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Occurrence of Oribatid Mites During the Revitalization of Bare Root Forest Nursery

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1. Introduction

Every year in Polish forestry there are huge requirements for fresh seedlings of forest trees because about 90% of forests are artificially regenerated (Walczyk and Tylek 2012). In Poland in 92% production of seedlings is conducted in field conditions (bare root forest nurseries). In these forest nurseries that produce bare root seedlings may sometimes experience disturbances in their soil biological balance. A direct effect of these disturbances is deteriorated quality of the seedlings. In-ground forest nurseries are usually established on forest soils where the stand was cut down. However, using agricultural models for the management of a forest nursery and production of tree seedlings causes gradual degradation of the nurseries. Major cause of this degradation is markedly reduced amount of organic matter resulting in limited microbiological activity and insufficient presence of ectomycorrhizal fungi (ECM) (Kropp and Langlois 1990; Aučina et al. 2014). To curb these processes and to restore biological balance of the forest soil, various enrichment procedures are introduced, involving fertilization with organic composts, peat, tree bark, or green fertilization (forecrop). Mulching the mineral surface of the soil with edaphon-rich raw humus is a technique particularly useful from the ecological point of view, and it directly improves soil environment revitalization. This treatment restores natural layered structure of forest soils (Leski et al. 2009; Aučina et al. 2014). Moreover, spreading forest litter allows for reintroduction of multiple microorganisms and small animals, such as oribatid mites (Oribatida). Oribatid mites are one of the most abundant and species-rich group of arthropods in forest soils. A single site may often harbor even up to a few hundred thousand individuals per square meter and from 20 to 50 species per research site (Norton1990; Behan-Pelletier 1999). Oribatid mites play many important environmental functions, they improve pedogenic processes and propagation of bacteria and fungi, and they indirectly affect the formation of endo- and ectomycorrhizas (Klironomos and Kendrick 1996; Schneider et al. 2005; Remén et al. 2010). They are also good bioindicators of soil biological activity (Behan-Pelletier 1999, 2003; Gulvik 2007). Our earlier studies showed that intensive cultivation practices in in-ground forest nurseries drastically reduced the abundance and species diversity of oribatid mites, down to only 3-4 species and 670-1,050 individuals per m^2 (Klimek et al. 2013a). The aim of this study was to analyze the prevalence of Oribatida during a 3-year cycle of revitalization conducted in in-ground nursery of Białe Błota near Bydgoszcz. Revitalization practices implemented in the nurseries of Scots pine (*Pinus sylvestris* L.), beech (*Fagus sylvatica* L.), and small-leaved linden (*Tilia cordata* Mill.) involved fertilization with bark-enriched compost and mulching with raw humus.

2. Material and methods

The study was conducted in the years 2008-2010 in Białe Błota nursery belonging to Bydgoszcz Forest District (53°06'12.3"N 17°55'41.5"E). The soil cover was brunic arenosol formed from alluvial sands. The surface layer had a texture of fine-grained slightly loamy sand and contained 6-7% of clay fraction (<0.002 mm). In terms of organic matter content the surface layer may be classified as mineral and humus one, as it contained from 35.7 to 38.4 $g \cdot kg^{-1}$ of organic carbon. Soil pH in 1M KCl ranged from 6.9 to 7.0.

The experiments were established in the spring of 2008, in the nurseries producing Scots pine, beech and small-leaved linden. Each nursery included 16 experimental plots (4 variants x 4 repetitions) with the area of 2 m^2 each. The experiments included the following variants: C – control, O – organic fertilization, M – mulching with raw humus, OM – organic fertilization and mulching with raw humus.

The organic fertilizer (compost) included sanitized sewage sludge (60%) and pine bark (40%). It was applied in the spring of 2008 at a dose of 100 t ha^{-1} and mixed with surface soil layer (to the depth of 10 cm) before sowing the seeds. Mulching with raw humus was carried out on 15 September 2008, and the dose was 100 m^3 ha^{-1}. The control variant was an in-ground nursery attended to as per recommended standard practices.

The experimental plots were irrigated by periodically operating stationary sprinkling machine. Irrigation doses and times were determined according to the recommendations for open area forest nurseries. Plants grown in the areas around Bydgoszcz, as well as in entire central Poland, need intense irrigation (Żarski 2011). In 2008, total precipitation rate in the vegetative period was 281.5 mm (Table 1). In 2009, it was two times lower, and in 2010 no irrigation was necessary as the natural precipitation was high enough. In 2008, total amount of precipitation was lower than normal, and especially low rainfall was recorded in May, June, and September. In 2009, the precipitation was lower than normal in April, August and September. In a generally wet vegetative period of 2010, low rainfall was recorded in June and October (30% and 78% of normal range, respectively). Soil samples for acarological studies were collected six times in the years 2008-2010, in the last ten days of May and October. In total, 720 soil samples were collected, i.e. 10 samples (two or three from each plot) per each experimental variant on each collection date. The soil was sampled from the area of 17 cm^2 and up to 3 cm deep. The mites were extracted over 7 days using Tullgren funnels, fixed in 70% ethanol, prepared and classified into species or genera. A total of 3,586 juvenile and adult oribatid mites were classified. Their mean density (N) was given per 1 m^2 of soil. Oribatida communities in each variant were described using a domination ratio D (%), total number of species (S), average number of species per sample (s) for a series of 60 samples, and Shannon's diversity index (H') (Magurran 1988). Prior to statistical analysis, the numerical data were subjected to a logarithmic transformation - ln (x+1) (Berthet and Gerard 1965).

Table 1. Rainfall (P) and irrigation (I) in the Białe Błota forest nursery during the vegetation period of the years 2008-2010 (mm)

Year		Months							Total IV-IX
		IV	V	VI	VII	VIII	IX	X	
2008	P	38.7	11.5	15.5	58.7	95.5	20.2	80.0	320.1
	I	57.4	63.7	74.9	53.9	24.8	6.8	0	281.5
2009	P	0.4	85.3	57.4	118	1.6	34.4	66.2	379.3
	I	16.6	30.3	35.6	32.9	19.3	6.3	0	141.0
2010	P	33.8	92.6	18.1	107	151	74.7	2.3	479.6
	I	0	0	0	0	0	0	0	0
Norm (long-term average)		29.8	60.6	47.3	83.1	62.8	44.1	40.2	367.9

The statistical analysis was performed using Statistica 10,0, and a compliance of the measurable parameters with the normal distribution was assessed using Kolmogorov-Smirnov test. As the normal distribution was not confirmed, a non-parametric analysis of variance (Kruskal-Wallis) was performed. For statistically significant differences ($p < 0.05$) an analysis for each pair was carried out (Mann-Whitney U test) to identify significantly different means.

3. Results

On the first sample collection date in mid-May 2008, the density of oribatid mites in the nurseries producing pine, beech and linden was extremely low for all experimental plots and did not exceed 200 individuals m^{-2} (Fig. 1). Mean density of the mites assessed over the 3-year study cycle on the control plots managed according to the standard nursery practices was low and amounted to 110-240 individuals m^{-2} (Table 2). The number of the mites slightly but significantly increased after fertilization with the compost (variant O) on the plots with deciduous seedlings. Mulching was the soil revitalization method that markedly improved the density of Oribatida. The greatest mean density of the mites (8,630 individuals m^{-2}) was observed in linden nursery, on the plots mulched with raw humus and fertilized with the compost (OM).

Shortly after mulching, in autumn 2008, the density of oribatid mites in all nurseries was high and ranged from 4,210 to 19,140 individuals m^{-2} (Fig. 1). In pine nursery, this high density lasted only until the spring of 2009 and then declined. High number of the mites in this nursery (4,270-23,540 individuals m^{-2}) was observed only at the end of the 3-year study cycle. In beech nursery, significant decrease in the density of the mites was recorded in May 2010, but a substantial spike in their numbers was observed as soon as the next season. Particularly high oribatid mite density (17,220 individuals m^{-2}) was noticed in linden nursery (variant M) in October 2009. In 2010, their number in this variant was much lower. Very high initial density of oribatid mites in linden nursery mulched with raw humus and fertilized with the compost (19,140 individuals m^{-2}) rapidly declined in May 2009. However, in October 2009, a huge increase in Oribatida count was found, and at the end of the study cycle it rose again to 12,820 individuals per m^2. In total, 37 Oribatida species were found in the investigated pine, beech, and linden nurseries. Depending on the tree species, the number of Oribatida species on the control plots (C) ranged from 3 to 5 (Table 3). A few more species (5-7) were observed on organically fertilized plots. Significantly more species were recorded on the mulched plots, i.e. 15-23 in M variant and 16-24 in OM variant.

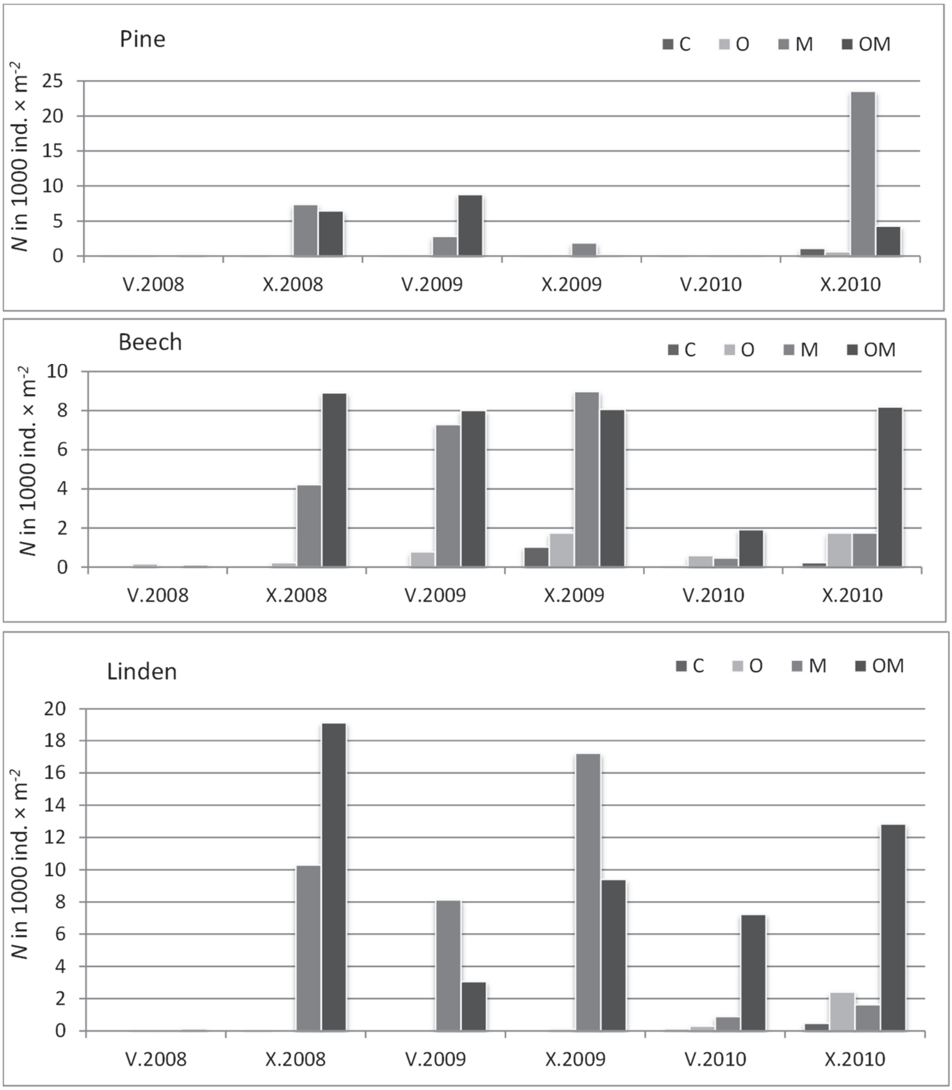

Fig. 1. Density (*N*) of oribatid mites in a three-year period of the study (2008-2010) in the variants of the experiment in the Białe Błota forest nursery

Table 2. The density of oribatid mites (N in 10^3 individuals m^{-2}) in the variants of the experiment for the forest nurseries: pine (P), beech (B) and linden (L) in Białe Błota

Taxon	Species of seed-lings	Experiment variant				Kruskal-Wallis test	
		C	O	M	OM	*H*	*p*
Eremaeus oblongus C.L. Koch, 1836	P	0	0	0.10^{Aa}	0.45^{Ba}	64.53	0.0000
	B	0	0	0.06^{Aa}	0.17^{Ba}		
	L	0	0	0.17^{Aa}	0.26^{Ba}		
Lauroppia neerlandica (Oudemans, 1900)	P	0	0	0	0.25^{a}	38.55	0.0001
	B	0	0	0.01^{Aa}	0.04^{Aa}		
	L	0	0	0.14^{a}	0		
Liochthonius sp.	P	0	0	0.02^{Aa}	0.02^{Aa}	38.53	0.0001
	B	0	0	0.02^{Aa}	0.07^{Aa}		
	L	0	0	0.09^{Aa}	0.29^{Bb}		
Oppiella nova (Oudemans, 1902)	P	0.21^{ACa}	0.05^{Ba}	4.20^{Ca}	0.60^{ABa}	75.08	0.0000
	B	0.05^{ABa}	0.01^{Aa}	0.17^{Ba}	0.49^{Ca}		
	L	0.03^{Aa}	0.05^{Aa}	0.28^{Aa}	0.94^{Ba}		

Table 2. cont.

Taxon	Species of seed-lings	Experiment variant				Kruskal-Wallis test	
		C	O	M	OM	*H*	*p*
Oribatula tibialis (Nicolet, 1855)	P	0.01^{Aa}	0.01^{Aa}	0.11^{Aa}	0.12^{Ba}	84.65	0.0000
	B	0.02^{Aa}	0.03^{Aa}	0.33^{Ba}	0.38^{Cb}		
	L	0.01^{Aa}	0.01^{Aa}	0.24^{Ba}	0.19^{Ba}		
Pergalumna nervosa (Berlese, 1914)	P	0	0	0.02^{Aa}	0.37^{Aa}	24.03	0.0126
	B	0	0	0.01^{Aa}	0.06^{Aa}		
	L	0	0	0.04^{Aa}	0.05^{Aa}		
Scutovertex sculptus (Michael, 1879)	P	0	0	0.03^{Aa}	0.05^{Aa}	45.77	0.0000
	B	0	0	0.30^{Aa}	0.10^{Ba}		
	L	0	0.01	0.04^{Aa}	0.02^{Aa}		
Suctobelba sp.	P	0	0	0.07^{Aa}	0.10^{Aa}	39.50	0.0000
	B	0	0	0.04^{Aa}	0.24^{Ba}		
	L	0	0	0.14^{Aa}	0.28^{Ba}		

Table 2. cont.

Taxon	Species of seed-lings	Experiment variant				Kruskal-Wallis test	
		C	O	M	OM	*H*	*p*
Tectocepheus velatus (Michael, 1880)	P	0.02^{Aa}	0.07^{Aa}	1.21^{Ba}	1.15^{Ba}	210.50	0.0000
	B	0.13^{Aa}	0.74^{Ba}	2.61^{Cb}	3.79^{Db}		
	L	0.07^{Aa}	0.40^{Ba}	4.78^{Cc}	6.07^{Dc}		
# Other species of Oribatida	P	0	0.02	0.23	0.86	-	-
	B	0.02	0.08	0.55	0.72		
	L	0	0.02	0.67	0.59		
Oribatida total	P	0.24^{Aa}	0.15^{Aa}	5.95^{Ba}	3.31^{Ca}	225.81	0.0000
	B	0.22^{Aa}	0.86^{Ba}	3.78^{Cb}	5.87^{Db}		
	L	0.11^{Aa}	0.48^{Ba}	6.37^{Ca}	8.63^{Db}		

Other species of Oribatida (*N* < 200 individuals m^{-2}): *Brachychthonius* sp. – L: M, OM; *Camisia biurus* (C.L. Koch, 1839) – L: M, OM; *Carabodes forsslundi* Sellnick, 1953 – P: M, OM, B: M, OM, L: M; *C. minusculus* Berlese, 1923 – L: M; *C. subarcticus* Trägardh, 1902 – P: M, OM, B: OM, L: M, OM; *Ceratozetella sellnicki* (Rajski, 1958) – B: M; *Chamobates schuetzi* (Oudemans, 1902) – B: O, M, OM; *Eupelops torulosus* (C.L. Koch, 1840) – B: O, M, OM; *Hemileius initialis* (Berlese, 1908) – P: M; *Hemi-nothrus peltifer* (C.L. Koch, 1839) – B: M; *Licneremaeus licnophorus* (Michael, 1882) – L: M, OM; *Metabelba pulverulenta* (C.L. Koch, 1839) – P: M, OM, B: M, OM, L: M, OM; *Micreremus brevipes* (Michael, 1888) – B: M, OM, L: OM; *Microppia minus* (Paoli, 1908) – P: O, L: M; *Microtritia minima* (Berlese, 1904) – B: M, L: M; *Nothrus silvestris* Nicolet, 1855 – B: OM; *Odonto-cepheus elongatus* (Michael, 1879) – L: OM; *Oppia denticulata* (Canestrini, 1882) – B: OM; *Phthiracarus longulus* (C.L. Koch, 1841) – B: M, OM, L: M, OM; *Punctoribates* sp. – B: M, OM, L: M, OM; *Quadroppia quadricarinata* (Michael, 1885) – L: M, OM; *Ramusella mihelcici* (Pérez-Íñigo, 1965) – P: O, OM, B: O, OM, L: O; *Rhysotritia duplicata* (Grandjean, 1953) – P: M, OM, B: C, OM, L: M, OM; *Scheloribates latipes* (C.L. Koch, 1844) – L: OM; *S. pallidulus* (C.L. Koch, 1841) – L: OM; *Steganacarus carinatus* (C. L. Koch, 1841) – P: OM, B: M, OM, L: M, OM; *Trhypochthonius tectorum* (Berlese, 1896) – P: M; *Trichoribates trimaculatus* (C. L. Koch, 1836) – P: M, OM, B: M, OM, L: OM.

^{ABC} – the same letter for a seedling species means lack of significant differences among the variants of the experiment – a the Mann-Whitney U test at $p < 0.05$)

^{abc} – the same letter for a single variant of the experiment means lack of significant differences among the species of the seedlings – a the Mann-Whitney U test at $p < 0.05$)

Table 3. Number of oribatid mite species (*S*), average number of species (*s*) and Shannon index (*H'*) in the variants of the experiment for the forest nurseries: pine (P), beech (B) and linden (L) in Białe Błota

Index	Species of plant	Experiment variant				Kruskal-Wallis test	
		C	O	M	OM	*H*	*p*
S	P	3	5	15	16	–	–
	B	5	7	20	22	–	–
	L	3	5	23	24	–	–
s	P	0.15^{Aa}	0.17^{Aa}	1.53^{Ba}	1.40^{Ba}	220.51	0.0000
	B	0.18^{Aa}	0.50^{Ba}	1.73^{Ca}	2.18^{Db}		
	L	0.12^{Aa}	0.28^{Ba}	1.83^{Ca}	2.33^{Db}		
H'	P	0.46	1.26	0.99	1.98	–	–
	B	1.15	0.64	1.28	1.52	–	–
	L	0.86	0.63	1.22	1.27	–	–

^{ABC} – the same letter for a seedling species means lack of significant differences among the variants of the experiment – a the Mann-Whitney U test at $p < 0.05$)
^{abc} – the same letter for a single variant of the experiment means lack of significant differences among the species of the seedlings – a the Mann-Whitney U test at $p < 0.05$)

Average number of species per sample (*s*) was always the lowest on the control plots (0.12-0.18), and its highest range was recorded in deciduous tree nurseries in OM variant (1.40-2.33), and in pine nursery in M variant (1.53). In pine nursery, both types of mulched plots harbored significantly more species than the non-mulched ones. In deciduous tree nurseries, *s* index was gradually increasing in consecutive variants (C, O, M, OM) and the differences between individual variants were significant. This shows positive effects of not only mulching but even organic fertilization alone on the occurrence of oribatid mites. No significant differences in the mean number of Oribatida species were found between individual tree species in C, O, and M variants. Significant differences were only found in OM variant between pine and deciduous trees, with improved mite species count in beech and linden nurseries. Shannon's diversity index (*H'*) was always the highest in OM variant and it ranged from 1.27 to 1.98. Average number of species per sample (*s*) in C and O variants usually slightly increased over the 3-year course of the study (Fig. 2). Only in compost-enriched beech and linden nurseries this increase was larger and *s* index was 2-3 times higher than in pine nursery. The highest values of this index (3.1-6.8) on the mulched plots were reported in the autumn of 2008, one month after mulching. Over the next seasons, the average number of species per sample *s* decreased, and in the last season it was between 0.9 and 2.8 for all the nurseries. From all Oribatida species native to the investigated area, three species were present in all variants: *Oppiella nova* (mean *D* 25%), *Oribatula tibialis* (mean *D* 5.1%), and *Tectocepheus velatus* (mean *D* 56.8%) (Table 2). The most abundant oribatid mite was *T. velatus* that dominated on all the plots in beech and linden nurseries and in O and OM variants in pine nursery. The other plots were dominated by *Oppiella nova*.

Mean density of the most common mite *Tectocepheus velatus* ranged from 20 to 6,070 individuals m^{-2}. In non-mulched pine nursery its count was low, and mulching caused a significant improvement in *T. velatus* abundance. At the control plots in deciduous trees and pine nurseries, the density of this mite was low and ranged from 70 to 130 individuals m^{-2}. The density of *T. velatus* in beech and linden nurseries was significantly higher in O variant than in control. This indicated a positive effect of compost fertilization on the occurrence of this mite over the 3-year course of the study. The dynamics of Oribatida count indicated a substantial increase in the number of the mites in the second year of the study for beech, and only at the end of the study (October 2010) for linden (Table 4). Positive effect of mulching on the count of *T. velatus* was clearly greater in beech and linden than in pine nursery (Table 2). In both deciduous tree nurseries, the highest density of this mite was observed at the plots that were both mulched and fertilized with the compost. The highest counts for M and OM variants were recorded for linden nursery (4,780 and 6,070 individuals m^{-2}, respectively), which demonstrated a highly positive effect of this tree species on the occurrence of *T. velatus*. This effect was also confirmed by an analysis of dynamic changes in this mite density that at the last evaluation stage was even higher than immediately after reintroduction (Table 4). The highest mean density of *Oppiella nova* (4,200 individuals m^{-2}) was observed in M variant in pine nursery (Table 2). Changes in this mite density indicated intense growth of its population in the autumn of 2010, resulting in 21,790 individuals m^{-2} (Table 4). No positive correlations were observed between compost fertilization and *O. nova* density (Table 2). The effect of mulching was not as clear as in the case of *Tectocepheus velatus*. The highest density of *Oppiella nova* in beech and linden nurseries was observed when the plots were both mulched and compost-fertilized, and the differences between C and OM variants were significant. Mean density of *Oribatula tibialis* on the investigated plots ranged from 10 to 380 individuals m^{-2}. Low density of this mite

(10-120 individuals m^{-2}) was observed in all variants in pine nursery and on non-mulched plots in beech and linden nurseries. On mulched plots in beech and linden nurseries this population was a bit larger (190-380 individuals m^{-2}).

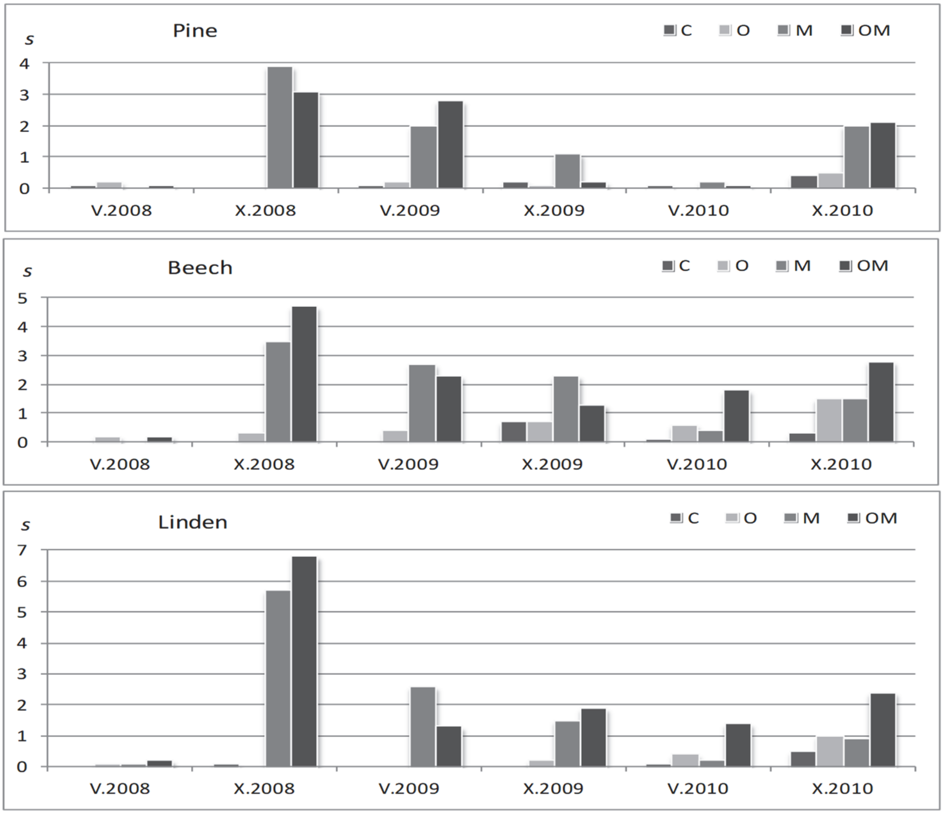

Fig. 2. Average number of Oribatida species per a sample (*s*) over the 3-year course of the study (2008-2010) in the variants of the experiment in the Białe Błota forest nursery

4. Discussion

Apart from their bioindicative role, the presence of Oribatida in in-ground forest nurseries has a strong practical aspect. Forest nurserymen believe that the most important soil organisms, directly affecting the quality of nursery material, are ECM fungi. Microorganisms, including ECM fungi present in nursery soils serve as a source of food for numerous Acari species (Schneider et al. 2005; Remén et al.2010). The presence of mites is also beneficial for the microorganisms, as the soil fauna feeding on mycorrhizas may stimulate their growth (Hanlon and Anderson1979, 1980) and inoculate the soil with fungal spores and hyphae via defecation or by transferring them to new substrates on their bodies (Lussenhop1992; Renker et al.2005).

Table 4. The dynamic changes in the density of *Oppiella nova* and *Tectocepheus velatus* (*N* in 10^3 individuals per m^2) over the 3-year course of the study in the variants of the experiment for the forest nurseries: pine (P), beech (B) and linden (L) in Białe Błota

Species of Oribatida	Species of seedlings	Variant	Research data					
			V. 2008	X. 2008	V. 2009	X. 2009	V. 2010	X. 2010
Oppiella nova	Pine	C	0	0	0	0.12	0.06	1.08
		O	0.06	0	0	0	0	0.24
		M	0	1.51	0.24	1.57	0.12	21.8
		OM	0	0.60	0.06	0	0.06	2.89
	Beech	C	0	0	0	0.12	0.06	0.12
		O	0	0	0	0	0	0.30
		M	0	0.42	0.12	0.18	0	0.30
		OM	0	1.51	0	0	0.30	1.14
	Linden	C	0	0	0	0	0.12	0.06
		O	0.06	0	0	0.06	0.12	0.06
		M	0.06	1.02	0.30	0.12	0	0.18
		OM	0	3.73	0	0.30	0.24	1.38

Table 4. cont.

Species of Oriba-tida	Species of seedlings	Variant	Research data					
			V. 2008	X. 2008	V. 2009	X. 2009	V. 2010	X. 2010
Tectocepheus velatus	Pine	C	0.06	0.06	0	0	0	0
		O	0	0	0.06	0	0	0.36
		M	0	3.61	1.93	0.12	0	1.63
		OM	0.18	2.95	2.53	0.12	0	1.14
	Beech	C	0	0	0	0.72	0	0.06
		O	0.06	0.12	0.78	1.75	0.36	1.14
		M	0	1.51	6.08	6.56	0.36	1.14
		OM	0.06	2.17	6.56	7.46	0.84	5.66
	Linden	C	0	0	0	0	0	0.42
		O	0	0	0	0	0.18	2.23
		M	0	4.21	5.60	16.6	0.90	1.38
		OM	0.06	8.55	2.41	7.95	6.86	10.6

The experiments carried out in Białe Błota nursery were aimed at soil revitalization. Organic fertilization with bark-enriched compost produced from municipal sewage sludge enhanced organic matter content and mulching with raw humus improved the soil structure and restored its natural layers. Moreover, the soil was inoculated with typical forest edaphon. The use of sewage sludge, and especially taking advantage of its fertilizing and pedogenic properties, is a very good idea from the environmental perspective. This is the simplest and cheapest method of disposing the waste harmful to people and environment.

Earlier studies confirmed positive effects of the practices implemented in this experiment on the quality of linden seedlings. Both treatments improved this plant growth and leaf number and area (Klimek et al. 2013b). The greatest diameter of root collar, and number and area of leaves were observed in 3-year old linden seedlings grown on the plots mulched and fertilized with the compost. Compost fertilization alone positively affected the density of oribatid mites, as significant increase in the count and average number of species per sample (*s*) were noticed in beech and linden nurseries (Table 2 and 3). Another experiment carried out for two years in the same nursery on the plots with pine and birch did not show any effect of compost fertilization on the density of oribatid mites (Klimek et al. 2008, 2009, 2013a).

An analysis of the abundance and species diversity of Oribatida revealed the most effective soil revitalization in deciduous tree nurseries where mulching was combined with organic fertilization (Table 2). Successful attempts at soil inoculation with mesofauna by spreading raw humus have been reported in numerous publications (Klimek et al.2008, 2009, 2011, 2012). Good revitalization results were achieved in birch nursery (Klimek et al. 2009), and the treatment was more successful than in pine (Klimek et al. 2008), and larch nursery (Klimek et al. 2012). The seedlings of deciduous trees grow faster and provide edaphon with better protection against harmful solar radiation than coniferous seedlings. Moreover, they enrich the soil with organic matter in the form of leaves falling down in the autumn. Poor effectiveness of edaphon inoculation may therefore be due to excessive drying of the exposed soil surface. Sensitivity of soil mesofauna, and particularly Oribatida to low moisture has been reported in the literature (Lindberg and Bengtsson 2005). When natural precipitation is too low, forest nurseries are irrigated. However, the amount of water provided as per irrigation standards for seedlings may be too small to make up for soil surface drying, especially on sunny spring and summer days. The effect of Oribatida on the quality of seedlings produced in forest nurseries is obviously indirect. It consists mainly in improving the activity of soil microorganisms (Wallwork 1983) and accelerating the processes of organic matter decomposition by its disintegration. By constant reduction of fungi and bacteria population, these small arthropods are capable of maintaining the organic matter in the growth phase (so called compensatory growth). Some researchers claim oribatid mites feed mainly on mycelium (Lindberg and Bengtsson 2005), and the environmental conditions facilitating mycelium development are also beneficial for Oribatida populations (Blakley et al. 2002; Pollierer et al.2007). It may be therefore assumed that abundant presence of oribatid mites indicates proper course of soil revitalization processes (bioindicative role) and occurrence of microorganisms typical for forest soils, especially fungi. This hypothesis was confirmed by abundant presence of two fungivorous mites *Oppiella nova* and *Tectocepheus velatus* on the mulched plots (Table 2 and 4). *T. velatus*, the species common in various biotopes, turned out to be a good bioindicator and was especially responsive to the implemented revitalization treatments. It is a par-thenogenetic species, characterized by short reproduction cycle, high reproduction rate and high ability to colonize new environments (Siepel 1994, Skubała and Gulvik 2005; Gulvik 2007). It belongs to fungivores (Luxton 1972; Ponge 1991) feeding on ectomycorrhizal fungi (Schneider, et al. 2005; Remén et al. 2010), and spreading them in the process, which makes it a good stimulant of the revitalization of nurseries.

4. Conclusion

Fertilization with bark-enriched compost prepared from sanitized municipal sewage sludge carried out in the in-ground nursery in Białe Błota positively affected the density and species diversity of oribatid mites in beech and linden nurseries. Substantial increase in the abundance and number of Oribatida species following mulching with raw humus and organic fertilization, particularly clear in deciduous tree nurseries, made this experimental variant stand out as the most effective soil revitalization treatment. The most effective bioindicator and stimulant of soil revitalization was a common fungivorous species *Tectocepheus velatus*.

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Abstract

The study was conducted in the years 2008-2010 in the bare root nursery Białe Błota that produced pine, beech and linden, and belonged to Bydgoszcz Forest District. The experiments included the following variants: C – control, O – organic fertilization, M – mulching with raw humus, OM – organic fertilization and mulching with raw humus. Relatively small but significant increase in the number and diversity of Oribatida species was observed in O variant for the deciduous trees. Mulching was the soil revitalization method that clearly improved the density and biodiversity of Oribatida species. In total, the investigated area harbored 37 species of oribatid mites. The most effective bioindicator and stimulant of soil revitalization was a common fungivorous species *Tectocepheus velatus*.

Keywords:
organic fertilization, mulching, tree seedlings, bioindication, oribatid mites.

Występowanie mechowców podczas rewitalizacji szkółek leśnych

Streszczenie

Badania były prowadzone w latach 2008-2010 w należącej do Nadleśnictwa Bydgoszcz, szkółce leśnej Białe Błota produkującej sosnę, buk oraz lipę. Badania prowadzone były w następujących wariantach: C – kontrola, O – nawożenie organiczne, M – mulczowanie świeżym humusem, OM – nawożenie organiczne i mulczowanie świeżym humusem. Stosunkowo mały, ale znaczący wzrost liczby i zróżnicowania gatunkowego mechowców zaobserwowano w wariancie O dla drzew liściastych. Mulczowanie było metodą rewitalizacji gleb, która wyraźnie wpłynęła na intensywność i zróżnicowanie gatunkowe mechowców. Na badanej powierzchni stwierdzono ogółem 37 gatunków mechowców. Najskuteczniejszym bioindykatorem i stymulatorem rewitalizacji gleby był powszechnie występujący gatunek grzybożerny *Tectocepheus velatus*.

Słowa kluczowe:
nawóz organiczny, mulczowanie, sadzonki drzew, bioindykacja, mechowce