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The Use of Chosen Biological Methods for Forest Soil Revitalization in Scots Pine Cultivation

Andrzej Klimek[1], Stanisław Rolbiecki[1], Roman Rolbiecki[1], Grzegorz Gackowski[1], Piotr Stachowski[2], Barbara Jagosz[3]*

[1]University of Science and Technology in Bydgoszcz, Poland
[2]Poznań University of Life Sciences, Poland
[3]University of Agriculture in Krakow, Poland
[*]corresponding author's e-mail: piotr.stachowski@up.poznan.pl

1. Introduction

The devastated and degraded land requiring reclamation (revitalization, remediation) cover in Poland approximately 64 thousand hectares (CSO 2017). The size of this area has changed only slightly over the last few years. Since 2005, only an area of between 1,222 and 1,861 hectares per year has been reclaimed, of which only 581 to 1,132 hectares were restored to cultivation.

Devastated and degraded soils are usually devoid of the humus layer that protects the soil against drying and creates a favorable environment for the development of soil microflora and microfauna. The lack of an organic matter layer on the soil surface also inhibits the process of natural succession and has a negative impact, mainly during warm and dry summer months, on the population size of soil mesofauna, such as moss mites (Oribatida) (Lindberg & Bengtsson 2005).

The restoration of the forest biocenosis – which is the most natural and biodiverse land biocenosis in our climate zone – is considered as the best wayfor revitalization of degraded land. Nowadays, in Poland, forest resources are steadily increasing through the implementation of a program of afforestation of economically inefficient land (Koreleski 2003). These areas usually have poor soil, so they are most often forested by Scots pine (*Pinus sylvestris* L.). In Poland, Scots pine is the dominant forest-forming species that covers 52% of the forest area in our country (Skolud 2006).

The aim of this study was to specify the most effective method of revitalizing degraded forest area. The different modifications of wood chips were used as a substitute for humus layer. The mites (Acari), as well moss mites as the bio-indicators of succession changes occurring in the reconstructed forest soil, were used. The study began 2 years after planting of Scots pine seedlings on the land devastated by military activity, at the former military training ground in Bydgoszcz-Jachcice.

2. Material and methods

2.1. Description of the experiment

The experiment was conducted at the former military training ground in Bydgoszcz-Jachcice, which is currently managed by the Żołędowo Forest District (Forestry Jagodowo, branch 222c, GPS: 53.156943N, 17.986440E). Before renewal, this area was a post-agricultural land overgrown with a rare and degraded Scots pine tree stand, which in 2010 has a fire. According to the Tree Stand Data Sheet of the Żołędowo Forest District, the soil on this area was in the type of rusty soils and subtype of the rusty algae soils. Before planting, the soil surface was tilled with a double-layer forest plow. For planting, Scots pine seedlings with a covered root system, from the Bielawa container nursery (Forest District Dobrzejewice), were used. Scots pine seedlings were planted in spring 2011, in a distance 1.5×0.8 m. After afforestation, this habitat was classified as "fresh boron", dominated by Scots pine with a 10% addition of silver birch (*Betula pendula* Roth).

One-factor experiment was located in forest cultivation. The studied factor was soil mulching with the Scots pine wood chips, used in the following four treatments: 1. uncovered soil (without mulching) as the control (C), 2. soil mulched with wood chips (W), 3. soil mulched with wood chips with the addition of mycorrhizal preparation (WM), 4. soil mulched with wood chips with the addition of forest litter (WL). Three replicates of microplots arrangement was applied. Each microplot was 5 m long and covered 3 rows of Scots pine plants. The surface of one replication covers 10 rows of Scots pine plants. Mulching with wood chips was carried out on April 12, 2012. Wood chips were prepared from scrub Scots pine trees cut in the former military training ground. The Scots pine wood was shredded with the BRUKS 805 disk-chipper. On October 25, 2012, the wood chips on the WM microplots were inoculated with the mycorrhizal biopreparation (2.5% biopreparation with the mycelium of *Hebeloma crustuliniforme* (Bull.) Quél.). At the same time, on the WL microplots, a 10% addition of fresh forest litter from the ripe fresh coniferous forest in the Białe Błota Forestry was applied.

2.2. Pluvial and thermal conditions

The average air temperature in the growing season i.e. from April 1 to September 30, in the years 2012-2014 was 14.5°C that was 0.3°C higher than the long-term average temperature (Table 1). The warmest growing period with the temperature 15.4°C (0.9°C higher than the long-term average) was noted in 2014. The highest air temperature occurred in July 2014 (21.5°C that was 2.8°C, i.e. 15%, higher than the long-term average for this month).

During the considered three-year interval, the lowest precipitation sum 289.9 mm (51 mm below the long-term average) in the vegetation period occurs in the year 2014. The highest rainfalls during the vegetation period were observed in the first year of study (2012), when the sum of precipitation was 378.2 mm (37.3 mm above long-term average). Particularly high rainfalls occurred in June (133.8 mm) and July (115.6 mm) 2012, that is 252 and 133% of the long-term average, respectively.

Table 1. Meteorological conditions in the study years according to standard measurements at the Mochełek Research Station of the University of Science and Technology in Bydgoszcz

Specification	Months of growing season						
	IV	V	VI	VII	VIII	IX	IV-IX
Air temperature (°C)							
2012	8.4	14.5	15.2	18.8	17.6	13.3	14.6
2013	7.0	14.2	17.4	18.9	18.1	10.7	14.4
2014	9.9	13.3	16.0	21.5	17.2	14.4	15.4
2012-2014	8.4	14.0	16.2	19.7	17.6	12.8	14.8
Long-term average	8.1	13.2	16.3	18.7	17.8	13.0	14.5
Difference (+/-)	+0.3	+0.8	-0.1	+1.0	-0.2	-0.2	+0.3
Precipitation (mm)							
2012	26.5	25.4	133.8	115.6	51.8	25.1	378.2
2013	13.6	91.7	49.3	79.0	56.6	64.1	354.3
2014	40.7	65.7	44.9	55.4	57.3	25.9	289.9
2012-2014	26.9	60.9	76.0	83.3	55.2	38.4	340.8
Long-term average	28.7	61.1	53.1	87.1	66.5	44.4	340.9
Difference (+/-)	-1.8	-0.2	+22.9	-3.8	-11.3	-6.0	-0.1

2.3. Scots pine growth and development measurement

At the end of 2012, 2013 and 2014, after the end of the growing season, a number of developmental features of young Scots pine trees were measured. The measurement was carried out: the height (cm), the root neck diameter (mm), the length of one-year increments in the last whorl (cm), the number of one-year increments of the last whorl (pcs) and the lengths of one-year increments of the last whorl (cm).

2.4. Acarological research

The samples for acarological tests were collected four times: June 25, 2013, October 15, 2013, June 3, 2014 and October 21, 2014. From each treatment of the experiment, at each sampling-time, 10 substrate samples were collected (3 or 4 samples from the microplot). In total, 40 samples with a volume of 50 cm^3 each were collected from each treatment. Mites extraction was carried out for 7 days in Tullgren apparatus. Then the mites were preserved in 70% ethyl alcohol. All mites were identified to the order, and moss mites to the species or genus, including juvenile stages. In total, 6,499 mites were identified, including 5,104 moss mites.

The average density (N) of mites was measured in 50 cm^3 of substrate. The dominance index (D) was estimated in %. The species richness and the diversity of moss mites was determined by the number of species (S), also the average number of species in the sample (s) and the Shannon general species diversity index (H) were calculated.

Before statistical analysis the measurement results were subjected to the logarithmic transformation – $\ln(x + 1)$ (Berthet & Gerard 1965). Statistical analysis was performed using the Statistica 13.3 software package. The Kolmogorov-Smirnov test was applied to evaluate the compliance of the distribution of measurable parameters with the normal distribution. However, due to the lack of normal distribution a non-parametric analysis of variance (Kruskal-Wallis test) was performed. In the case of the statistically significant differences ($p < 0.05$) the analysis was performed for each pair (Mann-Whitney *U* test) for selecting the significantly different means.

3. Results

3.1. Scots pine growth and development

The use of mulching treatments did not significantly affect the height of Scots pine plants during the first three years after planting (Table 2). The height of Scots pine trees ranged from 41.1 cm on the soil mulched with wood chips with addition of forest litter to 48.2 cm on the soil mulched only with wood chips.

On average, Scots pine plants cultivated on the control plots (without mulching) were by 4.9 cm higher comparing to the mulched plants. The mean value of studied feature ranged from 19.1 cm in 2012 to 71.5 cm in 2014. However, the differences between treatments were not statistically important.

Table 2. Effect of mulching with wood chips on Scots pine height (cm)

Treatment	Years			
	2012	2013	2014	2012-2014
C	20.4	45.9	78.3	48.2
W	19.1	45.5	66.2	43.6
WM	18.3	42.8	74.3	45.2
WL	18.6	37.7	67.1	41.1
Mean	19.1	43.0	71.5	44.5
$LSD_{0.05}$	ns	7.423	ns	ns

Explanations: C – control (uncovered soil – without mulching); W – soil mulched with wood chips; WM – soil mulched with wood chips with the addition of mycorrhizal preparation; WL – soil mulched with wood chips with the addition of forest litter; ns – not significant ($p < 0.05$).

The average diameter of the root neck of Scots pine plants grown in the years 2012-2014 on the plots mulched with wood chips (13.6 mm) was significantly lower than on the control plots (17.4 mm) (Table 3). However, there were no important differences in root neck diameter between individual mulching treatments. In each of the study years, the value of the observed characteristic of plants grown on the control plots were higher in comparison to the plants cultivated on mulched plots, but they were not statistically important.

Table 3. Effect of mulching with wood chips on the Scots pine root neck diameter (mm)

Treatment	Years			
	2012	2013	2014	2012-2014
C	7.2	16.7	28.1	17.4
W	5.8	13.1	22.0	13.6
WM	6.6	15.2	24.6	15.5
WH	6.2	13.8	24.3	14.8
Mean	6.5	14.7	24.7	15.3
$LSD_{0.05}$	ns	ns	ns	2.835

Explanations: see Table 2

There were no significant differences in the average length of one-year increments in the last whorl of Scots pine plants between the studied treatments (Table 4). The mean value of this feature ranged from 17.1 cm in 2012 to 20.8 cm in 2013. The lowest length of one-year increments (14.0 cm) was noted on the soil mulched with wood chips with the addition of forest litter and the highest (18.7 cm) on the soil mulched only with wood chips.

Table 4. Effect of mulching with wood chips on the average length of one-year increments in the last whorl (cm) of Scots pine

Treatment	Years			
	2012	2013	2014	2012-2014
C	17.8	21.0	19.4	17.8
W	18.7	19.5	19.1	18.7
WM	17.8	21.2	19.5	17.8
WL	14.0	21.3	17.7	14.0
Mean	17.1	20.8	18.9	17.1
$LSD_{0.05}$	ns	ns	ns	ns

Explanations: see Table 2

The number of one-year increments of the last whorl of Scots pine did not differ significantly among the tested treatments (Table 5). However, the highest value (6.2) of observed characteristic was noted in the case of control plants. The number of one-year increments of the last whorl was stable in the particular years of the study and ranging from 5.6 in 2012, and 2014 to 5.7 in 2013.

Table 5. Effect of mulching with wood chips on the number of one-year increments of the last whorl (pcs) of Scots pine

Treatments	Years			
	2012	2013	2014	2012-2014
C	6.2	6.5	6.4	6.2
W	5.4	4.7	5.1	5.4
WM	5.9	6.0	5.9	5.9
WL	4.8	5.7	5.2	4.8
Mean	5.6	5.7	5.6	5.6
$LSD_{0.05}$	ns	ns	ns	ns

Explanations: see Table 2

The sum of the lengths of one-year increments of the last whorl was not considerably modified by the performed mulching treatments (Table 6). The highest value of this trait (124.1 cm) was observes in the control plants, while the lowest on the plots mulched only with wood chips and on the plots mulched with wood chips with the addition of forest litter (95.4 cm). The sum of lengths of one-year increments of the last whorl varied between 96.7 cm in 2013 and 118.4 cm in 2014.

Table 6. Effect of mulching with wood chips on the sum of lengths of one-year increments of the last whorl (cm) of Scots pine

Treatments	Years		
	2013	2014	2012-2014
C	109.2	139.0	124.1
W	101.9	88.8	95.4
WM	104.7	127.0	115.9
WL	72.0	118.8	95.4
Mean	96.7	118.4	107.7
$LSD_{0.05}$	ns	ns	ns

Explanations: see Table 2

3.2. Analysis of mites number

Measurement of the number of mites carried out on the control plots revealed their low density, which was 4,020 individuals in 50 cm^3 of substrate (Table 7). Among the mites, Actinedida clearly dominated (88.6%). Another large group were moss mites which covered 9.2% of all mites. Therefore, the Oribatida to Actinedida ratio (Or : Ac) was extremely low (0.10). On the mulched plots, the density of mites was many times higher and ranged from 29,630 to 70,760 individuals in 50 cm^3 of substrate. Moreover, in contrast to the control plots, the mulched plots were dominated by moss mites, whose number ranged from 64.1 to 70.8% of all mites. On the mulched plots, Actinedida was the second large group, and Mesostigmata was the third largest group (on the plots WM and WL). The Oribatida to Actinedida ratio, on the mulched plots, was high and varied from 2.6 to 6.94. Acaridida and Tarsonemida were the least numerous mite groups in this study.

The most numerous population of moss mites was on the plots mulched only with wood chips (60,440 individuals in 50 cm^3 of substrate) (Table 7). In addition, the differences in the number of moss mites between the plots mulched only with wood chips and other mulching treatments were statistically significant. However, there was no important difference in the number of moss mites between the plots mulched with wood chips with the addition of mycorrhizal preparation and the plots mulched wood chips with the addition of forest litter. Compared to the control plots, the size of the Actinedida population on the mulched plots increased significantly, but the differences between the individual mulching treatments were not visible. The population size of Mesostigmata on the control plots and on the plots mulched only with wood chips was clearly lower than on the plots mulched with wood chips with the addition of mycorrhizal preparation, as well forest litter. Acaridida and Tarsonemida mites were found only on the plots mulched with wood chips with the addition of mycorrhizal preparation and on the plots mulched with wood chips with the addition of forest litter.

3.3. Analysis of moss mites clusters

24 species of moss mite were noted in the present study (Fig. 1). Most of them (21) were found on the plots mulched with wood chips with the addition of forest litter and only 2 on the control plots. On the plots mulched only with wood chips and on the plots mulched with wood chips with the addition of mycorrhizal preparation, 11 and 6 species of moss mites, respectively, were observed.

The analysis of the average number of species in the sample (s) presented the visible differences in the mite species abundance between the control plots and the plots mulched only with wood chips (Table 7). The highest value of this index (s = 3.7) was recorded on the plots mulched with wood chips with the addition of forest litter. The lowest Shannon's species diversity index (H) was noted on the control plots (H = 0.22) and the highest value of this index (H = 1.52) was found on the plots mulched with wood chips with the addition of forest litter.

In the group of moss mites, *Tectocepheus velatus* clearly dominated in all treatments of the experiment (Fig. 1). The highest domination index (D) (94.6%) estimated for this species was noted on the control plots, and the lowest (62.1%) was detected on the plots mulched with wood chips with the addition of forest litter.

Table. 7. Density of mites and selected species of moss mites (N in thousand individuals in 50 cm^3 of substrate), the ratio of Oribatida to Actinedida (Or : Ac), the number of species (S), the average number of species (s) and the Shannon's species diversity index (H) of moss mites in the studied mulching treatments of Scots pine

Index – Taxon	Treatments				Kruskal-Wallis test	
	C	W	WM	WL	*H*	*p*
N – Acaridida	0	0	0.03^{a}	1.53^{b}	31.09	0.000
N – Actinedida	3.56^{a}	8.71^{b}	6.78^{b}	7.13^{b}	29.53	0.000
N – Mesostigmata	0.09^{a}	0.09^{a}	1.39^{b}	1.45^{b}	26.73	0.000
N – Oribatida	0.37^{a}	60.44^{b}	27.80^{c}	18.99^{c}	71.56	0.000
N – Tarsonemida	0	0	0.57^{a}	0.53^{a}	8.69	0.034
N – Acari (Total)	4.02^{a}	70.76^{b}	36.57^{c}	29.63^{c}	72.28	0.000
N – *Oppiella nova* (Oudemans)	0	0.36^{a}	1.25^{a}	1.32^{a}	12.88	0.005
N – *Pergalumna nervosa* (Berlese)	-	-	-	1.26	-	-
N – *Scutovertex sculptus* Michael	0	6.95^{a}	2.87^{ab}	0.83^{b}	34.90	0.000
N – *Tectocepheus velatus* (Michael)	0.35^{a}	52.48^{b}	23.45^{c}	11.79^{c}	66.43	0.000
Others Oribatida (*N* < 1.0)*	0.02	0.65	0.23	3.79	-	-
Or : Ac	0.10	6.94	4.10	2.66	-	-
S – Oribatida	2	11	6	21	-	-
s – Oribatida	0.23^{a}	1.98^{b}	1.58^{b}	3.70^{c}	89.47	0.000
H – Oribatida	0.22	0.47	0.56	1.52	-	-

Explanations: [a,b,c] – data with the same letter do not differ significantly ($p < 0.05$)
**Autogneta longilamellata* (Michael) – W, WL; *Banksinoma lanceolata* (Michael) – WL; *Brachychthonius* sp. Berlese – WL; *Camisia biurus* (C. L. Koch) – W; *C. horrida* (Hermann) – WL; *C. segnis* (Hermann) – WM; *Carabodes minusculus* Berlese – WL; *C. subarcticus* Tragardh – WL; *Chamobates schuetzi* (Oudemans) – WL; *Eremaeus oblongus* C. L. Koch – WL; *Liochthonius* spp. van der Hammen – W; *Metabelba pulverulenta* (C.L. Koch) – W, WM, WL; *Oppiella neerlandica* (Oudemans) – W; *Oppiella nova* (Oudemans) – W, WM, WL; *Oribatula tibialis* (Nicolet) – C, WL; *Pergalumna nervosa* (Berlese) – WL; *Punctoribates punctum* (C. L. Koch) – WL; *Scheloribates laevigatus* (C. L. Koch) – WL; *Scheloribates latipes* (C. L. Koch) – W, WL; *Suctobelba* spp. Paoli – W, WM, WL; *Trhypochthonius tectorum* (Berlese) – WL; *Trichoribates trimaculatus* (C. L. Koch) – W, WL

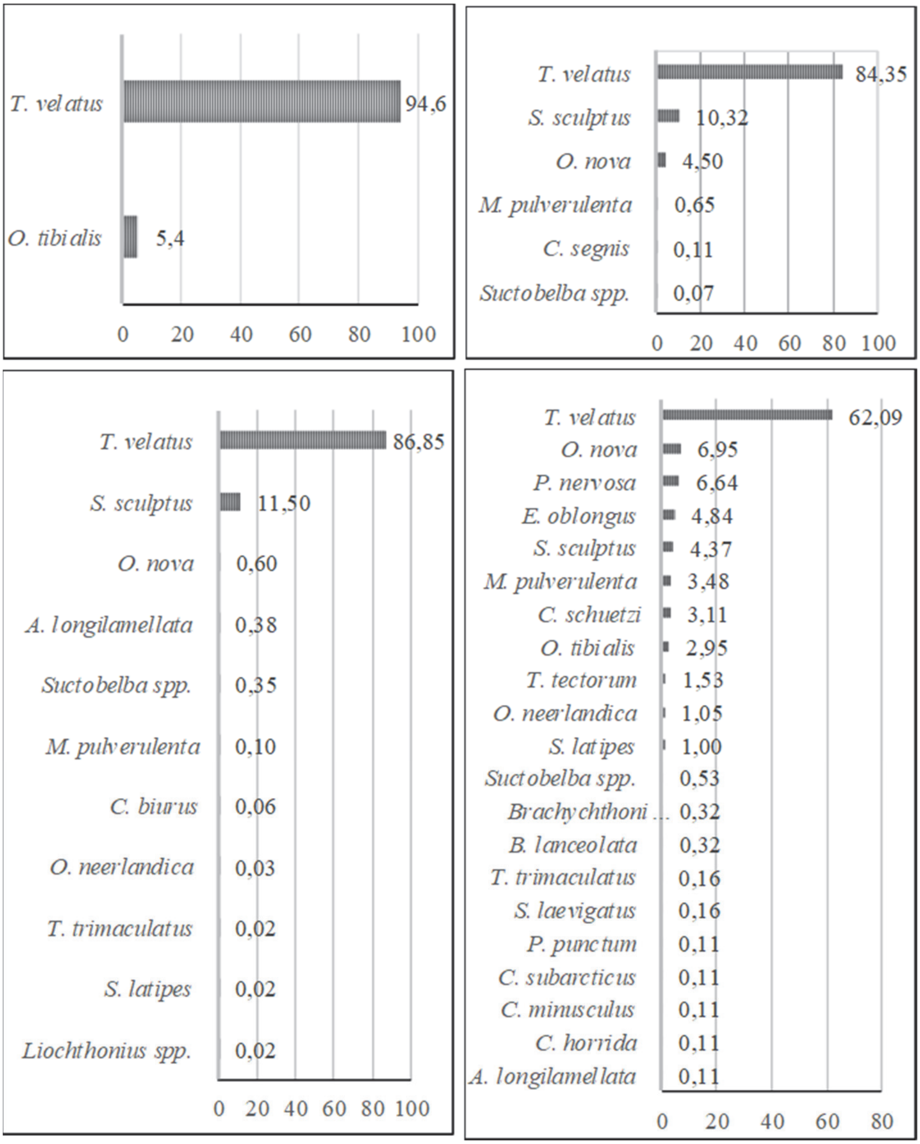

Fig. 1. Domination index (D) for the moss mites groups in the particular experiment treatments

3.4. Analysis of the occurrence of selected moss mites species

On the control plots the number of *Tectocepheus velatus* was only 350 individuals in 50 cm^3 (Table 7). The highest population of this species was observed in the case of mulching only with wood chips (522,480 individuals in 50 cm^3 of substrate). Much lower population of *Tectocepheus velatus* was noted on the plots mulched with wood chips with the addition of mycorrhizal preparation or forest litter. *Oribatula tibialis* also appeared on the control plots as the second species of mites (20 individuals in 50 cm^3 of substrate). On the plots mulched only with wood chips, the second most abundant species was *Scutovertex sculptus* (830-6,950 individuals in 50 cm^3 of substrate). *Oppiella nova* was also a large species of moss mites on the mulched plots (360-1,320 individuals in 50 cm^3 of substrate).

4. Discussion

The height and width of the trunk are the two most commonly measured features that determine the size of tree biomass (Orzeł 2007). In the present research, the height of Scots pine after the first growing season (measurement at the end of 2012) ranged from 18.3 to 20.4 cm (average 19.1 cm). For comparison, in the study reported by Klimek et al. (2009) the average height of Scots pine trees in the first year after planting on the former military training ground in Bydgoszcz-Jachcice (Żołędowo Forest District) was 36.2 cm. In the study presented by Klimek et al. (2009) the highest growth of the Scots pine was noted in the case of seedlings produced using mulching and fertilizing with compost mixed with sawdust, as well as grown on the plots, where lupine was not the forecrop. In the current study, the height of trees after the second growing period (measurement at the end of 2013) varied between 37.7 and 45.9 cm (average 43 cm). According to the research published by Klimek & Rolbiecki (2011), the height of Scots pine trees in the second year after planting on the former military training ground in Bydgoszcz-Jachcice (Żołędowo Forest District) was on average 57.7 cm. The plants grown on the former military training ground were higher (58.5 cm) than the plants grown on the control forest plots (51.7 cm). The different way of seedlings production is an important factor affecting plant growth after planting, as well biomass production (Klimek et al. 2008, 2009, 2011, 2013, Orzeł 2007). In the present experiment, for planting were used Scots pine seedlings with a covered root system production in a container nursery.

Compared to the results published by Klimek et al. (2009) as well Klimek & Rolbiecki (2011), in the current research lower growth and smaller diameter of the root neck of Scots pine plants in the first three years of cultivation on the plots mulched with wood chips with the addition of forest litter can be explained by the immobilization of nutrients occurring in this treatment. According to Prescott et al. (2000), the accumulation of organic matter on the soil surface can affect the forest ecosystem by immobilizing nutrients, which does not allow plants to absorb them. Generally, the physical and environmental conditions can hinder the growth and survival rate of tree seedlings. Szabla (2007), considering the development of selected growth parameters of Scots pine (the height, the diameter of root neck and the sum of length of the lateral shoots of the last whorl) in the different crop groups and on the different types of soil, the highest height increases observed successively for the seedlings mycorrhized and non-mycorrhized: in the crops on the former agricultural lands, next on the grounds after cutting down of forest or fire, on the forest areas degraded by industrial emissions and on the lands reclaimed after sand exploitation. At the same time, the author reports that in the first three years of cultivation the increase of height and diameter of the root neck of mycorrhized Scots pine seedlings was significantly greater (often 2-3 times) than in the case of non-mycorrhized seedlings. In each subsequent year, the differences in the height between mycorrhized and non-mycorrhized seedlings decreased.

A number of studies confirm the usefulness of the wood chips, especially Scots pine chips, as the mulching material that create a good conditions for the development of soil mesofauna (Klimek & Chachaj 2015, 2018, Klimek et al. 2017a, b). Therefore, in the current experiment this material was selected for mulching degraded forest soil for its revitalization. At the first stage of seedlings growth (forest succession), this treatment can replace the layer of forest litter, which naturally occurs on the forest soil of the renewed forests after cutting down the mature trees.

The size of the mites population on the control plots noted in the present experiment was low and similar to the number of mites recorded in the years 2008 and 2009 by Klimek et al. (2009) and Klimek & Rolbiecki (2011). Both in the above research and in the current study, a clear numerical superiority of Actinedida over Oribatida was observed. After mulching with wood chips, the total number of mites increased many times, and moss mites began to dominate in these group. The Oribatida to Actinedida ratio (Or : Ac) may indicate the environment quality, as well as the degree of its anthropogenisation (Werner & Dindal 1990, Gulvik 2007). According to Werner & Dindal (1990) the Oribatida to Actinedida ratio below 1.0 is recorded on arable land, while above 1.0 occurs in more stable ecosystems, e.g. semi-natural meadows and forests, i.e. on the soils with a significant share of the organic matter. In the present study, the high value of Or : Ac ratio noted after using the wood chip mulching on the degraded soil may indicate an increase in the biological balance of this habitat.

The former military training ground in Bydgoszcz-Jachcice, where the research was conducted, had a very small population of the soil mites and very low species diversity of moss mites. In 2008 and 2009, in another area of the same former military training ground, was conducted the research in which phytomelioration was carried out using lupine cultivation before forest planting (Klimek et al. 2009, Klimek & Rolbiecki 2011). The purpose of phytomelioration was to enrich the soil with nutrients to improve the physical properties and soil fertility. However, this treatment neither increased the population of soil fauna nor its diversity.

In the present study, mulching of soil with wood chips obviously increase the number, as well the species diversity of mites, especially moss mites. The largest increase in the moss mite population was observed in the wood chips without additives. However, the largest increase in the species diversity was recorded in wood chips with the addition of forest litter.

In the forest ecosystem, numerous micro-arthropods perform very important soil-forming functions, but one of the most important are moss mites. Unfortunately, these little animals have a limited adaptability to new habitats (Beckmann 1988, Wanner & Dunger 2002, Lehmitz et al. 2011). Haimi (2000) believes that the presence of mesofauna, which restores the soil biological activity, is important during the soil remediation operations. Therefore, the reclamation treatments can be supported by the addition of fresh forest litter, which contains a large amount of mesofauna and soil microorganisms such as fungi and bacteria. According to Klimek et al. (2008), Klimek (2010), Klimek & Rolbiecki (2011, 2014), Klimek at al. (2012, 2013) and Klimek & Chachaj (2015) for the effective inoculation of soil with forest mesoflora and mesofauna, 1 cm of the forest litter needs to be introduced into a suitable substrate, e.g. wood chips.

As Haimi (2000) reported that micro-arthropods can be used in the soil reclamation processes in two ways. First, micro-arthropods have a direct and indirect influence on the soil metabolism, as they feed on microorganisms, which stimulates their growth and reproduction. Secondly, micro-arthropods are bioindicators of the biological state of soils. Moss mites are considered as good bioindicators of the biological properties of soil (Behan-Pelletier 1999, 2003, Gulvik 2007). In addition, moss mites (as vectors) have a beneficial influence on the spread of bacteria and fungi, so they have an indirect effect on the development of mycorrhizae (Klironomos & Kenrick 1996, Behan-Pelletier 1999, Schneider et al. 2005, Remén et al. 2010).

Among the moss mites, *Tectocepheus velatus*, for which the dominance rate ranged from 62.9 to 94.6%, clearly dominated in all treatments of the present experiment (Fig. 1). *T. velatus* are a common soil moss mites that occurring in the different biotopes (Weigmann & Kratz 1981). *T. velatus* has a high reproduction rate and high ability to colonize new habitats. Generally, in the pine forests, this species most often dominates among moss mites, and is also a good bio-indicator of the soil biological activity (Klimek 2000). In the current study, *Oppiella nova* was second (mulching with wood chips with the addition of forest litter) or third (mulching only with wood chips and mulching with wood chips with the addition of mycorrhizal preparation) group of moss mites species in terms of population size. Both of the above-mentioned moss mites species are the pioneer species; they produce a large number of offspring, they are parthenogenic and develop according to the life strategy of the "r" type, which is a genetically conditioned set of the individual traits enabling survive (Siepel 1994, Skubała & Gulvik 2005). In addition, these moss mites species may prey on ectomycorrhizae, thus contributing to their spread (Schneider et al. 2004, Remén et al. 2010).

Scutovertex sculptus also occupied an important place in the hierarchy of the moss mites dominance. This species clearly preferred the wood chips without additions. *S. sculptus* is a large moss mite with strong sclerotization of the cuticle, and thus it is well protected against drying out and adapted to the life in the initial soils in the conditions of high sunlight, e.g. on the fallow soils and industrial heaps (Klimek et al. 1991, Skubała 1999, Rolbiecki et al. 2006). In the present research, no *S. sculptus* was observed on the control plots, however, in earlier studies at the former military training ground in Bydgoszcz-Jachcice, this species was noticed, as did *Oppiella nova* and *Tectocepheus velatus* (Klimek & Rolbiecki 2011). Moss mites, which rarely appearing on the experimental surface before the start of the study, most likely found favorable conditions for development in the wood chips and gradually inhabited them.

On the plots mulched with wood chips with the addition of forest litter, the moss mites domination structure was more even than in the other study treatments. The average number of species and the species diversity index on the plots mulched with wood chips with the addition of forest litter were much higher than for other treatments. After using this treatment, the average number of species and the species diversity index of the substrate were most similar to the forest soils (Klimek & Seniczak 2002, Klimek 2004).

The research indicates the great usefulness of Scots pine wood chips for practical use in the regeneration of degenerated soils, on which a stable forest ecosystem will be created in the future. For this purpose, the wood chips can be used without additions, but then the succession of soil micro-arthropods will last much longer, and the time of stable and species-diverse soil formation will be extended. This process can be accelerated by adding the forest soil mesoflora and mesofauna to the wood chips with the litter coming from a mature forest. In the case of the addition of mycorrhizal preparation to the wood chips, no effect on the number and the species diversity of mites in the substrate was observed.

5. Conclusions

1. The use of soil mulching with the Scots pine wood chips did not significantly affect the growth and developmental characteristics of the Scots pine plants.
2. After mulching with wood chips, the total number of mites increased many times, and moss mites began to dominate among micro-arthropods.
3. Mulching treatments increased the number and the species diversity of moss mites in the substrate. The number of moss mites increased the most in wood chips without additives. The highest species diversity was observed in the wood chips with the addition of forest litter.
4. Among moss mites *Tectocepheus velatus* visibly dominated in all study treatments. *Oppiella nova* and *Scutovertex sculptus* also constituted numerous mites populations.
5. The study shows that the wood chips are very useful for use in the regeneration of the degenerated forest soils.
6. In general, the use of soil mulching with Scots pine wood chips did not affect the growth characteristics of the young Scots pine trees.

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Note: Professor Andrzej Klimek – the first author of this paper – died on 10 June 2020. Our Colleague died while preparing this publication for printing. Scientific cooperation with Andrzej was an honor for us. Andrzej will always remain in our memory.

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Abstract

The purpose of this investigation was to indicate the most effective method of revitalizing degraded forest area. The different modifications of wood chips were used as a substitute for humus layer. The mites (Acari), and moss mites (Oribatida) as the bioindicators of soil succession changes were used. The study began 2 years after planting of Scots pine seedlings on the land devastated by military activity, at the former military training ground (GPS: 53.156943N, 17.986440E). The soil on this area was in the type of rusty soils and subtype of the rusty algae soils. Scots pine seedlings were planted in spring 2011, in a distance 1.5×0.8 m. In one-factor experiment four soil mulching treatments were tested: 1. uncovered soil – control (C), 2. soil mulched with wood chips (W), 3. W + mycorrhizal preparation (WM), 4. W + forest litter (WL). Three replicates of microplots arrangement was applied. Each microplot was 5 m long with 3 rows of Scots pine. Each replication covers 10 rows. Mulching with wood chips was carried out on April 12, 2012. On October 25, 2012, the wood chips on the WM microplots were inoculated with the mycorrhizal biopreparation, and on the WL microplots, a 10% addition of fresh forest litter from the ripe fresh coniferous forest was applied. After the end of the growing season of 2012, 2013 and 2014, the measurement of the plants was carried out (the height, the root neck diameter, the length of one-year increments in the last whorl, the number of one-year increments of the last whorl and the lengths of one-year increments of the last whorl). The samples for acarological tests were collected four times. In total, 40 substrate samples with a volume of 50 cm^3 each were collected from each treatment. Mites extraction was carried out for 7 days in Tullgren apparatus. Mites were identified to the order, and moss mites to the species or genus, including juvenile stages. Calculated: the average density of mites, the dominance index, the species richness, the diversity of moss mites, the average number of species, and the Shannon general species diversity index. The use of soil mulching with the Scots pine wood chips did not significantly affect the growth and developmental characteristics of the Scots pine plants. After mulching with wood chips, the total number of mites increased many times, and moss mites began to dominate among micro-arthropods. Mulching treatments increased the number and the species diversity of moss mites in the substrate. The number of moss mites increased the most in wood chips without additives. The highest species diversity was observed in the wood chips with the addition of forest litter. Among moss mites *Tectocepheus velatus* visibly dominated in all study treatments. *Oppiella nova* and *Scutovertex sculptus* also constituted numerous mites populations. The study shows that the wood chips are very useful for use in the regeneration of the devastated and degraded forest soils.

Keywords:
forest litter, mite, moss mite, mulching, mycorrhizal preparation, *Pinus sylvestris*