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# Effects of Mulching with Forest Litter and Compost Made of Sewage Sludge on the Presence of Oribatida as Bioindicators of Soil Revitalization in Larch and Pine In-Ground Forest Nurseries

*Andrzej Klimek, Stanisław Rolbiecki, Roman Rolbiecki*
*University of Technology and Life Sciences in Bydgoszcz*

## 1. Introduction

In-ground forest nurseries operating for over 20 years often suffer from degradation processes involving e.g. decreasing biological diversity of ectomycorrhizal fungi (ECM) (Aleksandrowicz-Trzcińska 2004). This is usually accompanied by lower quality of the produced seedlings. ECM fungi are a small but very important for trees part of the edaphon. In natural conditions, the microorganisms of forest soil form a web of relationships, often of trophic nature, with abundant soil micro- and mesofauna.

The main cause of nursery soil degradation is drastically decreasing content of organic matter. This results in reduced microbial activity and a shortage of ectomycorrhizal fungi (Kropp and Langlois 1990, Aučina et al. 2014). Biological condition of these soils may be improved by enriching them with organic matter, e.g. by fertilization with a compost or inoculation with edaphon, including zooedaphon, from forest soils. In the forest nurseries composts from sewage sludge (with addition of bark or sawdust) can be useful (Boruszko 2011, Klimek et al. 2013a). Mulching is one of effective methods of soil enrichment. Apart from supplying organic matter, this treatment restores natural layered structure of forest soil (Leski et al. 2009, Aučina et al. 2014). Therefore, mulching creates optimal conditions for the development of microorganisms and soil mesofauna (Forge et al. 2003). Spreading forest litter allows also for reintroduction of multiple microorganisms and arthropods, such as oribatid mites (Oribatida).

These small soil arthropods including Acari and especially Oribatida, are known to play many important functions in terrestrial ecosystems, they improve pedogenic processes and a propagation of bacteria and fungi, and they indirectly affect the formation of endo- and ectomycorrhizas (Klironomos & Kendrick 1996, Behan-Pelletier 1999, Schneider et al. 2005, Remén et al. 2010). They are also good bioindicators of soil biological activity (Behan-Pelletier 1999, 2003, Gulvik 2007).

The aim of the study was to determine the effects of mulching with forest litter and organic fertilization (compost prepared from sanitized sewage sludge supplemented with bark or sawdust) on the presence of oribatid mites in the nurseries producing European larch (*Larix decidua* L.) and Scots pine (*Pinus sylvestris* L.). The oribatid mites were treated as bioindicators of the effectiveness of soil revitalization treatments in in-ground nursery.

## 2. Material and Methods

The study was conducted in the years 2006-2007 in Białe Błota nursery belonging to Bydgoszcz Forest Inspectorate (53°06'12.3"N; 17°55'41.5"E), Poland. The experiment was established in the spring 2006 in the nurseries producing European larch and Scots pine. Each nursery included 16 experimental plots (4 variants x 4 repetitions) with the area of 2 $m^2$ each. The experiment included the following variants: Cb – compost made of sanitized sewage sludge (⅔) + pine bark (⅓), Cs – compost made of sanitized sewage sludge (⅔) + pine sawdust (⅓), M+Cb – mulching with forest litter + compost made of sanitized sewage sludge (⅔) + pine bark (⅓), M+Cs – mulching with forest litter + compost made of sanitized sewage sludge (⅔) + pine sawdust (⅓).

Detailed description of the investigated soils was presented in earlier works (Klimek et al. 2011, 2012). The compost contained 49% of organic matter, 56% of dry weight and its pH was 7.82. It was applied at a dose of 100 $t \cdot ha^{-1}$ and mixed with surface soil layer (to the depth of 10 cm) before sowing the seeds.

The entire experimental area was irrigated with "Nelson" micro sprinklers. Irrigation times and precipitation rates were determined as recommended in the guidelines for open area forest nurseries (Pierzgalski et al. 2002). Aggregate water doses in subsequent growing seasons were 88 and 65 mm, in 2006 and 2007, respectively. Plants grown in the areas around Bydgoszcz, as well as in entire central Poland, need intense irrigation (Żarski & Dudek 2009, Stachowski & Markiewicz 2011, Żarski 2011).

Soil samples for acarological studies were collected four times in mid-June and mid-October. Twelve samples (three from each plot) were always collected per each experimental variant on each collection date. In total, 384 soil samples were collected. The soil was sampled from the area of 17 $cm^2$ and down 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 2,622 juvenile and adult oribatid mites were classified. Their mean density ($N$) was given per 1 $m^2$ of soil. Oribatida aggregations 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 48 samples, and Shannon's diversity index ($H'$).

Prior to statistical analysis, the numerical data were subjected to alogarithmic transformation – ln (x+1) (Berthet and Gerard 1965). The statistical analysis was performed using Statistica 10.0: 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 ($p < 0.05$) a analysis for each pair was carried out (Mann-Whitney $U$ test) to identify significantly different means.

## 3. Results

The number of oribatid mites in larch and pine nurseries fertilized with the compost enriched with bark (Cb) or sawdust (Cs) ranged from 240 to 1,000 individuals per $m^2$ (Table 1). Differences between these variants were not significant. Oribatida density was markedly improved following mulching, and it was 3,560-4,150 individuals $m^{-2}$ in larch nursery and 10,660-12,320 individuals $m^{-2}$ in pine nursery. In both nurseries, the highest density of oribatid mites was observed on the plots that were both mulched and fertilized with bark-enriched compost (M+Cb).

On non-mulched plots evaluated in June 2006, the mite density was low and ranged from 0 to 300 individuals per $m^2$ (Table 2 and 3). On the last sampling date, an increase in the density up to 850 individuals $m^{-2}$ was observed in larch nursery. In pine nursery on Cb and Cs plots assessed over the two-year study, the increase in Oribatida density was greater than in larch nursery and ranged from 2,410 to 3,760 individuals $m^{-2}$. Contrary to that, the density of oribatid mites in June 2006 on mulched plots where edaphon was reintroduced was high (3,010-11,790 individuals $m^{-2}$). In the next season (autumn 2006), a significant decrease in this parameter was observed on most of the mulched plots. In the spring of 2007, oribatid mites were significantly more abundant on these plots than in the previous season, and in the autumn 2007 their density was usually higher than at the beginning of the study. The only exception was M+Cs variant in larch nursery. It is worth mentioning that in autumn 2007 the density of oribatid mites on the mulched plots was many times higher in pine than in larch nursery. The highest Oribatida density was observed for M+Cb variant where it amounted to 37,470 individuals $m^{-2}$.

**Table 1.** The density of oribatid mites (*N* in $10^3$ individuals $m^{-2}$) in the variants of the experiment for the forest nursery cultivations: larch (L) and pine (P)
**Tabela 1.** Liczebność mechowców (*N* w $10^3$ osobników $m^{-2}$) w wariantach doświadczenia w uprawach szkółkarskich modrzewia (L) i sosny (P)

| Taxon | Species of seedlings | Experiment variant | | | | Kruskal-Wallis test | |
|---|---|---|---|---|---|---|---|
| | | Cb | Cs | M+Cb | M+Cs | *H* | *p* |
| *Carabodes subarcticus* Tragardh | L | 0 | 0 | $0.24^{Aa}$ | $0.23^{Aa}$ | 25.5 | 0.001 |
| | P | 0 | 0 | $0.45^{Aa}$ | $0.43^{Aa}$ | | |
| *Eremaeus oblongus* C.L. Koch | L | 0 | 0 | $0.04^{Aa}$ | $0.09^{Aa}$ | 22.7 | 0.002 |
| | P | 0 | $0.01^{A}$ | $0.14^{Ba}$ | $0.70^{Ba}$ | | |
| *Metabelba pulverulenta* (C.L. Koch) | L | 0 | 0 | $0.09^{Aa}$ | $0.10^{Aa}$ | 15.8 | 0.027 |
| | P | 0 | 0 | $0.04^{Aa}$ | $0.51^{Aa}$ | | |
| *Oppiella nova* (Oudemans) | L | $0.01^{Aa}$ | $0.03^{ABa}$ | $0.26^{Ba}$ | $0.05^{ABa}$ | 32.8 | 0.000 |
| | P | $0.01^{Aa}$ | $0.09^{Aa}$ | $4.06^{ABa}$ | $2.23^{Bb}$ | | |

**Table 1.** cont.
**Tabela 1.** cd.

| Taxon | Species of seedlings | Experiment variant | | | | Kruskal-Wallis test | |
|---|---|---|---|---|---|---|---|
| | | Cb | Cs | M+Cb | M+Cs | *H* | *p* |
| *Oribatula tibialis* (Nicolet) | L | 0 | $0.03^{Aa}$ | $0.16^{Ba}$ | $0.71^{Ca}$ | 52.3 | 0.000 |
| | P | $0.01^{A}$ | $0.03^{Aa}$ | $0.26^{Ba}$ | $0.70^{Ca}$ | | |
| *Pergalumna nervosa* (Berlese) | L | 0 | 0 | $0.21^{Aa}$ | $0.21^{Aa}$ | 24.5 | 0.001 |
| | P | 0 | 0 | $0.29^{Aa}$ | $0.28^{Aa}$ | | |
| *Rhysotritia duplicata* (Grandjean) | L | 0 | 0 | $0.06^{Aa}$ | $0.01^{Aa}$ | 18.3 | 0.011 |
| | P | 0 | 0 | $0.28^{Aa}$ | $0.11^{Aa}$ | | |
| *Scutovertex sculptus* Michael | L | $0.11^{Aa}$ | $0.10^{Aa}$ | $1.23^{Ba}$ | $0.35^{Aa}$ | 98.6 | 0.000 |
| | P | $0.56^{Aa}$ | $0.77^{Ab}$ | $2.92^{Bb}$ | $1.08^{Bb}$ | | |
| *Steganacarus carinatus* C.L. Koch | L | 0 | 0 | $0.15^{Aa}$ | $0.24^{Aa}$ | 29.88 | 0.000 |
| | P | 0 | 0 | $0.15^{Aa}$ | $0.29^{Aa}$ | | |
| *Tectocepheus velatus* (Michael) | L | $0.11^{Aa}$ | $0.09^{Aa}$ | $1.37^{Ba}$ | $1.15^{Ba}$ | 60.1 | 0.000 |
| | P | $0.06^{Aa}$ | $0.09^{Aa}$ | $3.19^{Ba}$ | $3.71^{Ba}$ | | |
| *Other species of Oribatida | L | 0.00 | 0.06 | 0.34 | 0.41 | - | - |
| | P | 0.00 | 0.03 | 0.54 | 0.61 | | |
| Oribatida total | L | $0.24^{Aa}$ | $0.30^{Aa}$ | $4.15^{Ba}$ | $3.56^{Ba}$ | 100.3 | 0.000 |
| | P | $0.65^{Ab}$ | $1.00^{Ab}$ | $12.32^{Ba}$ | $10.66^{Ba}$ | | |

*Other species of Oribatida ($N$ < 200 individuals per $m^2$): *Camisia biurus* (C.L. Koch) – L: M+Cb; *C. horrida* (Hermann) – L: M+Cb; *C. segnis* (Hermann) – P: M+Cs; *C. spinifer* (C.L. Koch) – L: M+Cb, M+Cs; P: M+Cb, M+Cs; *Carabodes forsslundi* Sellnick – P: M+Cb, M+Cs; *C. minusculus* Berlese – L: M+Cb, M+Cs; P: M+Cb, M+Cs; *Chamobates schuetzi* (Oudemans) – L: M+Cb, M+Cs; P: M+Cb, M+Cs; *Eupelops torulosus* (C.L. Koch) – L: M+Cb, M+Cs; P: M+Cb, M+Cs; *Galumna lanceata* (Oudemans) – P: M+Cb; *Lauroppia neerlandica* (Oudemans) – L: M+Cs, P: M+Cs; *Licneremaeus licnophorus* (Michael) – L: M+Cs; P: M+Cs; *Liochthonius* sp. – P: M+Cs; *Micreremus brevipes* (Michael) – P: M+Cb; *Peloptulus phaenotus* (C.L. Koch) – L: M+Cb, P: M+Cb; *Phthiracarus longulus* (C.L. Koch) – L: M+Cb, M+Cs; P: M+Cb, M+Cs; *Protoribates variabilis* Rajski – L: M+Cs, P: M+Cb; *Quadroppia quadricarinata* (Michael) – L: M+Cs, P: M+Cb; *Ramusella mihelcici* (Pérez-Íñigo) – L: Cs, M+Cb, M+Cs; P: Cs, M+Cb, M+Cs; *Suctobelba* sp. – L: M+Cs, P: M+Cb, M+Cs; *Trhypochthonius tectorum* (Berlese) – L: M+Cb, P: M+Cb; *Trichoribates trimaculatus* C.L. Koch – L: M+Cb, P: M+Cb

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

**Table 2.** The dynamic changes in the density ($N$ in $10^3$ individuals $m^{-2}$) of oribatid mites over the 2-year course of the study in the forest nursery cultivation of larch
**Tabela 2.** Dynamika liczebności ($N$ w $10^3$ osobników $m^{-2}$) wybranych gatunków mechowców w 2-letnim cyklu badań w uprawie szkółkarskiej modrzewia

| Taxon | Variant | Research data | | | | Kruskal-Wallis test | |
|---|---|---|---|---|---|---|---|
| | | VI. 2006 | X. 2006 | V. 2007 | X. 2007 | *H* | *p* |
| *Oppiella nova* | Cb | 0 | 0 | 0 | 0.05 | 65.1 | 0.000 |
| | Cs | 0 | 0 | 0 | 0.10 | | |
| | M+Cb | 0 | 0 | 0 | 1.05 | | |
| | M+Cs | 0 | $0.05^A$ | 0 | $0.15^A$ | | |
| *Oribatula tibialis* | Cb | 0 | 0 | 0 | 0 | 77.5 | 0.000 |
| | Cs | $0.05^A$ | $0.05^A$ | 0 | 0 | | |
| | M+Cb | $0.55^A$ | 0 | $0.10^A$ | 0 | | |
| | M+Cs | $1.76^A$ | $0.10^B$ | $0.85^{AB}$ | $0.15^B$ | | |
| *Scutovertex sculptus* | Cb | $0.05^A$ | 0 | 0 | $0.40^B$ | 71.3 | 0.000 |
| | Cs | 0 | 0 | 0 | 0.40 | | |
| | M+Cb | $0.10^A$ | $0.40^A$ | $1.15^A$ | $3.26^B$ | | |
| | M+Cs | $0.15^A$ | 0 | $0.15^A$ | $1.10^A$ | | |
| *Tectocepheus velatus* | Cb | 0 | 0 | $0.05^A$ | $0.40^A$ | 92.7 | 0.000 |
| | Cs | 0 | 0 | 0 | 0.35 | | |
| | M+Cb | $0.40^A$ | $0.55^A$ | $1.30^A$ | $3.21^A$ | | |
| | M+Cs | $2.06^A$ | 0 | $0.80^A$ | $1.76^A$ | | |
| Oribatida total | Cb | $0.05^A$ | 0 | $0.05^A$ | $0.85^B$ | 127.9 | 0.000 |
| | Cs | $0.30^{AB}$ | $0.05^A$ | 0 | $0.85^B$ | | |
| | M+Cb | $3.01^A$ | $2.01^A$ | $3.71^{AB}$ | $7.88^B$ | | |
| | M+Cs | $7.63^A$ | $0.40^B$ | $2.61^A$ | $3.61^A$ | | |

Explanations see Table 1.

In total, the investigated area harbored 31 species of oribatid mites. Non-mulched plots yielded from 3 to 6 species, and after mulching this number increased to 21-26 species (Table 4). Statistical analysis based on the average number of species per sample ($s$) indicated significant increase in the number of species following mulching. Maximum values of this parameter in M+Cb and M+Cs variants were found in pine nursery. On non-mulched plots, $s$ parameter was low (0.1-0.3) in the first year of the study, and it significantly increased by the last sampling date, particularly in pine nursery, up to 1.2-1.6 (Figure 1). Contrary results were obtained on the mulched plots, where initially high average number of species *s* was reduced by the last sampling date. In pine nursery this decrease was significant. Shannon's diversity index (*H'*) was relatively low on non-mulched plots (0.50-1.47) (Table 4), and it markedly increased in both nurseries (1.80-2.21) following mulching treatment.

**Table 3.** The dynamic changes in the density (*N* in $10^3$ individuals $m^{-2}$) of oribatid mites over the 2-year course of the study in the forest nursery cultivation of pine
**Tabela 3.** Dynamika liczebności (*N* w $10^3$ osobników $m^{-2}$) wybranych gatunków mechowców w 2-letnim cyklu badań w uprawie szkółkarskiej sosny

| Taxon | Variant | Research data | | | | Kruskal-Wallis test | |
|---|---|---|---|---|---|---|---|
| | | VI. 2006 | X. 2006 | V. 2007 | X. 2007 | *H* | *p* |
| *Oppiella nova* | Cb | 0 | 0 | 0 | 0.05 | 73.7 | 0.000 |
| | Cs | 0 | 0 | 0 | 0.35 | | |
| | M+Cb | $0.05^A$ | $0.05^A$ | 0 | $16.15^B$ | | |
| | M+Cs | $0.90^A$ | $0.05^A$ | $0.25^A$ | $7.73^B$ | | |
| *Oribatula tibialis* | Cb | 0.05 | 0 | 0 | 0 | 80.4 | 0.000 |
| | Cs | $0.05^A$ | 0 | $0.05^A$ | 0 | | |
| | M+Cb | $0.90^A$ | $0.05^A$ | $0.05^A$ | $0.05^A$ | | |
| | M+Cs | $1.61^A$ | $0.45^A$ | $0.75^A$ | 0 | | |
| *Scutovertex sculptus* | Cb | 0 | 0 | $0.10^A$ | $2.16^A$ | 119.3 | 0.000 |
| | Cs | 0 | 0 | 0 | 3.06 | | |
| | M+Cb | 0 | $0.10^A$ | $0.85^A$ | $10.74^B$ | | |
| | M+Cs | 0 | 0 | $0.10^A$ | $4.21^B$ | | |
| *Tectocepheus velatus* | Cb | 0 | 0 | $0.05^A$ | $0.20^A$ | 104.6 | 0.000 |
| | Cs | 0 | 0 | 0 | 0.35 | | |
| | M+Cb | $1.81^A$ | $0.35^A$ | $1.51^A$ | $9.08^B$ | | |
| | M+Cs | $3.81^A$ | $0.40^A$ | $1.00^A$ | $9.63^B$ | | |
| Oribatida total | Cb | $0.05^A$ | 0 | $0.15^A$ | $2.41^B$ | 135.7 | 0.000 |
| | Cs | $0.20^A$ | 0 | $0.05^A$ | $3.76^B$ | | |
| | | | | | | | |
| | M+Cb | $7.17^A$ | $1.15^B$ | $3.46^C$ | $37.47^D$ | | |
| | M+Cs | $11.79^A$ | $1.51^B$ | $7.32^C$ | $22.02^D$ | | |

Explanations see Table 1.

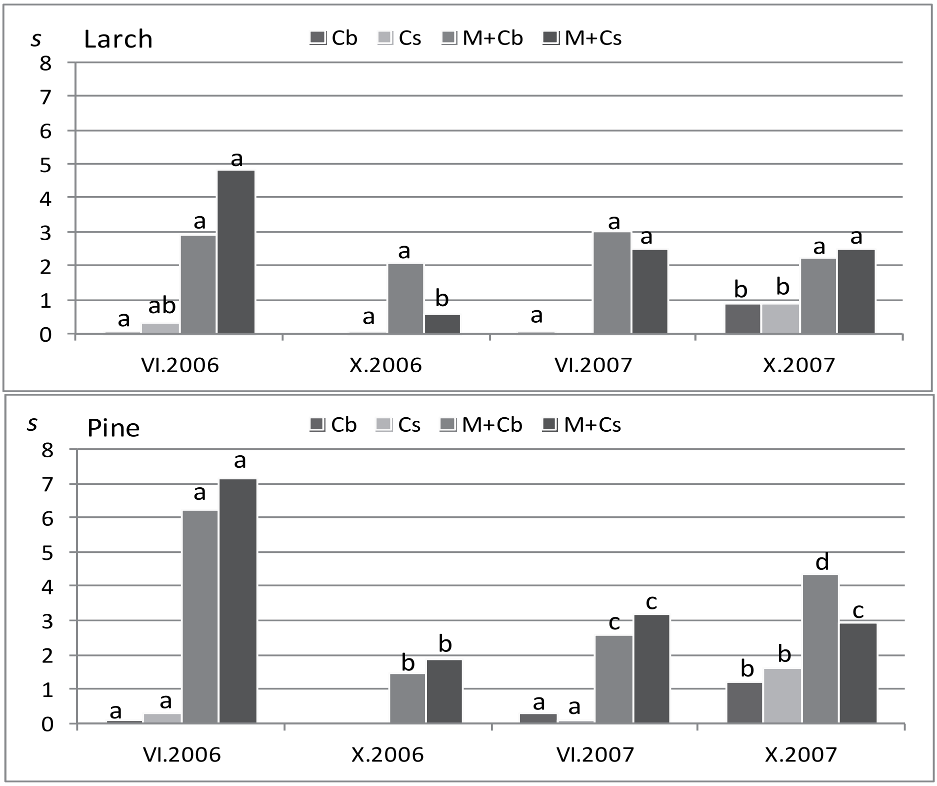


**Fig. 1.** Average number of species per sample (*s*) of oribatid mites over the 2-year course of the study (2006-2007) in the variants of the experiment at the forest nursery, [abc] – the same letter for a single variant of the experiment means lack of significant differences – a the Mann-Whitney *U* test at $p < 0.05$)

**Rys. 1.** Średnia liczba gatunków mechowców na próbkę (*s*) w 2-letnim cyklu badań (2006-2007) w wariantach doświadczenia w szkółce leśnej, [abc] – te same litery w ramach jednego wariantu doświadczenia oznaczają brak istotnych różnic – test U Manna-Whitneya, $p < 0.05$)

Only three Oribatida species, *Oppiella nova*, *Scutovertex sculptus* and *Tectocepheus velatus* were present in all experimental variants (Table 1). Oribatida communities on non-mulched plots were dominated by *Scutovertex sculptus* with *D* index ranging from 33 to 87%. Depending on the variant, the most abundant oribatid mites on mulched plots were *Tectocepheus velatus* (three times, *D* 32-35%) or *Oppiella nova* (once, *D* = 33%). Another species fairly common in the investigated area was

*Oribatula tibialis* that was absent in only one variant, and its mean domination rate was 7%. The other Oribatida species were less abundant and no effects of the experimental variants on their occurrence were observed.

**Table 4.** Number of oribatid mite species (*S*), average number of species (*s*) and Shannon index (*H'*) in the variants of the experiment for the forest nursery cultivations: larch (L) and pine (P)
**Tabela 4.** Liczba gatunków mechowców (*S*), średnia liczba gatunków na próbkę (*s*) i wskaźnik ogólnej różnorodności gatunkowej Shannona (*H'*) w badanych wariantach doświadczenia w uprawach szkółkarskich modrzewia (L) i sosny (P)

| Index | Species of plant | Experiment variant | | | | Kruskal-Wallis test | |
|---|---|---|---|---|---|---|---|
| | | Cb | Cs | M+Cb | M+Cs | H | p |
| *S* | L | 3 | 5 | 20 | 21 | - | - |
| | P | 4 | 6 | 26 | 22 | - | - |
| *s* | L | 0.3Aa | 0.3Aa | 2.6Ba | 2.6Ba | 93.5 | 0.000 |
| | P | 0.4Aa | 0.5Aa | 3.6Ba | 3.8Ba | | |
| *H'* | L | 0.86 | 1.47 | 2.01 | 2.21 | - | - |
| | P | 0.50 | 0.87 | 1.80 | 2.08 | - | - |

Explanations see Table 1.

*Scutovertex sculptus* was the most abundant oribatid mite on non-mulched plots, and it was particularly common in pine nursery (560-770 individuals $m^{-2}$). Mulching positively affected its density, especially in M+Cb variant (1,230-2,920 individuals $m^{-2}$). This species preferred pine nursery. Pine seedlings attracted also numerous representatives of *Oppiella nova*, which in M+Cb variant achieved its maximum density (4,060 individuals $m^{-2}$) and was twice as abundant as in M+Cs variant. Mulching considerably improved the density of *Tectocepheus velatus*.

This species, similarly to the previously described ones, preferred pine nursery but 3-fold difference between pine and larch nursery was too low to be significant. However, significant differences in its numbers between both nurseries were found for mulched and non-mulched plots. *Oribatula tibialis* was the most abundant species in both nurseries in M+Cs variant (700-710 individuals $m^{-2}$).

*Oppiella nova*, *Scutovertex sculptus* and *Tectocepheus velatus* were the most numerous on the last sampling date, i.e. in October 2007, achieving the count of 16,150, 10,740 and 9,630 individuals m$^{-2}$, respectively (Table 2). The first two species were the most abundant in the last season in all experimental variants, and only once *Tectocepheus velatus* was the most abundant at the beginning of the study (larch nursery, M+Cs).

## 3. Discussion

Our earlier reports on the same experiment revealed no effects of various composts enriched with bark or sawdust on the growth of larch (Klimek et al. 2011) and pine seedlings (Klimek et al. 2012). However, their growth was considerably affected by mulching. This treatment reduced pH and increased the content of organic carbon and general nitrogen. Also ECM fungi on the seedling roots were found to be well developed and the use of the compost made of sewage sludge did not bring about any negative effects.

Therefore, increased abundance of oribatid mites after mulching observed in this study corresponded to improved quality of the produced seedlings. This confirmed proper course of soil revitalization processes. A study carried out in Lithuania that tested different forest litters revealed improvements in plant growth and ECM formation in pine seedlings fertilized with this substrate (Aučina et al. 2014). The results of this study indicated a key role of forest litter in improving environmental conditions conducive to the development of ECM fungi previously present in the soil. The forest litter probably did not serve as an inoculum for specific fungal species.

In our study, the forest litter introduced into the nurseries was most probably the source of numerous mesofauna species. However, not all populations from the soil of matured stands survived in new ecological conditions of the nurseries. Dynamics of mean number of species per samples *s* over the two-year study cycle indicated at first a drop in this parameter and then its gradual growth. In autumn 2007, 57% of the species present in the spring 2006 were detected. It should be remembered that oribatid mites do not have as many spreading options as fungi. Literature reports indicated that the colonization of initial soils is a slow process that may last for many months or even years (Wanner & Dunger 2002, Lehmitz et al. 2011).

Oribatid mites indirectly affect a nursery performance as they speed up the processes of organic matter decomposition (Wallwork 1983) and improve the activity of soil microorganisms including ECM fungi (Klironomos & Kendrick 1996, Behan-Pelletier 1999, Schneider et al. 2005, Remén et al. 2010). Some studies suggested that oribatid mites feed mainly on mycelium (Lindberg & Bengtsson 2005, Renker et al. 2005), and environmental conditions beneficial to the mycelium development are also favorable for Oribatida populations (Blakley et al. 2002, Pollierer et al. 2007). Good or improving condition of Oribatida communities and populations may therefore indicate their optimal performance.

After mulching, in both nurseries but particularly in the pine one, high density of fungivorous (Luxton 1972, Ponge 1991) *Oppiella nova* and *Tectocepheus velatus* were observed. According to literature data, *Oppiella nova* is a parthenogenetic species with short life cycle (20 days), and its population grows very rapidly (Siepel 1994, Skubała & Gulvik 2005). Similar survival strategy is exercised by *Tectocepheus velatus* (Gulvik 2007) but its life cycle is slightly longer. *T. velatus* is a eurytopic soil species (Weigmann & Kratz 1981), characterized by high reproduction rate and capability of colonizing new environments. Moreover, Remen et al. (2010) claimed that *Oppiella nova* feeds mainly on active ECM fungi, while *Tectocepheus velatus* is rather a general fungivore. It is worth mentioning that these species were also numerous at a similar experiment on the linden nursery cultivation (Klimek et al. 2013a). Both species were the most abundant on the last sampling date, and this may suggest progressive soil revitalization also within fungal communities.

The density of another oribatid mite, *Oribatula tibialis*, which was fairly high in the beginning of the study, considerably decreased or it was not detected at all on the last sampling date. Interestingly, similar trends in density changes over time were observed for these species when forest litter was added to containers during the production of pine seedlings (Klimek et al. 2013b).

The sites fertilized with the compost alone (no mulching) were dominated by *Scutovertex sculptus*. This species is adapted to initial soils and high solar radiation and is commonly found in Poland e.g. on wastelands and industrial waste heaps (Skubała 1999, Rolbiecki et al. 2006). Therefore, it was not introduced from a forest but it had been probably present in the nursery soil before the experiment was established. However, its abundance increased in all experimental variants and it reached its maximum density on the last sampling date.

This study mainly indicated very positive effects of mulching with forest litter on the presence of oribatid mites. The changes in their density indicate their affinity to the compost enriched with pine bark, especially at the end of the study. The highest density of oribatid mites, unprecedented in forest nurseries, was obtained in pine nursery by combined treatment involving mulching and fertilizing with the compost enriched with pine bark. Given high bioindicative value of this group of arthropods (Behan-Pelletier 1999, 2003, Gulvik 2007) it can be assumed that the implemented treatments resulted in desired soil revitalization that affected the quality of the produced seedlings.

## 4. Conclusions

The study showed a strong positive effect of mulching larch and pine nurseries with forest litter on the abundance and species diversity of oribatid mites. Dynamics of changes in Oribatida presence in this two-year study revealed positive effects of mulching on soil revitalization, particularly in pine nursery and when combined with fertilization with bark-enriched compost.

High abundance and growing population of such fungivores as *Oppiella nova* and *Tectocepheus velatus* may indicate positive changes in fungal communities. The study suggests that these species may be good bioindicators of soil biological activity in in-ground forest nurseries.

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# Wpływ ściółkowania ektopróchnicą leśną i nawożenia kompostowanym osadem ściekowym na mechowce (Acari: Oribatida) jako bioindykatory rewitalizacji gleb w uprawach szkółkarskich modrzewia i sosny

## Streszczenie

Badania terenowe prowadzono w latach 2006-2007 w należącej do Nadleśnictwa Bydgoszcz gruntowej szkółce leśnej Białe Błota. Ich celem było określenie wpływu ściółkowania ektopróchnicą leśną i nawożenia kompostem przygotowanym na bazie higienizowanych osadów ściekowych z dodatkiem kory lub trocin na występowanie mechowców w uprawach szkółkarskich modrzewia europejskiego i sosny zwyczajnej. Mechowce traktowano jako bioindykatory zabiegów rewitalizacji gleb szkółki. Z przeprowadzonych badań wynika, iż ściółkowanie upraw modrzewia i sosny miało wyraźny dodatni wpływ na liczebność i różnorodność gatunkową mechowców. Przebieg dynamiki występowania tych roztoczy w 2-letnim cyklu badań świadczy o pozytywnym wpływie ściółkowania na rewitalizację gleb, szczególnie w uprawie sosny i w połączeniu z nawożeniem kompostem z dodatkiem kory. Liczne występowanie i rosnąca liczebność populacji mykofagów – *Oppiella nova* i *Tectocepheus velatus* – może świadczyć o pozytywnych zmianach w obrębie zbiorowisk grzybów. Wymienione gatunki mogą być dobrymi bioindykatorami aktywności biologicznej gleb w gruntowych szkółkach leśnych.

## Abstract

The study was conducted in the years 2006-2007 in Białe Błota nursery belonging to Bydgoszcz Forest Inspectorate (53°06'12.3"N; 17°55'41.5"E), Poland. The aim of the study was to determine the effects of mulching with forest litter and organic fertilization (compost prepared from sanitized sewage sludge supplemented with bark or sawdust) on the presence of oribatid mites in the nurseries producing European larch (*Larix decidua* L.) and Scots pine (*Pinus sylvestris* L.). The oribatid mites were treated as bioindicators of the effectiveness of soil revitalization treatments in in-ground nursery. The study showed a strong positive effect of mulching larch and pine nurseries with forest litter on the abundance and species diversity of oribatid mites. Dynamics of changes in Oribatida presence in this two-year study revealed positive effects of mulching on soil revitalization, particularly in pine nursery and when combined with fertilization with bark-enriched compost. High abundance and growing population of such fungivores as *Oppiella nova* and *Tectocepheus velatus* may indicate positive changes in fungal communities. The study suggests that these species may be good bioindicators of soil biological activity in in-ground forest nurseries.

**Słowa kluczowe:**
osady ściekowe, ściółkowanie, rewitalizacja gleb, bioindykacja, Oribatida

**Keywords:**
sewage sludge, mulching, soil revitalization, bioindicators, oribatid mites