

Impact of former long-term fertilization on springtail communities in a reforested experimental area

István HARTA¹ – Dániel WINKLER² – György FÜLEKY¹

1: Szent István University, Institute of Environmental Sciences, Páter Károly u. 1. Gödöllő H-2100, Hungary, Email: hartaistvan1990@gmail.com

2: University of Sopron, Institute of Wildlife Management and Vertebrate Zoology, Bajcsy-Zs. u. 4. Sopron H-9400, Hungary

Abstract: At the beginning of the 1970's, two fertilization experimental areas were established in Gödöllő. After different long-term fertilization treatments, sessile oak (*Quercus petraea*) and black locust (*Robinia pseudoacacia*) plantations were planted in the second half of the 1990's. In the present research, the effects of former fertilization were studied in these two different forests, with the help of soil Collembola communities as indicators. Soil cores and litter samples were collected from the chosen 30 plots to determine the most important soil parameters and to extract Collembola specimens. According to the results, soil organic carbon (SOC), AL-P₂O₅ and AL-K₂O contents were significantly higher in the two highest-dose treatments of the sessile oak plantation compared to the control. In the black locust plantation, only AL-P₂O₅ content differed significantly in the second highest-dose treatment when compared to the control. Among the two plantations significant differences can be observed in almost every parameter, except for AL-K₂O and nitrogen content. The effects of former fertilizer application are reflected in occasional differences in total Collembola abundance, species richness and diversity, mostly related to the treatments with the highest doses. Due to the relatively young age of the plantations, very few typical forest Collembola species were observed, while species characteristic for open habitats are still predominant. The higher SOC content in the black locust plots is well reflected in the higher Collembola abundance compared to the sessile oak plots. Nevertheless, species richness, diversity and equitability were higher in the plantations of the native sessile oak.

Keywords: black locust, sessile oak, afforestation, soil biota

Introduction

Fertilizers entering ecosystems have considerable impact on chemical and physical properties of the soil and the nutrient flow of the soil-plant system (e.g. Haynes and Naidu 1998; Kádár et al. 2007; Kovács and Füleky 1991). Therefore, reasonable use of soil nutrient stock is indispensable, as well as the investigations of nutrient flow and long-term effects of fertilization (Németh and Várallyay 1998). For this kind of researches, long-term fertilization experiments are the most appropriate due to the over-decade achievements providing important information on soil-plant nutrient turnover. With their help, long-term effects of treatments can also be investigated (Berzsenyi 2009) and useful information on changes in soil nutrient stock can be derived (Körshens 2006). Present researches often highlight also the environmental protection aspect of these types of experiments (e.g. Csathó et al. 2012; Kádár and Németh 2003; Szalókiné and Szalóki 2003; Szováti et al.

2006; Tolner et al. 2010). These considerations led to the reforestation of the area of former fertilization experiments established in 1970 in Gödöllő. These experimental areas have been used as arable land for centuries, but the natural vegetation corresponding to climatic and edaphic conditions was the forest. Over the course of the 48-year period experiment, research topics shifted towards the environmental effects of intensive fertilization (Kovács and Füleky 1991). In a unique way, on the plots of the former arable land, black locust (*Robinia pseudoacacia*) and sessile oak (*Quercus petraea*) plantations were established 20 years ago. Extending the area of forests including reforestation of low quality arable lands is an important objective worldwide (UN 2014; UNEP 2014), as well as in the European Union (CEU 2014). Reforestation can mitigate the effects of climate changing efficiently (Hooper et al. 2005), since forests can store a much larger amount of carbon compared to other land use types (Pan et al. 2011). Although plantations

lack the structural complexity of a mature forest, they mitigate the effects of radiation and wind (Cunningham et al. 2015), decrease soil erosion, increase biodiversity (Jackson et al. 2005), make connection among populations and thereby help gene flow (Gilbert-Norton et al. 2010) and participate in the biogeochemical cycle of carbon, oxygen and nutrients (Arneith et al. 2010). After forests were planted, only few results have been published from the experiment area of Gödöllő (Ockert 2006; Szováti et al. 2006; Tolner et al. 2010; Harta et al. 2016). Publications dealing with fertilization effects on biomass, growth, structure and nutrient flow of forests are scarce even worldwide (Burner 2005; Grunewald et al. 2007; Mäkipää 1994; Mirmanto et al. 1999; Plass 1972; Tanner et Kapos 1992; Turkington et al 1998). The presence of mesofauna is indispensable for the nutrient flow in soil (Giller et al. 1997). One of the most important groups is Collembola, which plays an important role in the mineralization of organic matter and also in the distribution of mycorrhiza. Through the responses reflected in their community characteristics, Collembola are considered as excellent test organisms for bioindication analyses. They can respond quickly to any type of soil degradations as well as the changes in land use (Paul et al. 2011; Sousa et al. 2006). The correlations between fertilization and soil biological characteristics are, however not fully clarified (Giller et al. 1997).

The aim of the current research was to study the effect of former fertilization on two types of plantations, as well as to evaluate the effect of forests recultivation with the help of selected indicator organisms (Collembola) of mesofauna.

Materials and methods

Research area

The experimental area is situated in the “Szárítópuszta” research field of Szent István University in Gödöllő (Pest County, Hungary), located in the Gödöllő hills at 247 m a.s.l., where climatic condition is moderately dry continental (Dövényi 2010). The soil type is rust-brown forest soil (Luvic Calcic Phaeozem) according to

the Hungarian classification system (Stefanovits 1972), formed on bedrock typed sand mixed loess. Soil thickness is 60–90 cm. The texture in the 0–20 cm layer is loamy sand, where the total porosity is 51.2 % and soil density is 1.58 g cm⁻³ on average (Ockert 2006). The ratio of the gravity pores is large (20.7%), indicating appropriate habitat for soil mesofauna. Nevertheless, the water holding capacity is weak. The nutrient management of this type of soil is basically low (Kovács and Füleky 1991).

Two plantations with different tree species, black locust (*Robinia pseudoacacia*) and sessile oak (*Quercus petraea*), were studied. The total area of the studied tree plantations is 11 900 m², whereof the assigned treatment plots cover 4622 m². In both plantations, 5 treatments were selected where different long term fertilization had been applied from the establishment of research fields until the plantation of trees. The extent of each treatment affected by a certain type of fertilization was at least 420 m². Treatments are indicated as SO1 (sessile oak – 1st treatment), SO2, SO3, SO4 and SO5, respectively; as well as BL1 (black locust – 1st treatment), BL2, BL3, BL4 and BL5, respectively. In both plantations, the 1st treatment always means the control, without any former fertilization.

The sessile oak plantation was established in a former crop rotation research field. The fertilizer doses changed depending on the cultivated crop. *Table 1* contains the fertilizer doses applied during the 25-year period of experiment before the sessile oak plantation was established (Kovács and Füleky 1991). The actual black locust plantation was a former maize monoculture where definite fertilizer doses were *Table 1*. Applied fertilizer doses in the plant rotation research field during the 25-year period before the establishment of the sessile oak (SO) plantation

Treatment	N	P ₂ O ₅	K ₂ O	Sum
kg * ha ⁻¹ * 25 y ⁻¹				
SO1	0	0	0	0
SO2	1660	1020	1288	3968
SO3	3270	1980	2418	7668
SO4	5400	3245	3923	12568
SO5	7530	4510	5428	17468

applied yearly in the assigned plots, depending on treatment category. *Table 2* contains the different fertilizer doses applied in this experiment during the 20-year period prior to the establishment of the black locust plantation.

Table 2. Applied fertilizer doses in the maize monoculture research field during the 20-year period, before the establishment of the black locust (BL) plantation

Treatment	N	P ₂ O ₅	K ₂ O	Sum
kg * ha ⁻¹ * 20 y ⁻¹				
BL1	0	0	0	0
BL2	1800	1200	1000	4000
BL3	3600	2400	2000	8000
BL4	5400	3600	3000	12000
BL5	7200	4800	4000	16000

Soil sampling and laboratory methods

From each selected plots, 5 soil cores (ca. 50 g) were collected randomly from the surface layer (0–20 cm). Composite samples were thoroughly mixed from every 5 soil samples collected from the same plots, thus, 30 samples were obtained in total. Soil samples were air-dried, crashed and sieved with a 2.0 mm grid size. During laboratory work, the following chemical parameters were determined from every soil samples; pH_{H₂O} in distilled water and pH_{KCl} in potassium-chloride suspension (Buzás 1988), soil organic carbon content (SOC) defined by wet oxidation with K₂Cr₂O₇ and H₂SO₄ according to the Tyurin method (Buzás 1988), accessible nitrogen (NO₃⁻ + NH₄⁺) by using potassium-chloride (Bacsó et al. 1972), ammonium-lactate soluble phosphorus (AL-P₂O₅) and potassium content (AL-K₂O) (Egnér et al. 1960), calcium-carbonate (CaCO₃) content (Buzás 1988) and soil texture type according to water binding capacity (K_A) (Buzás 1993).

Sampling and extraction of Collembola

From each selected plots, 5 soil cores of 100 cm³ volume (3.6 cm in diameter and 10 cm in depth) were sampled randomly. Collembola specimens were extracted from the soil samples within 14 days using Berlese–Tullgren funnels. Specimens

were identified to species level following main taxonomical keys by Deharveng (1982), Fjellberg (1980, 1998), Babenko et al. (1994), Zimdars & Dunger (1994), Weiner (1996), Jordana et al. (1997), Pomorski (1998), Bretfeld (1999), Potapov (2001), Thibaud et al. (2004) and Jordana (2012). Taxonomic classification is primarily based on the checklist of the Hungarian fauna (Dányi and Traser 2008).

Data analyses

To determine the differences among treatments, one-way ANOVA was performed for all soil parameters separately, while for the comparison of the two types of tree plantation two-way ANOVA was applied. Randomized experimental design ensured the independence of cases. Prior to ANOVA, the data were tested for normality and homoscedasticity (Chi square test, Levene's test, respectively). LSD_{5%} (Least Significant Difference) was counted to determine significant differences between the treatments, with a maximum allowed error rate of 5%.

For the evaluation of Collembola communities, three measures of species α diversity were calculated: the actual species richness, the Shannon–Weaver's index (Shannon and Weaver 1949) and Pielou's evenness index (Pielou 1966). The Shannon indices were compared according to the modified t-test proposed by Hutcheson (1970). Collembola abundance was expressed as the number of individuals per m². Dominance distribution was expressed by McNaughton's community dominance index (CDI) calculated as the sum of percentage abundance of the first and second most abundant species, respectively (McNaughton 1967). To compare abundance and species richness, Friedman's two-way analysis of variance (ANOVA) was used taking into account tree species and fertilization level simultaneously. Analyses were performed using the software SPSS vs20 (IBM Corp. Released 2011) and Past ver. 2.17b (Hammer et al. 2001).

Results

Soil parameters

Table 3 presents the defined soil parameters in

Table 3. Results of the measured soil parameters in the sessile oak (SO) plantations in the formerly fertilized plots (significant differences compared to the control are signed with bold numbers)

Treatment	pH _{KCl}	pH _{H₂O}	SOC %	AL-P ₂ O ₅	AL-K ₂ O	NO ₃ ⁻ + NH ₄ ⁺	K _A
				mg/kg			
SO1	5.45	6.28	1.51	80.03	165.00	10.23	26.33
SO2	5.00	6.01	1.57	95.83	183.33	12.47	27.00
SO3	4.61	5.70	1.66	148.67	184.33	9.97	27.00
SO4	4.72	5.70	1.87	211.33	221.00	12.63	26.67
SO5	4.56	5.57	2.11	280.00	270.33	12.83	27.00
LSD _{5%}	1.70	1.26	0.31	58.68	51.30	6.11	1.14

Table 4. Results of the measured soil parameters in the black locust (BL) plantations in the formerly fertilized plots (significant differences compared to the control are signed with bold numbers)

Treatment	pH _{KCl}	pH _{H₂O}	SOC %	AL-P ₂ O ₅	AL-K ₂ O	NO ₃ ⁻ + NH ₄ ⁺	K _A
				mg/kg			
BL1	6.35	7.00	2.21	10.57	217.00	15.13	29.00
BL2	6.37	6.98	2.30	24.74	209.67	8.97	28.67
BL3	6.30	6.95	2.19	27.17	212.67	15.60	29.67
BL4	5.96	6.68	2.11	63.47	191.00	9.37	29.00
BL5	6.26	6.85	2.22	45.60	188.33	9.00	28.33
LSD _{5%}	0.68	0.46	0.62	40.11	70.28	14.63	2.62

Table 4. Results of the measured soil parameters in the sessile oak (SO) and black locust (BL) plantations in the formerly fertilized plots (significant differences are signed with bold numbers)

	pH _{KCl}	pH _{H₂O}	SOC %	AL-P ₂ O ₅	AL-K ₂ O	NO ₃ ⁻ + NH ₄ ⁺	K _A
				mg/kg			
SO_mean	4.87	5.85	1.74	108.18	204.80	11.63	26.80
BL_mean	6.25	6.98	2.21	34.31	203.73	11.61	28.93
LSD _{5%}	0.52	0.38	0.23	22.00	27.50	4.45	1.13

the sessile oak plantation, divided by the former fertilizer types. According to the results, there is no significant difference among the two types of pH, however they show decreasing tendency towards to the higher fertilization doses. On the contrary, the amount of soil organic carbon (SOC) is higher in the soil where more intensive fertilization treatments occurred before the plantation; where treatments SO4 and SO5 are significantly different from the control (SO1). Both AL-P₂O₅ and AL-K₂O are increasing with the higher dose of fertilizers. Treatments SO3 (in the case of AL-P₂O₅ only), SO4 and SO5 (for both AL-P₂O₅ and AL-K₂O) differed significantly from the control. Among the nitrogen content and the K_A values no significant differences were observed.

Table 4 contains the defined soil parameters in the black locust plantation, divided by the former fertilizer types. Significant difference was found only in the AL-P₂O₅ content, between the treatment BL4 and the control (BL1).

The comparison results of the defined soil parameters of the two plantations (black locust and sessile oak) are presented in *Table 5*. Among the two plantations, significant differences can be observed in almost every parameter, except for AL-K₂O and nitrogen contents.

Both types of pH, the K_A value and also the SOC are higher in the black locust plantation, only the phosphorus content shows higher values in the soil of the sessile oak plantation.

Table 6. Mean abundance (ind. m⁻²) of Collembola species in the former fertilized plots of sessile oak and black locust plantations.

	sessile oak					black locust				
	SO1	SO2	SO3	SO4	SO5	BL1	BL2	BL3	BL4	BL5
Hypogastruridae										
<i>Ceratophysella luteospina</i> (Stach, 1920)	0	0	0	13	20	0	0	0	0	0
<i>Willemia virae</i> Kaprus, 1997	300	127	160	220	280	313	420	213	187	193
Neanuridae										
<i>Neanura muscorum</i> (Templeton, 1835)	0	13	0	7	27	0	0	0	0	0
<i>Pseudachorutes parvulus</i> Börner, 1901	27	0	27	47	33	27	0	0	0	7
<i>Pseudachorutes pratensis</i> Rusek, 1973	13	0	0	0	0	0	7	0	13	0
Odontellidae										
<i>Superodontella lamellifera</i> (Axelson, 1903)	0	0	0	7	13	0	0	0	0	0
Onychiuridae										
<i>Protaphorura armata</i> (Tullberg, 1869)	433	287	407	500	747	527	440	453	440	347
<i>Protaphorura campata</i> (Gisin, 1952)	0	13	0	0	20	20	7	13	0	47
Tullbergidae										
<i>Mesaphorura critica</i> Ellis, 1976	80	60	113	220	93	400	520	540	413	373
<i>Mesaphorura italica</i> (Rusek, 1971)	73	53	13	47	0	107	27	20	47	53
<i>Mesaphorura krausbaueri</i> Börner, 1901	360	100	387	133	100	347	513	467	487	453
<i>Mesaphorura macrochaeta</i> Rusek, 1976	33	33	13	40	27	320	173	267	253	180
<i>Metaphorura denisi</i> Simon, 1985	0	7	0	0	0	0	0	0	0	0
Entomobryidae										
<i>Entomobrya dorsalis</i> Uzel, 1891	0	7	20	13	13	0	7	0	0	0
<i>Entomobrya multifasciata</i> (Tullberg, 1871)	320	260	240	567	220	513	473	487	460	433
<i>Entomobrya muscorum</i> (Nicolet, 1842)	0	13	0	0	0	0	0	0	0	0
<i>Lepidocyrtus cyaneus</i> Tullberg, 1871	13	0	0	0	0	0	27	0	13	0
<i>Lepidocyrtus lanuginosus</i> (Gmelin, 1788)	173	207	320	267	427	147	180	133	140	133
<i>Pseudosinella alba</i> (Packard, 1873)	173	113	167	180	133	60	87	47	60	67
<i>Pseudosinella petterseni</i> Börner, 1901	0	13	20	20	33	0	20	33	13	20
<i>Heteromurus major</i> (Moniez, 1889)	13	0	0	0	0	0	0	0	0	0
<i>Heteromurus nitidus</i> (Templeton, 1835)	0	13	0	33	0	0	0	7	0	0
<i>Orchesella cincta</i> (Linnaeus, 1758)	187	193	160	200	147	167	233	227	120	153
<i>Orchesella flavescens</i> (Bourlet, 1839)	0	0	0	0	7	0	0	0	0	0
<i>Orchesella multifasciata</i> (Stscherbakow, 1898)	307	300	433	507	447	240	267	287	120	267
Isotomidae										
<i>Cryptopygus bipunctatus</i> (Axelson, 1903)	0	0	20	27	13	0	0	13	0	0
<i>Folsomia manolachei</i> Bagnall, 1939	613	700	573	533	567	1180	720	1267	1047	833
<i>Folsomia quadrioculata</i> (Tullberg, 1871)	360	427	413	420	373	920	1093	787	1027	973
<i>Isotomiella minor</i> (Schäffer, 1896)	327	340	387	440	347	120	120	160	200	133
<i>Parisotoma notabilis</i> (Schäffer, 1896)	633	700	600	507	627	1133	1707	1433	953	1727
<i>Proisotoma minuta</i> (Tullberg, 1871)	7	0	0	0	20	0	0	0	0	0
Neelidae										
<i>Megalothorax minimus</i> Willem, 1900	13	20	13	213	167	7	27	0	0	20
Katiannidae										
<i>Sminthurinus elegans</i> (Fitch, 1863)	40	13	80	7	53	20	47	27	33	7
Sminthurididae										
<i>Sphaeridia pumilis</i> (Krausbauer, 1898)	20	167	73	107	93	73	100	60	40	20
Σ	4520	4180	4640	5273	5047	6640	7213	6940	6067	6440

Collembola species richness, diversity and abundance

A total of 8,545 Collembola individuals,

representing 10 families, 21 genera and 34 species were extracted from the collected soil samples. Mean abundance of the species occurred are presented in Table 6, whereas

Table 7 shows the most important structural characteristics of Collembola communities found in the different plots of the studied sessile oak and black locust plantations.

Mean Collembola abundance was significantly higher ($p < 0.05$) in the black locust plantation, while according to the former treatments, abundance is significantly higher ($p < 0.05$) in the SO4 and SO5 treatments of the sessile oak plantation compared to the control (SO1).

of the black locust plantation, only the BL2 treatment was significantly higher ($p < 0.05$) compared to the control (BL1).

There were marked differences (Hutcheson t test, $p < 0.05$) in community diversity between the two plantation types (sessile oak and black locust), while only occasional differences have been observed between the different former treatments within the same plantation type (Table 8).

Table 7. Structural indices of Collembola communities in the sampled plots

	SO1	SO2	SO3	SO4	SO5	BL1	BL2	BL3	BL4	BL5
S_{total}	23	25	22	26	27	20	23	21	20	21
S_{mean}	17	18	18	19	20	17	19	17	17	18
H'	2.644	2.604	2.653	2.767	2.712	2.488	2.476	2.436	2.445	2.372
J	0.843	0.809	0.858	0.849	0.823	0.830	0.790	0.800	0.816	0.779
CDI	27.58	33.49	25.29	20.86	27.21	34.84	38.82	38.90	34.17	41.93

S – number of species; H' – Shannon–Weaver’s diversity index; J – Pielou’s evenness index; CDI – community dominance index (%)

With regard to the black locust plantation, no significant differences were revealed between the different former treatments.

Between the mean species richness there is no significant difference ($p < 0.05$) according to the type of plantation, while the total number of species identified was higher in the sessile oak plantation (34 species) compared to the black locust plantation (26 species). According to the former treatments, species richness was significantly higher ($p < 0.05$) in the SO4 and SO5 treatments of the sessile oak plantation compared to the control (SO1), while in case

Discussion

Soil properties

In most cases, canopy closure and thus the emergence of the forest structure mostly occurs in the first 20 years after reforestation (Oliver and Larson 1996). Suitable plant litter layer also develop within 20 years after planting (Cunningham et al. 2012), which corroborates the time-appropriateness of this research. According to the results obtained, some determined soil parameters in the sessile oak forest do not differ significantly among treatments, with the exception of SOC (%), AL- P_2O_5 (mg/kg)

Table 8. Results of Shannon diversity comparison (Hutcheson t test) in the sessile oak (SO) and black locust (BL) plantations. Significant differences are marked with* ($P < 0.05$) and ** ($P < 0.01$)

	SO1	SO2	SO3	SO4	SO5	BL1	BL2	BL3	BL4
SO2	0.956								
SO3	-0.247	-1.197							
SO4	-3.182**	-3.801**	-3.022**						
SO5	-1.583	-2.349*	-1.389	1.376					
BL1	3.907**	2.478*	4.286**	7.422**	5.355**				
BL2	4.105**	2.700**	4.473**	7.505**	5.506**	0.329			
BL3	5.164**	3.619**	5.572**	8.677**	6.535**	1.372	1.004		
BL4	4.831**	3.348**	5.220**	8.267**	6.201**	1.084	0.731	-0.262	
BL5	6.339**	4.803**	6.737**	9.613**	7.587**	2.865**	2.485*	1.575	1.796

and AL-K₂O (mg/kg) in the former larger doses of fertilizers (treatment 4th and 5th), which can be interpreted as a non-efficient nutrient utilization of the sessile oak trees. Most often, nutrient uptake is very efficient in forests due to mikorrhiza, but fertilization has negative impacts on this symbiotic relation and thus the nutrient supply of trees (Berki 1999). Moreover, according to a research in boreal forests, N-fertilization led to 54% decline of fungi and bacteria biomass in the soil (Wallenstein et al. 2006). Another study carried out in a boreal forest showed that N-fertilization raised soil organic matter content (Mäkipää 1994).

With respect to the soil parameters in the black locust plantation, no significant differences were found among former treatments, with the only exception of the AL-P₂O₅ (mg/kg) content in the 4th treatment (BL4) when compared to the control. Phosphorus can bound much longer in the soil than other macronutrients (Kovács and Füleky 1991), which is undoubtedly the consequence of the higher fertilization dose applied to the treatment in question before the tree plantation.

When comparing the two different tree plantations, significant differences were detected in almost all soil parameters except for AL-K₂O (mg/kg) and NO₃⁻ + NH₄⁺ (mg/kg). The organic carbon content of the soil is higher in the black locust plantation, while the phosphorus content is markedly higher in the soil of the sessile oak forest. The mineralization of the black locust leaves is much faster due to their more optimal C/N ratio (Tanteno et al. 2007), which generally result in higher SOC content. As a fast-growing species, the black locust can sequester atmospheric carbon more efficiently than the native sessile oak (Lindenmayer et al. 2003). Moreover, the closure of canopy and the development of structure are faster in the black locust stands (Hagggar et al. 1997). The remarkably lower phosphorus content of the black locust plantation can be explained by the much higher phosphorus demand of black locust as a legume (Kanzler et al. 2015; Loch 1999; Plass 1972). Rhizobium bacteria help N-fixation

for legumes (Mantovani et al. 2015) and their growth increases when K-fertilization occurs (Berki 1999). The loss of phosphorus is also confirmed as an accelerated growing of black locust in case of P-fertilization (Burner 2005; Grunewald et al. 2007). When NPK-fertilization applied, the amount of biomass and leaf litter can increase significantly (Tanner and Kapos 1992; Turkington et al. 1998).

Collembola species richness, diversity and abundance

The application of fertilizers into the soil may affect the abundance of Collembola, the species richness, diversity and the dominance structure (Hopkin 1997). In a forest soil fertilization experiment, Geissen et al. (1997) found no relation between the treatment and collembolan abundance, while dominance of certain species varied between the P/K-fertilized and unfertilized control plots. As a consequence of a forest soil-liming and fertilization experiment, Geissen and Kampichler (2004) found no change in springtail community composition and no relationship between total and single species abundances and soil chemical parameters. In a pine plantation, effect of N fertilizer application was found to be weak on Collembola population, while in the same experiment Vilkamaa and Huhta (1986) emphasized the role of soil pH in relation of collembolan community composition and dominance structure. In our study, the effects of former fertilizer application are reflected in occasional differences in total Collembola abundance, species richness and diversity, mostly related to the treatments with the highest doses.

As a consequence of the geographical nature and climate of the area we recorded a number of typical xerothermophilic species (e.g. *Mesaphorura critica*, *Metaphorura denisi*, *Entomobrya multifasciata*, *Orchesella cincta*). Due to the relatively young age of the plantations, very few typical forest species were observed (*Ceratophysella luteospina*, *Neanura muscorum*, *Entomobrya muscorum*) while species characteristic for open habitats

(e.g. *Pseudachorutes pratensis*, *Lepidocyrtus cyaneus*) are still predominant. This kind of species composition can be explained by the absence of surrounding forest habitats and, at the same time, the slow dispersal ability and thus the lack of colonization of certain euedaphic species (Salmon and Ponge 1998, Huhta and Ojala 2006).

Paradoxically, both deforestation and afforestation can have strong negative impact on soil collembolan communities (Jordana et al. 1987; Deharveng 1996; Ponge et al. 2006). It is particularly true for our study area, where there was a shift from a long-term fertilized agricultural land to woodland habitat through reforestation. We have no former data on soil mesofauna, but literature usually report low diversity from arable fields (e.g. Kováč et al. 2001; Winkler and Traser 2017). Although the collembolan abundance detected in the sessile oak and black locust plantations is relatively low, diversity values (2.4–2.7) shows the signs of revitalization and diversification mostly owing to the vegetation cover and leaf-litter accumulation.

Choice of tree species for reforestation is crucial and can have major impact on soil and soil biota in the long term. Among the invasive tree species, black locust has high importance, since almost 25% of the Hungarian forest stands are covered

by this tree species (Bartha et al. 2008). Black locust has complex effects on soil characteristics, most notably, increasing total nitrogen and nitrate content and soil organic matter content (Rice et al. 2004; Tateno et al. 2007). Latter characteristic is well reflected in the higher Collembola abundance in the studied black locust plots compared to the sessile oak plots. Nevertheless, species richness, diversity and equitability were higher in the plantations of the native sessile oak. This phenomenon might be explained by the allelopathic effect of black locust, which can produce and release secondary metabolites (e.g. toxalbumins, robin and phasin) that can reveal inhibition effects on protein synthesis that certain species cannot tolerate (Hui et al. 2004; Rahmonov 2009; Lazzaro et al. 2018). Community structure as emphasized by the CDI index is more evenly distributed among species in the native sessile oak plots, while the few eudominants with higher abundance and the majority of species at relatively low numbers in the black locust plantation might also reflect unfavourable conditions for certain groups of Collembola.

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References

- Arneith, A., Harrison, S.P., Zaehle, S., Tsigaridis, K., Menon, S., Bartlein, P.J., Feichter, J., Korhola, A., Kulmala, M., O'Donnell, D., Schurgers, G., Sorvari, S., Vesala, T. (2010): Terrestrial biogeochemical feedbacks in the climate system. *Nature Geoscience*, **3**: 8. 525–532. DOI: 10.1038/ngeo905
- Babenko, A.B., Chernova, N.M., Potapov, M.B., Stebaeva, M.B. (1994): Collembola of Russia and adjacent countries: Family Hypogastruridae. Nauka, Moscow.
- Bacsó A., Dezső I., Maul F., Stefanovics P., Tusz Zs. (1972): Talajtani gyakorlatok. Egyetemi jegyzet, Agrártudományi Egyetem Mezőgazdaságtudományi Kar, Gödöllő.
- Bartha, D., Csiszár, Á., Zsigmond, V. (2008): Black locust (*Robinia pseudoacacia* L.). In Botta-Dukát, Z., Balogh, L. (eds.) *The Most Important Invasive Plants in Hungary*. Hungarian Academy of Sciences, Institute of Ecology and Botany, Vácrátót. 63–76.
- Berki I. (1999): Az erdők tápanyag-ellátása. In: Füleky Gy. (szerk.): *Tápanyag-gazdálkodás. Mezőgazda Kiadó, Budapest*, 536–558. Berzsenyi, Z., (2009): Az ötvenéves martonvásári tartamkísérletek jelentősége a növénytermesztés fejlesztésében. In: *Tartamkísérletek jelentősége a növénytermesztés fejlesztésében. Jubileumi tudományos konferencia, Martonvásár, 2009. október 15.* 37–49.

- Bretfeld, G. (1999): Symphypleona. In Dunger, W., (Ed.), Synopses on Palaearctic Collembola. Vol. 2. Abhandlungen und Berichte des Naturkundemuseums Görlitz, **71**:1. 1–318.
- Burner, D.M., Pote, D.H., Ares, A. (2005): Management effects on biomass and foliar nutritive value of *Robinia pseudoacacia* and *Gleditsia triacanthos* f. *inermis* in Arkansas, USA. *Agroforestry Systems*, **65**:3. 207–214. DOI: 10.1007/s10457-005-0923-9
- Buzás I. eds. (1988): Talaj- és agrokémiai vizsgálati módszerkönyv 2. (Soil- and agrochemical methods manual. Part 2.) Budapest, Mezőgazdasági Kiadó.
- Buzás I. eds. (1993): Talaj- és agrokémiai vizsgálati módszerkönyv 1. (Soil- and agrochemical methods manual. Part 1.) Budapest, INDA 4231 Kiadó.
- CEU (2014): New EU Forest strategy: conclusions adopted by the Council. Council of the European Union, Brussels.
- Csathó, P., Magyar, M., Osztóics, E., Debreczeni, K., Sárdi, K. (2012): Talaj- és diagnosztikai célú növényvizsgálati módszerek kalibrálása az OMTK kísérletekben. II. Környezetvédelmi célú talaj P-teszt módszerek összehasonlítása a tartamkísérletek talajaiban. *Agrokémia és Talajtan*, **61**:1. 117–132. DOI: 10.1556/Agrokem.60.2012.1.9
- Cunningham, S. C., Metzeling, K. J., Mac Nally, R., Thomson, J. R., Cavagnaro, T. R. (2012): Changes in soil carbon of pastures after afforestation with mixed species: sampling, heterogeneity and surrogates. *Agriculture, Ecosystems & Environment*, **158**, 58–65.
- Cunningham, S.C., Mac Nally, R., Baker, P. J., Cavagnaro, T. R., Beringer, J., Thomson, J. R., Thompson, R. M. (2015): Balancing the environmental benefits of reforestation in agricultural regions. *Perspectives in Plant Ecology, Evolution and Systematics*, **17**:4. 301–317. DOI: 10.1016/j.ppees.2015.06.001
- Dányi, L., Traser, G. (2008) An annotated checklist of the springtail fauna of Hungary (Hexapoda: Collembola). *Opuscula Zoologica*, **38**. 3–82.
- Deharveng, L. (1982): Cle de détermination des genres de Neanurinae (Collembola) d'Europe et la région Méditerranéenne, avec description de deux nouveaux genres. *Trav. Lab. Ecobiol. Arthr. Edaph.*, **3**. 7–13.
- Deharveng, L. (1996): Soil Collembola diversity, endemism, and reforestation: a case study in the Pyrenees (France). *Conservation Biology*, **10**. 74–84. DOI: 10.1046/j.1523-1739.1996.10010074.x
- Dövényi, Z. (ed.) (2010): Magyarország kistájainak katasztere. MTA FKI, Budapest.
- Egnér, H. A. N. S., Riehm, H., Domingo, W. R. (1960): Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nährstoffzustandes der Böden. II. Chemische Extraktionsmethoden zur Phosphor- und Kaliumbestimmung. *Kungliga Lantbrukshögskolans Annaler*, **26**. 199–215.
- Fjellberg, A. (1980): Identification keys to Norwegian Collembola. *Norsk Entomol. Forening*, 1–152.
- Fjellberg, A. (1998): The Collembola of Fennoscandia and Denmark. Part I.: Poduromorpha. *Fauna Entomologica Scandinavica*, **35**. 1–184.
- Geissen, V., Kampichler, C. (2004). Limits to the bioindication potential of Collembola in environmental impact analysis: a case study of forest soil-liming and fertilization. *Biology and Fertility of Soils*, **39**(6). 383–390. DOI: 10.1007/s00374-003-0714-2
- Geissen, V., Illmann, J., Flohr, A., Kahrer, R. & Brümmer, G.W. (1997): Effects of liming and fertilization on Collembola in forest soils in relation to soil chemical parameters. *Pedobiologia*, **41**(1). 194–201.
- Gilbert-Norton, L., Wilson, R., Stevens, J.R., Beard, K.H. (2010): A meta-analytic review of corridor effectiveness. *Conservation Biology*, **24**:3. 660–668. DOI: 10.1111/j.1523-1739.2010.01450.x
- Giller, K.E., Beare, M.H., Lavelle, P., Izac, A.-M.N. Swift, M.J. (1997): Agricultural intensification, soil biodiversity and agroecosystem function. *Applied Soil Ecology*, **6**. 3–16. DOI: 10.1016/S0929-1393(96)00149-7

- Grunewald, H., Brandt, K.V.B., Schneider, B.U., Bens, O., Kendzia G., Hüttl L.F. (2007): Agroforestry systems for the production of woody biomass for energy transformation purposes. *Ecological Engineering*, **29**:4. 319–328. DOI: 10.1016/j.ecoleng.2006.09.012
- Haggar, J., Wightman, K., Fisher, R. (1997): The potential of plantations to foster woody regeneration within a deforested landscape in lowland Costa Rica. *Forest Ecology and Management*, **99**(1-2). 55–64.
- Hammer, Ř., Harper, D.A.T., Ryan, P.D. (2001): PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica*, **4**. 1–9.
- Harta, I., Gulyás, M., Füleky, Gy. (2016): Műtrágyázás tartamhatásának vizsgálata akácosban. *Agrokémia és Talajtan*, **65**:1. 35–45. DOI: 10.1556/0088.2016.65.1.3
- Haynes, R.J., Naidu, R. (1998): Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. *Nutrient Cycling in Agroecosystems*, **51**:2. 123–137. DOI: 10.1023/A:1009738307837
- Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setälä, H., Symstad, A.J., Vandermeer, J., Wardle, D.A. (2005): Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs*, **75**:1. 3–35. DOI: 10.1890/04-0922
- Hopkin, S.P., 1997. *Biology of the Springtails (Insecta: Collembola)*. Oxford University Press. pp. 1–330.
- Huhta, V., & Ojala, R. (2006). Collembolan communities in deciduous forests of different origin in Finland. *Applied Soil Ecology*, **31**(1-2). 83–90. DOI: 10.1016/j.apsoil.2005.04.001
- Hui, A., Marraffa, J.M., Stork, C.M., 2004. A rare ingestion of the Black Locust tree. *Journal of Toxicology. Clinical Toxicology*, **42**:1. 93–95.
- Hutcheson, K. (1970): A test for comparing diversities based on the Shannon formula. *Journal of Theoretical Biology*, **29**:1. 151–154. DOI: 10.1016/0022-5193(70)90124-4
- IBM Corp. Released (2011): *IBM SPSS Statistics for Windows, Version 20.0*. IBM Corp., Armonk, NY.
- Jackson, R.B., Jobbágy, E.G., Avissar, R., Roy, S.B., Barrett, D.J., Cook, C.W., Farley, K.A., le Maitre, D.C., McCarl, B.A., Murray, B.C. (2005): Trading water for carbon with biological carbon sequestration. *Science*, **310**(5756), 1944–1947. DOI: 10.1126/science.1119282
- Jordana, R. (2012): Capbryinae & Entomobryini. In Dunger, W., Burkhardt, U. (Eds.), *Synopses on Palaearctic Collembola*. Vol. 7/1. *Soil Organisms*, **84**:1. 1–390.
- Jordana, R., Arbea, J.I., Carlos Simón, M.J.L. (1997): *Collembola, Poduromorpha*. Fauna Iberica, Vol. 8. Museo Nacional de Ciencias Naturales, Madrid. 1–807.
- Jordana, R., Arbea, J.I., Moraza, L., Montenegro, E., Mateo, M.D., Hernandez, M.A., Herrera, L. (1987): Effect of reforestation by conifers in natural biotopes of middle and South Navarra (Northern Spain). *Revue Suisse de Zoologie* **94**. 491–502. DOI: 10.5962/bhl.part.79528
- Kádár, I., Márton, L., Németh, T., Szemes, I. (2007): Meszezés és műtrágyázás hatása a talajra és növényre a 44 éves nyírlugosi tartamkísérletben. *Agrokémia és Talajtan*, **56**:2. 255–270. 10.1556/Agrokem.56.2007.2.5
- Kádár, I., Németh, T. (2003): Mikroelem-szennyezők kimosódásának vizsgálata szabadföldi terheléses tartamkísérletben. *Agrokémia és Talajtan*, **52**:3-4. 315–330. DOI: 10.1556/Agrokem.52.2003.3-4.6
- Kanzler, M., Böhm, C., Freese, D. (2015): Impact of P fertilisation on the growth performance of black locust (*Robinia pseudoacacia* L.) in a lignite post-mining area in Germany. *Annals of Forest Research*, **58**:1. 39–54.
- Körschens, M. (2006): The importance of long-term experiments for soil science and environmental research – a review. *Plant, Soil and Environment*, **52**: Special Issue. 1–8.

- Kováč, L., Luptáčík, P., Miklisová, D., Mati, R. (2001) Soil Oribatida and Collembola communities across a land depression in an arable field. *European Journal of Soil Biology*, **37**. 285–289. DOI: 10.1016/S1164-5563(01)01106-2
- Kovács, K., Füleky, Gy. (1991): Trágyázási tartamkísérlet eredményei Gödöllő barna erdőtalajon. 1972-1990. Gödöllői Agrártudományi Egyetem, Mezőgazdaságtudományi Kar, Talajtani és Agrokémiai Tanszék.
- Lazzaro, L., Mazza, G., d’Errico, G., Fabiani, A., Giuliani, C. Inghilesi, A.F., Lagomarsino, A., Landi, S., Lastrucci, L., Pastorelli, R., Roversi, P.F., Torrini, G., Tricarico, E., Foggi, B. (2018): How ecosystems change following invasion by *Robinia pseudoacacia*: Insights from soil chemical properties and soil microbial, nematode, microarthropod and plant communities. *Science of the Total Environment*, **622–623**. 1509-1518. DOI: 10.1016/j.scitotenv.2017.10.017
- Lindenmayer, D. B., Hobbs, R. J. Salt, D. (2003): Plantation forests and biodiversity conservation. *Australian Forestry*, **66**:1. 62–66. DOI: 10.1080/00049158.2003.10674891
- Loch J. (1999): A trágyázás agrokémiai alapjai. In: Füleky Gy. (szerk.): Tápanyag-gazdálkodás. Mezőgazda Kiadó, Budapest, p. 228–268.
- McNaughton, S.J. (1967): Relationship among functional properties of California grassland. *Nature* **216**. 168–169.
- Mäkipää, R. (1994): Effects of nitrogen fertilization on the humus layer and ground vegetation under closed canopy in boreal coniferous stands. *Silva Fennica*, **28**:2. 81–94.
- Mantovani, D., Veste, M., Boldt-Burisch, K., Fritsch, S., Koning, L. A., Freese, D. (2015): Carbon allocation, nodulation, and biological nitrogen fixation of black locust (*Robinia pseudoacacia* L.) under soil water limitation. *Annals of Forest Research*, **58**:2. 1–16. DOI: 10.15287/afr.2015.420
- Mirmanto, E., Proctor, J., Green, J., Nagy, L., Suriantata (1999): Effects of nitrogen and phosphorus fertilization in a lowland evergreen rainforest. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, **354**. 1825–1829. DOI: 10.1098/rstb.1999.0524
- Németh, T., Várallyay, GY. (1998): A trágyázás és tápanyag utánpótlás jelenlegi helyzete és lehetőségei. *Agrofórum*, **9**:13. 2–4.
- Ockert, J. (2006): Biomasse- und Nährstoffbilanzierung für einen unterschiedlich gedüngten 11jährigen Robinienbestand (*Robinia pseudoacacia* L.) auf einer ehemaligen landwirtschaftlichen Dauerversuchsfläche bei Gödöllő (Ungarn). Diplomarbeit, Westungarische Universität, Sopron,
- Oliver, C. D., Larson, B. C. (1996): *Forest stand dynamics*. Updated edition. John Wiley and Sons.
- Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G., Ciais, P., Jackson, R.B., Pacala, S., McGuire, A.D., Piao, S., Rautiainen, A., Sitch, S., Hayes, D. (2011): A large and persistent carbon sink in the world’s forests. *Science*, **333**:6045. 988–993. DOI: 10.1126/science.1201609
- Paul, D., Nongmaithem, A., Jha, L.K. (2011): Collembolan Density and Diversity in a Forest and an Agroecosystem. *Open Journal of Soil Science* **1**:2. 54–60. DOI: 10.4236/ojss.2011.12008
- Pielou, E.C. (1966): The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology*, **13**. 131–144.
- Plass, W.T. (1972): Fertilization treatments increase black locust growth on extremely acid surface-mine spoils. *Tree Planters’ Notes*, **23**:4. 10–12.
- Pomorski, R.J. (1998): Onychiurinae of Poland (Collembola: Onychiuridae). *Genus (Supplement)*, Polish Taxonomical Society, Wrocław, 1–201.
- Ponge, J-F., Dubs, F., Gillet, S., Sousa, J.P., Lavelle, P. (2006): Decreased biodiversity in soil springtail communities: the importance of dispersal and landuse history in heterogeneous landscapes. *Soil Biology & Biochemistry* **38**: 1158–1161. DOI: 10.1016/j.soilbio.2005.09.004

- Potapov, M. (2001): Synopses on Palaearctic Collembola: Isotomidae. *Abhandlungen und Berichte des Naturkundemuseums Görlitz*, **73**:2. 1–603.
- Rahmonov, O. (2009): The chemical composition of plant litter of black locust (*Robinia pseudoacacia* L.) and its ecological role in sandy ecosystems. *Acta Ecologica Sinica*, **29**:4. 237–243. DOI: 10.1016/j.chnaes.2009.08.006.
- Rice, S. K., Westerman, B., Federici, R. (2004): Impacts of the exotic, nitrogen-fixing Black locust (*Robinia pseudoacacia*) on nitrogen-cycling in a pine-oak ecosystem. *Plant Ecology*, **174**:1. 97–107. DOI: 10.1023/B:VEGE.0000046049.21900.5a
- Salmon, S., Ponge, J.F. (1998): Responses to light in a soil-dwelling springtail. *European Journal of Soil Biology*, **34**:4. 199–201. DOI: 10.1016/S1164-5563(00)86662-5
- Shannon, C.E., Weaver, W. (1949): *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, 1–117.
- Sousa, J.P., Bolger, T., Da Gama, M.M., Lukkari, T., Ponge, J.F., Simón, C., Traser, G., Vanbergen, A.J., Brennan, A., Dubs, F., Ivtis, E., Keating, A., Stofer, S., Watt, A.D. (2006): Changes in Collembola richness and diversity along a gradient of land-use intensity: a pan European study. *Pedobiologia*, **50**:2. 147–156. DOI: 10.1016/j.pedobi.2005.10.005
- Stefanovits P., 1972. *Talajtan. Mezőgazda Kiadó. Budapest.*
- Szalókiné Zima, I., Szalóki, S. (2003): Nitrátleemosódás vizsgálata liziméteres és szabadföldi tartamkísérletben. *Agrokémia és Talajtan*, **52**:1–2. 35–52. DOI: 10.1556/Agrokem.52.2003.1-2.4
- Szováti K., Füleky Gy., Tolner L. (2006): Nitrate accumulation in the soil affected by nitrogen fertilization. *Bulletin of the Szent István University Gödöllő* 2006. 97–104.
- Tanner, E.V.J., Kapos, V., Franco, W. (1992): Nitrogen and phosphorus fertilization effects on Venezuelan montane forest trunk growth and litterfall. *Ecology*, **73**:1. 78–86. DOI: 10.2307/1938722
- Tateno, R., Tokuchi, N., Yamanaka, N., Du, S., Otsuki, K., Shimamura, T., Xue, Z.D., Wang, S.Q., Hou, Q.C. (2007). Comparison of litterfall production and leaf litter decomposition between an exotic black locust plantation and an indigenous oak forest near Yan'an on the Loess Plateau, China. *Forest Ecology and Management*, **241**:1–3. 84–90. DOI: 10.1016/j.foreco.2006.12.026
- Thibaud, J.M., Shulz, H.J., Da Gama, M.M. (2004): Synopses on Palaearctic Collembola: Hypogastruridae. *Abhandlungen und Berichte des Naturkundemuseums Görlitz*, **75**:2. 1–603.
- Tolner L., Vágó I., Sipos M., Tolner, I., Füleky Gy. (2010): Energiaerdő hatása a talaj nitrát tartalmának mélységi eloszlására. (The effect of energy plantations on the depth distribution of soil nitrate-ions). XII. Nemzetközi Tudományos Napok (12-th International Scientific Days, XII. Internationale Wissenschaftliche Tagung), Gyöngyös, 2010.03.25-26. Programme 174.
- Turkington, R., John, E., Krebs, C.J., Dale, M.R.T., Nams, V.O., Boonstra, R., Boutin, S., Martin, K., Sinclair, A.R.E., Smith, J.N.M. (1998): The effects of NPK fertilization for nine years on boreal forest vegetation in northwestern Canada. *Journal of Vegetation Science*, **9**:3. 333–346. DOI: 10.2307/3237098
- UN (2014): *The New York Declaration on Forests*. United Nations Climate Summit, New York.
- UNEP, C.A. (2014): *Initiative 20 x 20. Climate Action & United Nations Environment Program*, Lima.
- Vilkamaa, P. & Huhta, V. (1986). Effects of fertilization and pH on communities of Collembola in pine forest soil. *Annales zoologici fennici*, **23**. 167–174.
- Wallenstein, M.D., McNulty, S., Fernandez, I.J., Boggs, J., Schlesinger, W.H. (2006): Nitrogen fertilization decreases forest soil fungal and bacterial biomass in three long-term experiments. *Forest Ecology and*

Management, **222**:1. 459–468.

Weiner, W.M. (1996): Generic revision of Onychiurinae (Collembola: Onychiuridae) with a cladistic analysis. *Annales de la Société Entomologique de France*, **32**:2. 163–200.

Winkler, D., Traser, Gy. (2017): Talajlakó mezofauna (Collembola) vizsgálatok a Lajta Project területén. *Magyar Ápróvad Közlemények*, **13**. 213–224. DOI: 10.17243/mavk.2017.213

Zimdars, B., Dunger, W. (1994): Tullbergiinae. In: Dunger, W. (ed.): *Synopses on Palaearctic Collembola*. Vol.: I. *Abhandlungen und Berichte des Naturkundemuseums Görlitz*, **68**:3–4. 1–71.