

Moss mites (Acari: Oribatida) in soil revitalizing: a chance for practical application in silviculture

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Abstract: The Oribatida (known as moss mites or beetle mites) increase the breakdown of organic material in the soil. The paper analyses the dynamics of their abundance and number of species after various treatments enriching the soil in 4 study areas: afforested post-agricultural area in the Tuchola Forest, afforested degraded post-military training area in Bydgoszcz-Jachcice, and forest nurseries at Białe Błota and Bielawy. The results show that in post-agricultural and degraded soils at the initial stages of forest succession, the density and number of species of oribatid mites were low, even after phyto-land-improvement (afforestation and lupin as green manure). In the forest nurseries, however, we recorded a positive effect of soil revitalizing after mulching with forest ectohumus (i.e. organic surface layer of the soil). The inoculation of soils with forest mesofauna appeared more effective in nursery plantations of silver birch (*Betula pendula*) and small-leaved lime (*Tilia cordata*), as compared with Scots pine (*Pinus sylvestris*). Thus to revitalize degraded soils effectively and to accelerate forest succession, apart from phyto-land-improvement, it is advisable also to reintroduce mesofauna, e.g. with the use of forest ectohumus.

Keywords: post-agricultural area, degraded soil, soil revitalizing, bioindication, reintroduction, oribatid mites

INTRODUCTION

Small soil animals affect many processes taking place in soil and their presence mostly positively affects its fertility and productivity. Thus mesofauna may intensify the soil processes and revitalize degraded soils. The soil fauna can be used in the processes of revitalizing soils in 2 ways: as soil health bioindicators or as soil supplements, because the introduction of mesofauna can speed up soil metabolism (HAIMI 2000). The restoration of soil fauna usually also takes place in 2 ways: by improving the life conditions (stimulation of native populations) as well as soil inoculation: introducing species potentially beneficial for us.

In soil environments, mites (Acari) are mostly dominated by oribatid mites (Oribatida), which have a positive effect on the formation and maintenance of proper soil structure, the spread of bacteria and fungi, and indirectly on the formation of endo- and ectomycorrhizae (KLIRONOMOS & KENDRICK 1996; BEHAN-PELLETIER 1999; SCHNEIDER et al. 2005; REMÉN et al. 2010).

In our long-term research, we analysed the occurrence of oribatid mites, to evaluate effects of soil revitalizing treatments in various conditions: phyto-land-improvement by means of afforestation and/or organic fertilization (lupin as green manure), and reintroduction of the edaphon (soil organisms). The treatments were performed in soils that were formerly degraded or used for agriculture and in forest nurseries. The aim of this paper is to show the influence of various treatments on communities of oribatid mites (in respect of the density of mites and number of species) in 4 areas: afforested post-agricultural area in the Tuchola Forest, afforested degraded post-military training area in Bydgoszcz-Jachcice, and forest nurseries at Białe Błota and Bielawy.

MATERIAL AND METHODS

Post-agricultural area, Linówek, Tuchola Forest (53°43'41.7"N, 18°14'03.9"E)

Field research was performed in 2006 and 2009 in young forest stands of Scots pine (*Pinus sylvestris* L., 1753) and silver birch (*Betula pendula* Roth, 1788) on a fresh (i.e. moderately moist) coniferous forest site (Bśw according to the Polish classification of forest sites), planted in 2001 in a post-agricultural area. In 2009 the forest stands, having achieved full crown closure, were at the early stage of young tree. More information on the research area can be found in papers published earlier: KLIMEK & POKORA (2009), KLIMEK & KOWALSKA (2013).

Degraded area, Bydgoszcz-Jachcice (53°08'45.0"N, 17°58'57.0"E)

Research was performed in 2008–2009 in a post-military training area in Bydgoszcz-Jachcice, after its afforestation with Scots pine. Pine was planted there in the spring of 2008 on a fresh pine forest site (Bśw according to the Polish classification). We analysed 2 variants of the experiment: plots with lupin (*Lupinus luteus* L., 1753) as green manure (grown in 2007) and without that treatment. A detailed description of the experiment is provided by KLIMEK et al. (2009a), KLIMEK & ROLBIECKI (2011).

Forest nursery, Białe Błota, Bydgoszcz Forest District (53°06'11.4"N, 17°55'41.4"E)

In 2008–2009 we performed research in the forest nursery at Białe Błota near Bydgoszcz, in plantations of Scots pine and small-leaved lime (*Tilia cordata* Mill., 1768). The experimental factor was mulching with forest ectohumus (i.e. organic surface layer of the soil) derived from a fresh forest site (Bśw according to the Polish classification). The seeds were sown in late April 2008. Mulching with fresh ectohumus was performed in mid-September 2008. It was applied at a rate of 100 m³·ha⁻¹, and mixed with the soil layer down to about 1–2 cm deep. The plants were irrigated with a stationary sprinklers, following the guidelines developed for forest nurseries. The irrigation pattern, weather conditions as well as soil characteristics were described in earlier publications (KLIMEK et al. 2011; ROLBIECKI et al. 2013).

Forest nursery, Bielawy, Dobrzejewice Forest District (53°01'35.4"N, 18°43'03.0"E)

The experiment was performed in 2008–2009 at the forest nursery Bielawy near Toruń in the nursery plantations of Scots pine and silver birch. The seeds were sown in late April 2008. Mulching with forest ectohumus derived from a fresh forest site (Bśw according to the Polish classification) was performed in mid-September 2008. It was applied at a rate of $100 \text{ m}^3 \text{ ha}^{-1}$, placed between rows of seedlings and then mixed with top soil (about 1–2 cm deep). The plants were irrigated with a stationary sprinkler, following the guidelines developed for forest nurseries. The irrigation pattern, weather conditions, and soil characteristics were given in earlier publications (ROLBIECKI et al. 2009; 2010a, b; 2011).

Sampling and observation of oribatid mites

Some of the mite research results used in this study were published earlier by KLIMEK & KOWALSKA (2013), KLIMEK & POKORA (2009), KLIMEK & ROLBIECKI (2011), KLIMEK et al. (2009a; 2011), ROLBIECKI et al. 2009; 2010a, b; 2011; 2013). To make the results from different experiments comparable in that paper, we analysed a 2-year research cycle, 2 sampling dates (spring & autumn) as well as selected factors of more thorough research. The samples for mite research were taken from an area of 17 cm^2 to the depth of 3 cm, in 10 replicates. Mites were extracted from the soil for 7 days using the modified Tullgren extractor. Next, they were preserved in ethanol and prepared. Oribatid mites were identified to the species or genus level, including juvenile stages. A total of 2671 oribatid mites were identified, including 52 species.

The mean density (N) of Oribatida per 1 m^2 of soil was calculated, and their species richness was expressed as the mean number of species/sample (s). Numerical data prior to the statistical analysis were subjected to logarithmic transformation – $\ln(x+1)$ (Berthet & Gerard 1965). The statistical analysis was performed with Statistica 10.0 package. Normality was verified with the Kolmogorov-Smirnov test. Their distribution was not normal, so we performed a non-parametric analysis of variance (ANOVA: Kruskal-Wallis test), and in the case of significant differences ($P < 0.05$), also a *post-hoc* analysis for each pair (the Dunn's z test), to select significantly different means.

RESULTS

Post-agricultural area, Linówek

In Poland, on poor sites in post-agricultural landscapes but also on forest soils, Scots pine is mostly planted and additionally silver birch is introduced. These species show different rates of growth – birch grows faster, producing shade to soil and in autumn producing abundant litter. Introduction of birch on post-agricultural land can be thus treated as a method of phyto-land-improvement.

The mean density of oribatid mites in the young pine stand was 7740 individuals/ m^2 (Fig. 1). In the soil under the forest stand of silver birch it was lower and the differences between pine and birch were significant (ANOVA: $H = 13.39$, $P = 0.0003$; z test: $z = 3.60$, $P = 0.0003$). Similarly, in the case of mean number of species (s), a higher richness of Oribatida was found under pine than under birch (ANOVA:

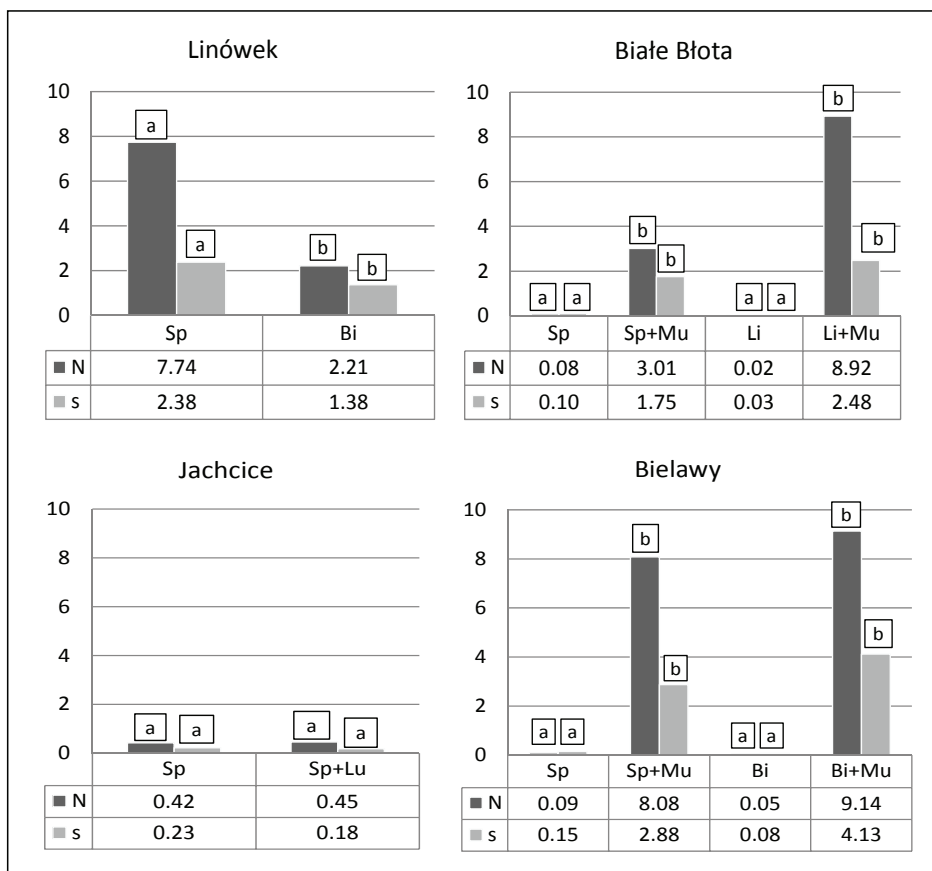


Fig. 1. Mean density of Oribatida (N in 10^3 individuals/ m^2) and mean number of species per sample (s) in the studied variants (Sp = Scots pine; Bi = birch; Li = lime; Lu = lupine; Mu = mulch; a, b = the same letters denote non-significant differences, *post hoc* Dunn's z test, $P < 0.05$) in 4 study areas

$H = 6.35$, $P = 0.0117$; z test: $z = 2.46$, $P = 0.0137$). On successive sampling dates (spring of 2006 to autumn of 2009), the density and species richness of oribatid mites was always higher under pine than under birch (Table 1). Both the oribatid mite species abundance and their richness from the spring of 2006 to the spring of 2009 remained low. A many-fold increase in the values of both indices was noted only on the last date of research, in the autumn of 2009.

Degraded area, Bydgoszcz-Jachcice

Phyto-land-improvement treatments are applied in practice for the revitalizing and restoration of degraded post-agricultural soils allocated to afforestation. Such

treatments include sowing sweet lupin as green manure a year before establishing a forest plantation. The treatment aims at improving the bioactivity of soils. Performed in the Bydgoszcz-Jachcice post-military training area, the treatment with lupin before starting a forest plantation increased neither the oribatid mites abundance nor the oribatid mites species richness (Fig. 1). In this area those mites occurred sporadically from the spring of 2008 to the spring of 2009. Slightly more abundant occurrence of oribatid mites was noted only on the last research date: 1510–1690 individuals/m² in the autumn of 2009 (Table 1).

Table 1. Seasonal dynamics of Oribatida (N , in 10³ individuals/m²) and mean number of species per sample (s) in the studied variants of experiments in the 2-year research cycle

Study area	Experimental variant	Index	First year		Second year	
			spring	autumn	spring	autumn
Linówek	pine	N	5.60	4.76	3.73	16.86
		s	1.20	2.20	1.60	4.50
	birch	N	0.54	1.57	0.36	6.38
		s	0.80	1.70	0.50	2.50
Jachcice	pine	N	0.00	0.12	0.06	1.51
		s	0.00	0.10	0.10	0.70
	pine + lupine	N	0.12	0.00	0.00	1.69
		s	0.10	0.00	0.00	0.60
Białe Błota	pine	N	0.06	0.06	0.06	0.12
		s	0.10	0.00	0.10	0.20
	pine + mulch	N	0.00	7.34	2.83	1.87
		s	0.00	3.90	2.00	1.10
	lime	N	0.00	0.06	0.00	0.00
		s	0.00	0.10	0.00	0.00
	lime + mulch	N	0.06	10.29	8.13	17.22
		s	0.10	5.70	2.60	1.50
Bielawy	pine	N	0.06	0.24	0.00	0.06
		s	0.10	0.40	0.00	0.10
	pine + mulch	N	0.00	27.57	0.24	4.52
		s	0.00	9.80	0.30	1.40
	birch	N	0.00	0.06	0.06	0.06
		s	0.00	0.10	0.10	0.10
	birch + mulch	N	0.00	24.86	2.59	9.09
		s	0.00	10.00	2.10	4.40

Białe Błota forest nursery

The conditions of growth of young trees in forest nurseries differ considerably from the conditions typical for them in forest ecosystems. As a result of frequent agrotechnical treatments and intensive production of the seedlings, the nursery soils are degraded. The biological conditions of soils can be improved by enriching the nursery with organic matter, e.g. by fertilizing it with composts or inoculating with edaphon, including the soil fauna derived from forest soil (e.g. by mulching). In the Białe Błota nursery, non-mulched plantations of pine and lime showed exceptionally low abundance and species richness of oribatid mites (Fig. 1). During the 2-year research cycle (2008–2009), the values of both indices remained low (Table 1), unlike in the stands where in September of 2008 mulching was made with forest ectohumus. Under pine in the autumn of the first study year, the density of Oribatida increased after mulching to 7340 individuals/m². In that case, however, the soil inoculation with mesofauna can be considered moderately successful, since the abundance of oribatid mites on successive sampling dates gradually decreased. Similarly, the number of species (*s*) right after mulching was high (3.9), but later it decreased to only 1.4 species/sample at the end of the cycle.

Better results of the treatment were reported in the nursery plantation of lime. In the autumn of 2008, indices *N* and *s* were high (even higher than in pine plantations): 10 290 individuals/m² and 5.70 species/sample, respectively. Although the species richness on successive sampling dates decreased, the density of oribatid mites in the autumn of 2009 increased considerably, to 17 220 individuals/m².

Bielawy forest nursery

The experimental design in the Bielawy forest nursery was similar to the one described in the Białe Błota forest nursery, but beside the nursery plantation of pine, we investigated also the soil mite fauna of a silver birch plantation. Birch grows faster than pine, providing shade to soil and organic matter in autumn in the form of abundant leaf litter. However, during the entire 2-year research cycle the occurrence of oribatid mites in the non-mulched stands of both species was sporadic: 60–240 individuals/m² and 0.1–0.4 species/sample (Table 1). In contrast, after the mulching with ectohumus, the maximum values of both indices were noted in the autumn of 2008, but in the spring of 2009 the numbers dropped remarkably and during the second growing season they increased. It is noteworthy that the decrease in oribatid mite abundance and species richness in the spring of 2009 under birch was milder than under pine, and the values of those indices at the end of the research period were clearly higher under birch. The 2-year mean values of *N* and *s* differed significantly between the mulched and non-mulched stands, both for pine (ANOVA: $H = 15.86$, $P = 0.0001$; *z* test: $z = 3.34$, $P = 0.0008$; and ANOVA: $H = 15.61$, $P = 0.0001$; *z* test: $z = 3.31$, $P = 0.0009$; respectively) and for birch (ANOVA: $H = 34.04$, $P = 0.0000$; *z* test: $z = 5.11$, $P = 0.0000$; and ANOVA: $H = 34.05$, $P = 0.0000$; *z* test: $z = 5.11$, $P = 0.0000$; respectively) (Fig. 1).

DISCUSSION

In forest soils, oribatid mites are some of the most important representatives of the mesofauna; their presence determines the adequate functioning of the entire forest ecosystem. Those Acari, besides participation in organic matter decomposition, are stimulants and vectors of many microorganisms essential for the forest economy, e.g. mycorrhizal and saprotrophic fungi (SETALA 1995; RENKER et al. 2005). Soil animals feeding on fungi stimulate their growth (HANLON & ANDERSON 1980) and when migrating they can inoculate the substrate with spores of fungi and hyphae (LUSSENHOP 1992; RENKER et al. 2005).

This study shows that in the post-agricultural and degraded soils at the initial stages of forest succession the abundance and richness of oribatid mites are very low. The phyto-land-improvement in the degraded post-military training area and post-agricultural land did not give the expected effect of increased biodiversity. In the post-military training area in the first 2 years after the afforestation and treatment with lupin, the density of oribatid mites was extremely low (120–1690 individuals/m²). In comparison, in forest soil in a 2-year-old pine plantation set up after the forest stand was cut down, the density of those Acari was about 8180 individuals/m² (KLIMEK & ROLBIECKI 2011). In the post-agricultural area in the Tuchola Forest, both in birch and pine plantations, 5 years after the afforestation the density and species richness of oribatid mites were 2-fold lower than in a forest area after restoration of the forest stand (KLIMEK & KOWALSKA 2013). Eight years after the establishment of forest plantations those disproportions in birch plantations were even greater. The acarological research performed in degraded and post-agricultural soils demonstrates that the succession of oribatid mites in those areas was much slower than in forest soils once the forest stand was cut down. It seems that to solve that problem, soils can be inoculated with living edaphon by using forest ectohumus in which soil mesofauna is very abundant.

In 2003–2004 in the Białe Błota forest nursery, we made the first attempts at inoculating the soil with the edaphon, with the use of forest ectohumus derived from an adult pine stand (KLIMEK et al. 2013a). The treatment was more effective in the nursery plantation of birch, as compared with pine. Our research team also found a positive effect of irrigation on the abundance and species richness of oribatid mites in birch and pine plantations (KLIMEK et al. 2008; 2009b; 2013a).

A favourable effect of birch on soil inoculation with edaphon was also noted in the experiment performed in 2008–2009 in the Bielawy nursery (ROLBIECKI et al. 2009; 2010a, b; 2011). The values of the indices analysed (*N* and *s*) on the last research date were higher under birch than under pine (Table 1). The high abundance and species richness of oribatid mites in the birch plantation indicate a positive effect of this tree species on the biological activity of soils. This observation can be important for nursery practice, especially facing the need for soil revitalizing in degraded forest nurseries.

In a similar experiment performed in the same years in the nursery plantations of pine and small-leaved lime in the Białe Błota nursery, we also noted a positive effect of soil inoculation with edaphon on seedlings of deciduous tree species. However,

the species richness of oribatid mites some time after mulching in pine and in lime plantations usually decreased. The density of oribatid mites in the lime plantation in the autumn of 2009 was maximum, while in the pine plantation on the same date it was several-fold lower (Table 1).

The effect of oribatid mites on the quality of the production in forest nurseries is obviously indirect; it mostly involves increasing the activity of soil microflora (WALLWORK 1983) and accelerating organic matter decomposition processes by breaking it down into smaller particles. Oribatids, through a continuous reduction of the populations of bacteria and fungi, keep them at the growth stage (the so-called compensation growth). Some researchers claim that oribatid mites feed mostly on mycelium (LINDBERG & BENGTTSSON 2005), and the environmental conditions enhancing mycelium growth also have a positive effect on their populations (BLAKLEY et al. 2002; POLLIERER et al. 2007), which additionally justifies their use as bioindicators of soil revitalizing.

The analysis of the occurrence of oribatid mites in afforested post-agricultural and degraded areas presented here points to a low biological activity of soils at the beginning of forest succession in those areas, even after phyto-land-improvement treatments. Literature on this subject shows that in raw soils, with difficult conditions for small arthropods, soil colonization by mites is rather slow and can take many months or even years (BECKMANN 1988; WANNER & DUNGER 2002; LEHMITS et al. 2011; KLIMEK et al. 2013a). LEHMITS et al. (2012) claim that active migration plays an important role in the colonization of this type of soils and various species of oribatid mites can use various modes of dispersal. However, only 35% of oribatid mites spread by underground migration, while 65% by overground migration. Passive migration paths, e.g. with the wind, are also possible (LEHMITS et al. 2011).

SZUJECKI (1996) claims that the the set of soil fauna characteristic for forest soils is formed as late as 20-45 years after afforestation of agricultural soils. With that in mind, most afforestations should occur in an active restitution system, preceded by the introduction of organic matter with retention properties. With that in mind, MAZUR & TRACZ (1996) suggest the recovery of the proper structure of soil fauna in post-agricultural land by treatments stimulating the populations that already exist in a given area and by reintroduction of the desired species. Those authors claim that an additional aspect of such activities can be an activation of microorganisms antagonistic to *Heterobasidion annosum* (Fr.) Bref., 1888, the main agent of root rot, which is a big problem in post-agricultural areas.

For many years we have made more or less successful attempts at inoculating soils with mesofauna, with the use of forest ectohumus and mulching of the soil surface (KLIMEK et al. 2008; 2009b; 2012; 2013a). The observations show that a lower effectiveness of that treatment can be due to excessive drying of the soil surface. The sensitivity of soil mesofauna, especially the Oribatida, to low moisture has already been reported (e.g. LINDBERG & BENGTTSSON 2005). In forest nurseries, in case of a lack of natural precipitation, irrigation is applied. In the post-agricultural and degraded areas, in general, there are no such possibilities and initial soils are deprived of the protective layer of ectohumus. With that in mind, one shall search for methods of water retention in soil over the periods of its deficits in the environment. It seems

that a good idea to solve that problem is the application of mulching, preferably using the materials natural for forest ecosystems, such as wood waste remaining after logging. The resultant woodchips are a natural material used for orchard mulching, enhancing the soil microclimate properties, especially moisture (TREDER et al. 2009). It turned out that in woodchips used for the mulching of non-irrigated strawberry in a 2-year experiment cycle, a very rich Acari fauna developed, especially oribatid mites (KLIMEK et al. 2014). In the post-military training area exposed to revitalizing in Bydgoszcz-Jachcice, in the autumn of 2012 we set up an experiment in the pine plantation with the application of mulching with woodchips inoculated with edaphon from forest ectohumus. Preliminary observations of the samples with mites collected in 2013 are optimistic and show a chance of obtaining good results of reintroduction of soil mesofauna.

There is also a possibility of using the container nursery production to inoculate the soils with mites. It turned out that in small root clumps of the seedlings produced with the so-called covered root system, very abundant oribatid mites can live (KLIMEK 2013). Especially favourable conditions for the development of oribatid mites occur in small root clumps of deciduous species: small-leaved lime and silver birch. In 2013, the first attempt was made to introduce edaphon to some root clumps of pine (KLIMEK et al. 2013b). The experiment, however, turned out moderately successful, so further research is necessary to investigate the possibilities of restitution of soil mesofauna with small root clumps of tree seedlings.

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