movements and feeding of earthworms. Dekemati et al. [10] measuredthe soil distribution between the grains at a depth of 0–20 cm. At the same time, the abundance of earthworms was also measured. The granules were air-dried and carefully sieved. Bouché [12] categorised them into 3 main types, firstly, the dead leaf dwellers (epigeic) species, secondly, those that penetrate deep into the soil (anexic), and thirdly those feeding on organic matter that has undergone certain humification processes, secondary degrader (endogeic) species. According to their role, they are classified into these 3 groups.

Zicsi [6] sampled 25×25 cm soil slices in the Gödöllő Hills, which he measured and examined their vital functions in different media (water only, sand only, topsoil, natural soils). Their weight and biomass were measured. We conducted our research based on these same methods with some minor changes. Dekemati et al. [10] used the methodology of earlier publications in the field, used 25×25 cmsampling pits at a depth of 30 cm, seven times with four replicates. The method of manual sorting (which is the most common and most frequently used method today) was chosen according to the ISO 2006 standard. The sites were randomly selected and the distance between the points was approximately 5–10 m. Horváth et al. [13] worked with 50×50 cm quadrants at a depth of 15 cm both in fenced and non-fenced areas. They examined the vegetation and number of earthworms and compared the number of earthworms, with the effects of wild boar rootings.

Salomé et al. [14] studied the abundance of earthworms at different mountain altitude levels. Biomass and other study categories were examined by the ANOVA analysis of variance method. Soil parameters, vegetation, forest elevation levels were monitored and earthworm communities were compared. Samples were taken in alpine, sub-alpine mountain and upland areas, as far as possiblefrom human influences. The mustard-extract method was used. The sampling pits were 20×20×20 cm. In the research, 27 species were identified (11 sub-alpine, 11 at mountain level and 19 at highland levels).

Due to the mosaic nature of the Gödöllő Hills Landscape Protection Area, the diversity of the physical genetic groups of the soil, the nature of the vegetation, as well as climate change and environmental effects, a diverse and rich earthworm population occurrence could be expected. In this respect, the sampling took place in the natural or near-natural areas of the land protection area for almost 2 years. The aim was to determine the biomass and number of earthworms and compare these with soil parameters to find out the relation between the two.

MATERIALS AND METHODS

The investigated area, the Gödöllő Hillside

The area of investigation was the Gödöllő Hillside (Figure 1.). The area's geology is characterized by the presence of loess materials and sand. The areas where the elevation is above 200 m above sea level (a.s.l.) are characterised by cool and moderately dry, while below 200 m a.s.l. is a warm and dry climate. The number of hours of sunshine per year is around 1950. The average annual temperature is 9.5–9.7°C in the north and 9.7–10.0° C in the south. This average temperature is expected for 194–198days. Frost-free period 186–190 days in the North, 195 in the South. The long-term average summer maximum is 32.5–33.0° C, the average winter minimum is -16°C.

Annual rainfall is relatively low, ranging from 540 to 580 mm. The average number of days covered by snow in the area is 36–40, with a maximum snow thickness of 22 cm. NW wind direction is predominant. Higher areas are used for forestry; lower ones are suitable for growing vegetables and other crops (Dövényi et al. 2010). Microclimates are different due to the diversity of habitats, and the climate is generally neither lowland nor mountainous (Láng, 1967). The wettest part is the area bordered by Gödöllő-Bag-Kistarcsa-Budapest-Rákospalota-Isaszeg-Pécel, the area bordered by Monor-Zsámbok-Veresegyháza is the driest (Demény, 2007).

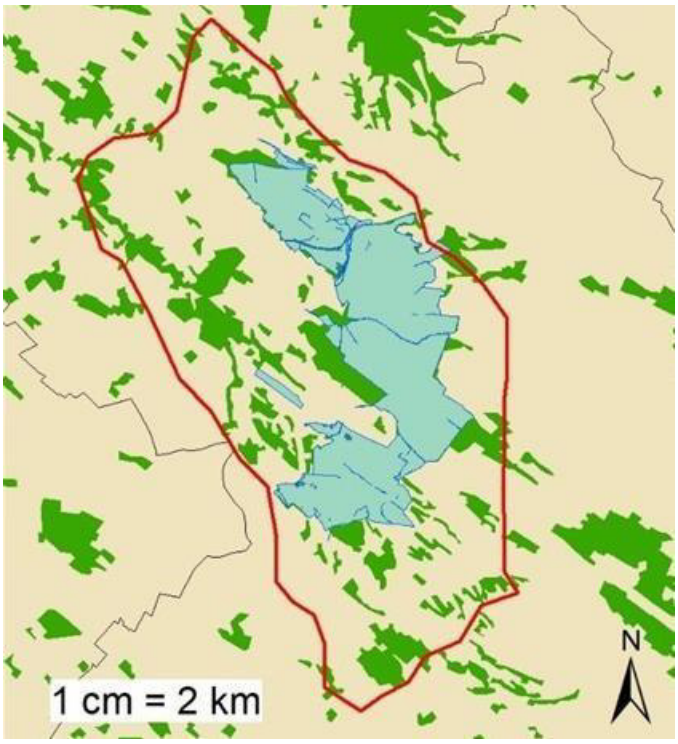

Figure 1. The area under investigation for soil-earthworm relations, the Gödöllő Hillside (green areas are forested, the red contour line is the limit of the hillside, while blue areas are marked for the Gödöllő Hillside Landscape Protection Area (mostly forested as well))

The Gödöllő Hills micro-region covers the watercourses on the left bank of the Danube, the rivers on the right side of the Galga and the catchment area of the Upper Tápió source region. The flow and flow of water move between extremes, resulting in a fairly dry area. They try to compensate for the water deficit with reservoirs, so there is a lot of it in the area, such as. Lake Isaszegi, Vácegresi fishpond, Babati reservoir (Dövényi et al. 2010). Lake Álomhegy in Veresegyháza is an important habitat for birds.

Groundwater is found at a depth of 5-6 m, only in the valleys and on the edges. These are moderately hard waters of calcium, magnesium, hydrocarbonate and low sulfate content. The depth of artesian wells is around 100 m (Dövényi et al. 2010). The water flow of watercourses fluctuates because water-permeable rocks are found on the surface (Láng, 1967).

Field measurements

The investigated area belongs mostly to the naturally protected area, so most of the samplings were done in forested land. Before the field sampling, Google Earth, geography, soil types and vegetation was analysed (Dövényi et al. 2010). Samples were taken at least 20 meters from human interventions, such as roads, fences, buildings, electric lines, etc. 25×25×25 cm pits were dug and earthworms were hand-picked. Five replicates were done at each site. Soil samples were collected from the same pit for analysis.

Measurements in the laboratory

Earthworms were classified in the laboratory. Juveniles and adults were separated and weighed. A handheld Near Infrared Reflectance (NIR) device (1300–2600 nm) was used for soil analyses in the laboratory. Soil organic matter (m/m%), cation exchange capacity (CEC, mmol/kg), pH(H_2O), total N (g/kg), plant-available P (ppm), exchangeable potassium (mmol/kg), clay (m/m%), soil moisture (m/m%) and on almost half of the samples exchangeable calcium (mmol/kg), exchangeable magnesium (mmol/kg), total aluminium (g/kg) and total iron (g/kg) were measured. Plant available potassium was calculated by the multiplication of the exchangeable potassium (mmol/kg) by 39.0983.

Statistical analyses
The statistical analyses were done based on ANOVA and linear regression.

RESULTS AND DISCUSSION

Earthworm classification of adult individuals resulted in 4 species as follows (numbers and species are related to the replicates, if there are less than five lines, it means that there were replicates with no data):
Gödöllő, university forest:
- *2* Aporrectodea rosea*, 1* Aporrectodea caliginosa
- *1* Eisenia fetida
- *2* Eisenia fetida

Szada, Margita Hill:
- *3* Aporrectodea caliginosa*, 2* Aporrectodea rosea
- *1* Aporrectodea rosea

Domony, Black Forest:
- *3* Aporrectodea caliginosa*, 2* Aporrectodea rosea
- *1* Aporrectodea rosea

Gödöllői Botanical Garden:
- *1* Lumbricus terrestris
- *7* Aporrectodea rosea
- *1* Aporrectodea caliginosa

Bag, Hajagvölgy Spring:
- *1* Aporrectodea rosea

Vácegres, alder forest:
- *1* Aporrectodea rosea

The results cannot be compared as no former data was found related to the earthworm species of the landscape protection area.

The basic statistical data of the number and weights of the earthworms
The basic statistical values of the number of earthworms are in Table 1.

Table 1. The basic statistical data of the number of earthworms found in the Gödöllő Hillside Landscape Protection Area

Name of sampling site	Number of earthworms (individual per square meter)				
	Maximum	Minimum	Median	Sum of squares	Average
Gödöllő, university, forest	64	0	16	26.29068	19.2
Szada, Margita Hill	352	0	32	146.2053	96
Domony, Black forest	16	0	0	8.763561	6.4
Gödöllő, University Campus, Botanical Garden	176	0	16	74.53321	51.2
Bag, Hajagvölgy Spring	16	0	16	8.763561	9.6
Vácegres, alder forest	48	0	0	22.62742	16

It is important that 4 of the 10 sites had no earthworms when examined in the field. In general, these areas are very sandy and thus very dry. The maximum numbers varied greatly, the lowest was 16 while the highest was 352. The highest maximum number was in Margita Hill where sampling was done on a former sampling site, in the same pits, so these pits can be considered as artificial wild boar rootings. It highlights that the loosening of compacted forest soil is favourable for earthworms. The second biggest number is related to the botanical garden that can be because of the good natural status of the area, compared to the ones under forestry use.
The basic statistical values of the weights of earthworms are in Table 2.

Table 2. The basic statistical data of the weights of earthworms found in the Gödöllő Hillside Landscape Protection Area

Name of sampling site	Weights of earthworms (grams per square meter)				
	Maximum	Minimum	Median	Sum of squares	Average
Gödöllő, university, forest	23.67	0	5.92	9.71	7.21
Szada, Margita Hill	223.55	0	25.09	9.76	61.66
Domony, Black forest	11.83	0	0	5.33	3.61
Gödöllő, University Campus, Botanical Garden	107.29	0	18.90	44.75	29.08
Bag, Hajagvölgy Spring	12.9856	0	2.88	5.36	4.19912
Vácegres, alder forest	9.69	0	0	4.24	2.70

The biggest maximum weight is also connected to the Margita Hill site. The second biggest maximum weight value was also similar to the second biggest maximum number that was in the botanical garden.

The basic statistical data of the measured soil parameters

The basic statistical data of the pH (H_2O) values of the examined soils are in Table 3.

Table 3. The basic statistical data of the pH (H_2O) of the examined soils in the Gödöllő Hillside Landscape Protection Area

Name of sampling site	pH (H_2O)				
	Maximum	Minimum	Median	Sum of squares	Average
Gödöllő, university, forest	7.4	6.8	7	0.22	7.06
Szada, Margita Hill	7.6	6.5	7.4	0.44	7.22
Domony, Black forest	7.1	6.5	6.8	0.23	6.88
Gödöllő, University Campus, Botanical Garden	7.3	6.6	6.8	0.30	6.88
Bag, Hajagvölgy Spring	7.3	6.7	7.2	0.25	7.10
Vácegres, alder forest	7.9	7.4	7.7	0.19	7.70

The pH of the upper 25 cm is mainly in the neutral, slightly acid and slightly alkalic categories. This is most likely the effect of the big lime content in the parent material (loess) that is due to the anthropogenic effects that can be found close to the surface sometimes. The basic statistical data of thesoil organic matter or humus content (m/m %) values of the examined soils are in Table 4.

Table 4. The basic statistical data of the soil organic matter or humus content (m/m%) of the examined soils in the Gödöllő Hillside Landscape Protection Area

Name of sampling site	soil organic matter or humus content (m/m%)				
	Maximum	Minimum	Median	Sum of squares	Average
Gödöllő, university, forest	6.2	2.3	2.8	1.59	3.62
Szada, Margita Hill	13.2	2.7	3.4	4.39	5.44
Domony, Black forest	2.4	1.6	1.8	0.33	1.86
Gödöllő, University Campus, Botanical Garden	5.2	2.2	4	1.13	3.94
Bag, Hajagvölgy Spring	6.8	1.3	2.3	2.20	2.96
Vácegres, alder forest	5.7	1.7	2.8	1.73	3.48

The highest maximum value belongs to Margita Hill (again) where the biggest maximum number and weights of the earthworms were found. However, the averages can be considered normal for forest soils. The Domony area had the lowest average and the Bag area had the lowest minimum values. The basic statistical data of the total nitrogen content (g/kg) values of the examined soils are in Table 5.

Table 5 The basic statistical data of the total nitrogen content (g/kg) of the examined soils in the Gödöllő Hillside Landscape Protection Area

Name of sampling site	total nitrogen content (g/kg)				
	Maximum	Minimum	Median	Sum of squares	Average
Gödöllő, university, forest	3	1.1	1.4	0.76	1.74
Szada, Margita Hill	6	1.3	1.7	1.95	2.6
Domony, Black forest	1.3	0.9	1.1	0.17	1.06
Gödöllő, University Campus, Botanical Garden	3.1	1.7	2.4	0.63	2.46
Bag, Hajagvölgy Spring	3.6	0.8	1.3	1.09	1.72
Vácegres, alder forest	3.3	1	1.9	0.88	2.1

The values are very low. The highest maximum value belongs to Margita Hill again, just as well as the highest average. Furthermore, the lowest minimum values are in Domony and Bag again. It is normal as total nitrogen is connected with soil organic matter content. The basic statistical data of the plant-available potassium (ppm) values of the examined soils are in Table 6.

Table 6. The basic statistical data of the plant-available potassium (ppm) of the examined soils in the Gödöllő Hillside Landscape Protection Area

Name of sampling site	plant-available potassium (ppm)				
	Maximum	Minimum	Median	Sum of squares	Average
Gödöllő, university, forest	222.86	175.94	195.49	17.92	195.49
Szada, Margita Hill	316.69	175.94	203.31	79.20	228.07
Domony, Black forest	164.21	39.09	43	53.85	73.498
Gödöllő, University Campus, Botanical Garden	195.49	46.91	152.48	52.79	123.546
Bag, Hajagvölgy Spring	195.49	113.38	152.48	32.83	152.48
Vácegres, alder forest	140.75	50.83	86.02	34.37	88.364

The highest maximum value belongs to Margita Hill again, just as well as the highest average. The lowest minimum values belong to Domony and the Gödöllő botanical garden that is also very similar to the alder forest of Vácegres. The basic statistical data of the clay content (m/m %) values of the examined soils are in Table 7.

Table 7. The basic statistical data of the clay content (m/m %) values of the examined soils in the Gödöllő Hillside Landscape Protection Area

Name of sampling site	clay content (m/m %)				
	Maximum	Minimum	Median	Sum of squares	Average
Gödöllő, university, forest	22.5	14.1	15.4	3.40	16.52
Szada, Margita Hill	33.2	10.8	18.4	9.10	20.42
Domony, Black forest	21.4	15	17.1	2.36	17.68
Gödöllő, University Campus, Botanical Garden	24	16	39	3.44	21.4
Bag, Hajagvölgy Spring	24	10	16	5.55	16.6
Vácegres, alder forest	29	16	22	5.45	21.8

The highest maximum value belongs to Margita Hill again, just as well as the highest average. The lowest minimum values belong also to Margita and the Bag. Averages are between 16.52 and 21.8, so the areas can be considered similar. The basic statistical data of the CEC (mmol/kg) values of the examined soils are in Table 8.

Table 8. The basic statistical data of cation exchange capacity (mmol/kg) of the examined soils in the Gödöllő Hillside Landscape Protection Area

Name of sampling site	cation exchange capacity (mmol/kg)				
	Maximum	Minimum	Median	Sum of squares	Average
Gödöllő, university, forest	277.5	111	150.5	64.02	169.46
Szada, Margita Hill	352.7	137	240.4	83.53	241.66
Domony, Black forest	149.1	80.5	89.8	27.63	103.18
Gödöllő, University Campus, Botanical Garden	232	138	197	43.11	185.2
Bag, Hajagvölgy Spring	209	119	159	32.43	161
Vácegres, alder forest	269	116	202	55.19	200.8

The highest maximum value belongs to Margita Hill again, just as well as the highest average. The lowest minimum value belongs to Domony. CEC can be related to soil organic matter, so in this case, it is also explained why Margita has the highest maximum value.

Statistical analyses of the connection between earthworms and soil data

The correlation (R) between the earthworm and soil data is moderately strong, and the R^2 value (coefficient of determination) shows that these soil data explain the variability in the number of adult earthworms by 50.5%. It means that other factors were not measured but affected the occurrence of earthworms.

The number of adult individuals was mostly influenced by the humus content in the negative direction, as the B (slope) value is -18.722 with humus (p=0.005). The clay also had a negative correlation (B=-3.177, p=0.002). The CEC has a small positive effect (B=0.374, p=0.017).

No significant connections were found in the case of the juvenile individuals.

The number of all earthworms was also influenced by soil characteristics but here the correlation is already weaker (R and R^2 values). Clay content was a stronger negative influencing factor (B=8.655, p=0.005), while CEC had a slightly positive influence (B=1.366, p=0.005) number of pieces.

The weight of the adult individuals was also influenced by the soil data (ANOVA table), the relationship is slightly weaker (R and R^2 values) than the number of individuals. Clay content was a negative influencing factor (B=-3.158, p=0.004), while CEC had a slightly positive influence (B=0.465, p=0.006) related to the number of pieces.

In contrast to the number of young individuals, there is already a correlation between their mass and soil characteristics. In this case, the clay content was also a negative influencing factor (B=-2.576, p=0.004), while the CEC had a slightly positive effect (B=0.42, p=0.003) on the number of pieces.

There is also a correlation between the mass of all earthworms and soil properties. In this case, the clay content was also the negative influencing factor (B=-5.732, p=0.003), while the CEC had a slightly positive effect (B=0.885, p=0.003) on the number of pieces.

CONCLUSIONS AND RECOMMENDATIONS

One of the main results of the research is the new data on earthworm species. We can not conclude about the diversity of the species as there were no former data found in the literature. So, the conclusion is that there is a data gap and the recommendation is that further researches are greatly needed in this area. The other results are related to the earthworm-soil relations. We can conclude that there is a relationship between soil data and the number of adult earthworms, as shown by the ANOVA of linear regression.

Based on the data, we can conclude that the main influencing measured factors are the clay content and the cation exchange capacity. Interestingly in the case of the adult individuals, there was a negative correlation between the number of adult individuals and the humus content We should expect it vice versa. Also interesting is that there were no significant connections found between the Ca-, Mg-, Al- and Fe-content of the soil. There should be as Ca is one of the major elements that is always cited in relation with earthworms, so we can conclude that there is more data needed.

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