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USE OF COMPOSTED SLUDGE AND FOREST ECTOHUMUS TO ENRICH SOIL IN TWO – AND THREE-YEAR CULTIVATION OF COMMON BEECH SEEDLINGS

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Abstract

This study examined the effect of fertilisation with compost prepared from hygienised sludge with an addition of pine-tree bark and mulching with fresh forest ectohumus on selected growth parameters in two – and three-year seedlings of common beech and the occurrence of mites (*Acari*) in soil. The experiment was carried out in 2009-2010 in the Białe Błota forest nursery (Bydgoszcz Forest District) on proper rusty soil. The entire area of the experiment was irrigated with a stationary sprinkler. The beech seedlings on the plots where compost had been used as fertiliser were significantly taller than those growing on the plots where mineral fertilisers had been applied. Mulching increased the height of the seedlings significantly only in the last, third year of the study. The tallest three-year-old seedlings were found on the plots in which both of the tested procedures had been carried out. Neither of the factors under study had a significant effect on the diameter of the root neck in the second year of the nursery cultivation, but they increased it significantly in the third year. Fertilisation with compost with an addition of pine-tree bark increased the number of leaves per plant and the leaf area in two – and three-year-old seedlings. A beneficial and significant effect of mulching on these parameters was found in the third year of cultivation. A significantly positive effect of mulching on the mite gathering density was recorded in the second year of the nursery cultivation. However, both of the experimental factors had a positive effect on the occurrence of those arthropods in the third year of the study.

Oribatid mites were the most numerous mite order and they were found in the greatest density on plots where mulching had been applied. Fertilisation and mulching increased the *Oribatida*/*Actinedida* ratio, which may indicate an improvement of the biological balance in the soil environment.

Key words: forest nursery, common beech, compost, mulching, *Acari*.

INTRODUCTION

Common beech is a valuable species in the forest economy as it improves the diversity of forest ecosystems and – being resistant to pollution – it is planted in urban areas. Moreover, an ability to use common beech in diverse ways in green areas, in wood industry and in other branches of the economy justifies taking up and carrying out actions which aim to spread it throughout Europe.

Beech should be introduced on new areas with high-quality planting material in order to ensure the right growth and development of plants (Tarasiuk 1999). Planting material adapted to the planting conditions – healthy, well-conditioned, properly shaped – increases the possibility that the species will be a proper forest-forming species in Poland (Dziemidek and Tarasiuk 2005).

It is an important research task related to forest nursery production to develop and to identify the best methods and materials for organic fertilisation (Barzdajn *et al*. 1999). A frequent supply of organic matter to soil is usually a necessity in open forest nurseries (Szołtyk and Hilszczańska 2003). Soil in nurseries is enriched in humus by an addition of compost, less frequently crude peat, bark or sawdust. Another option is to use hygienised, composted sludge. Composting sludge requires mixing it with a structure-forming agent (e.g. straw, sawdust, bark, green plant mass), which supplies additional organic mass and ensures an optimum C:N ratio of about 30:1 (Siuta and Wasiak 2001).

External mycorrhiza is the main type of mycorrhiza cohabitation of forest trees and an undisturbed forest biocenosis is a condition of such symbiosis (Urbański 1998). The greatest number of mycorrhiza roots are situated in surface layers of the nursery soil, which contain a lot of humus and oxygen. Soil can be inoculated by microorganisms by scattering soil taken from an afforested area and mixing it with soil in a nursery. This procedure is usually called mulching. Mulch can be used in nursing practice in two ways: as a layer spread on the ground or by mixing a specified volume of mulch with the surface layer of soil (Leski *et al*. 2009). Numerous mites (*Acari*), especially oribatid mites (*Oribatida*), which occur commonly in soils, are trophically related to microorganisms of forest soils. These small arthropods are very often mycophages, and they also contribute to the spreading of microorganisms, indirectly promoting the formation of ectomycorrhiza (Schneider *et al*. 2005, Renker *et al*. 2005, Remén *et al*.

2010). Moss mites are a large group of soil microorganisms, which makes them good bioindicators of the soil system (Behan-Pelletier 1999, 2003, Ruf and Beck 2005, Gulvik 2007).

The aim of this study was to determine the effect of fertilisation with compost prepared from hygienised sludge with an addition of pine-tree bark and of mulching with fresh forest ectohumus on selected growth parameters for two – and three-year seedlings of common beech and on the incidence of mites (Acari) in the soil. Preliminary results – only for one-year-old beech seedlings – were published in a separate paper (Rolbiecki *et al*. 2011).

MATERIAL AND METHODS

The experiment was carried out in 2009-2010 in the Białe Błota forest nursery (Bydgoszcz Forest District) in a nursery cultivation of common beech (Photo 1 and 2). Soil cover was made up of rusty soil formed from alluvial sand. The grain size distribution of the surface layer was that of slightly loamy sand. A more detailed description of the soil conditions was given in a previous paper (Rolbiecki *et al*. 2011).

The experiment was set up in 2008 in a two-factor dependent arrangement in four replications. Fertilisation in the following two options was the first factor: M – mineral fertilisation – as per the recommendations for forest nurseries, O – organic fertilisation – hygienised sludge (60%) + pine-tree bark (40%). Mulching, also applied in the following two options, was another factor: C – no mulching (control), E – mulching with fresh forest ectohumus. Beech seeds were sown on 22 April 2008 in the stripe-4-row system. Each plot area was 2 m^2. The total number of plots in the experiment was 16 (2 factors under study x 2 options for each factor x 4 replications).

The organic fertiliser (compost) was produced from hygienised sludge (60%) and pine-tree bark (40%) applied at 100 t ha^{-1} in spring of 2008 and mixed with the surface layer of the soil down to a depth of 10 cm before beech seeds were sown. Mulching was carried out on 15 September 2008 with fresh ectohumus obtained on that day from fresh coniferous forest. A dose of 100 m^3 ha^{-1} was applied.

Irrigation was carried out with a periodical stationary sprinkler. The dates of irrigation and the doses of water were established in accordance with the guidelines for forest nurseries in open areas (Pierzgalski *et al*. 2002).

Rainfall and irrigation. The weather conditions and irrigation during the 2008 vegetation period were presented in an earlier publication (Rolbiecki *et al*. 2011). The total rainfall in the summer half-year period (from 1 April to 30 September) of 2009 amounted to 313 mm. According to irrigation guidelines for nurseries (Pierzgalski *et al*. 2002), a total of 141 mm of water was supplied in the cultivation of two-year-old beech that year, with the greatest amount (35.5 mm) supplied in June. No irrigation was applied in the third year (2010). On the one hand, this resulted from the guidelines for the irrigation of nurseries and, on the other – from the quantity and distribution of natural precipitation (the total rainfall between 1.04 and 30.09 amounted to 477 mm, i.e. 166% of the normal amount).

Plant growth. The growth of the beech seedlings was determined in late October. The height of the plants (cm) and the diameter of the root neck (mm) were determined. Moreover, the average number of leaves per plant and the average leaf area (cm^2) were determined. The results were analysed statistically with the Fisher-Snedecor test in order to establish the significance of the experimental factors, and with the Tukey test to compare the differences.

Photo 1. Seedlings of common beech in the third year of cultivation in a forest nursery

Acarological studies. Soil samples were collected for acarological studies four times in the years 2009-2010, in the last ten days of May and October. Ten samples were collected from each experimental option (2 or 3 from each plot) on four consecutive dates, which altogether gave 160 samples. Soil sections were collected from 17 cm^2 to the depth of 3 cm. Mites were driven out of the soil in a Tullgren funnels for 7 days, preserved in 70% ethanol and prepared and then classified into orders. Altogether, 1,240 mites were classified. The average mite density (*N*) was given per 1 m^2 of soil. Before the statistical analysis, the figures were converted into logarithms – ln(x+1) (Berthet and Gerard 1965). Statistical calculations were done with the Statistica 10 software by means of a two-way ANOVA analysis of variance. The significance of differences was verified by Tukey's HSD *post hoc* test.

Photo 2. Interrows of 2-year-old common beech tree cultivation mulched with ectohumus

RESULTS AND DISCUSSION

Growth of two-year-old seedlings. Regardless of mulching, fertilisation with compost increased the height of two-year-old beech seedlings significantly, from 43.3 cm to 62.0 cm (Table 1). Therefore, the increase in the plant height achieved thanks to organic fertilisation compared to the variant with mineral fertilisation was 18.7 cm (43%).

Mulching did not have a significant effect on the height of two-year-old beech seedlings.

In a parallel experiment with lime trees, carried out in the same nursery (Klimek *et al*. 2013), two-year-old lime seedlings which grew on plots where compost was applied were significantly taller (by 55%) than those cultivated on plots with mineral fertilisation. Mulching did not have a significant effect on this growth parameter, although the plants growing on mulched plots tended to be taller.

An analysis of the combined effect of both the factors under study on the growth of beech seedlings showed those grown on plots where organic fertilisation was applied but without mulching to be the tallest. This parameter – the average for the four replications of the experiment – was 63.7 cm. No significant synergy of the factors under study was observed in their effect on the seedling height.

Table 1. Parameters of two-year seedling growth in the year 2009

Fertilization	Mulching		Mean
	without mulching (C)	mulching (E)	
Height of seedling (cm)			
Mineral (M)	40.9	45.8	43.3
Organic (O)	63.7	60.4	62.0
Mean	52.3	53.1	52.7
$LSD_{0,05}$ for: Fertilization (I) – 11.199; Mulching (II) – ns; Interaction (II/I) – ns; Interaction (I/II) – ns			
Diameter (mm)			
Mineral (M)	6.6	7.3	6.9
Organic (O)	8.1	7.9	8.0
Mean	7.4	7.6	7.5
$LSD_{0,05}$ for: Fertilization (I) – ns; Mulching (II) – ns; Interaction (II/I) – ns; Interaction (I/II) – ns			
Number of leaves (pcs)			
Mineral (M)	75.1	79.6	77.4
Organic (O)	140.5	139.7	140.1
Mean	107.8	109.7	108.7
$LSD_{0,05}$ for: Fertilization (I) – 9.425; Mulching (II) – ns; Interaction (II/I) – ns; Interaction (I/II) – ns			
Area of a single leaf (cm^2)			
Mineral (M)	11.4	14.5	13.0
Organic (O)	19.5	20.0	19.7
Mean	15.4	17.3	16.3
$LSD_{0,05}$ for: Fertilization (I) – 2.375; Mulching (II) – ns; Interaction (II/I) – ns; Interaction (I/II) – ns			

The diameter of the root neck of two-year-old beech seedlings ranged from 6.6 to 8.1 mm. No significant effect of the factors under study was observed in their effect on this feature of beech seedlings.

Regardless of mulching, fertilisation with compost with an addition of pine-tree bark increased the number of leaves per seedling significantly, from 77.4 to 140.1 leaves (increase by 62.7 leaves, i.e. by 81%). No significant synergy of the factors under study was observed in their effect on the number of leaves per plant.

Organic fertilisation increased the average area of a leaf on a two-year-old beech seedling from 13.0 to 19.7 cm^2 (area increase by 6.7 cm^2 i.e. by 51%). Mulching did not have a significant effect on this feature in two-year-old beech seedlings. No significant interaction of the factors under study was observed in their effect on the leaf area.

For comparison, in the lime tree experiment mentioned above (Klimek *et al*. 2013), the number and area of leaves on two-year-old seedlings grown on plots fertilised with compost were bigger compared to those growing on the plots where mineral fertilisation alone was applied. Mulching with fresh ectohumus did not have a statistically significant effect on the number of leaves per plant, but it reduced the average leaf area.

Growth of three-year-old seedlings. Three-year-old beech seedlings grown on plots fertilised with compost with pine-tree bark were – regardless of mulching – statistically taller (by 8.6 cm, i.e. by 13%) than those grown on the plots where no organic fertilisation was applied. Regardless of organic fertilisation, mulching significantly increased the height of seedlings (by 24 cm, i.e. by 20%). Although no statistically significant interaction of the factors under study was observed in their effect on the seedling height, it must be noted that the tallest seedlings (89.3 cm) were grown on the plots in which both of the tested procedures (organic fertilisation and mulching) were carried out.

In a parallel experiment with small-leaved lime, organic fertilisation significantly increased the height of three-year-old lime trees (by 18%, on average) (Klimek *et al*. 2013).

Organic fertilisation increased the diameter of the root neck from 10.0 to 12.0 mm (by 20%). Mulching – regardless of fertilisation – increased this diameter from 9.2 to 12.8 mm (by 39%). As with height, no significant synergy of the factors under study was observed in their effect on diameter, but it should be noted that the greatest diameter (14.6 mm) was recorded in the seedlings grown on the plots where organic fertilisation and mulching were applied.

In the lime experiment (Klimek *et al*. 2013), a statistically significant synergy of both experimental factors in their effect on the parameter was observed – the greatest diameter was recorded in three-year-old lime seedlings grown on plots fertilised with compost and mulched.

Fertilisation with compost with an addition of pine-tree bark increased the number of leaves and the leaf area significantly (by 7% on average). Mulching also had a positive effect on those features, causing them to increase significantly (by 68% and 18%, respectively).

Table 2. Parameters of three-year seedling growth in the year 2010

Fertilization	Mulching		Mean
	without mulching (C)	mulching (E)	
Height of seedling (cm)			
Mineral (M)	56.7	79.2	67.9
Organic (O)	63.7	89.3	76.5
Mean	60.2	84.2	72.2
$LSD_{0,05}$ for: Fertilization (I) – 5.385; Mulching (II) – 4.488; Interaction (II/I) – ns; Interaction (I/II) – ns			
Diameter (mm)			
Mineral (M)	9.1	11.0	10.0
Organic (O)	9.4	14.6	12.0
Mean	9.2	12.8	11.0
$LSD_{0,05}$ for: Fertilization (I) – 0.749; Mulching (II) – 0.840; Interaction (II/I) – ns; Interaction (I/II) – ns			
Number of leaves (pcs)			
Mineral (M)	88.8	157.0	122.9
Organic (O)	101.8	162.7	132.2
Mean	95.3	159.8	127.5
$LSD_{0,05}$ for: Fertilization (I) – 7.697; Mulching (II) – 9,135; Interaction (II/I) – ns; Interaction (I/II) – ns			
Area of a single leaf (cm^2)			
Mineral (M)	19.5	22.8	21.2
Organic (O)	20.9	24.9	22.9
Mean	20.2	23.8	22.0
$LSD_{0,05}$ for: Fertilization (I) – 0.853; Mulching (II) – 1.559; Interaction (II/I) – ns; Interaction (I/II) – ns			

For comparison, both fertilisation and mulching also increased the number of leaves per lime tree in the third year of nursery cultivation. In addition, the leaf area increased significantly, both on plots with compost used as a fertiliser and on those where mulching was applied (Klimek *et al*. 2013).

Occurrence of mites. A statistical analysis (ANOVA) carried out in the second year of nursery beech cultivation showed a statistically significant effect of mulching on the total density of mites (Table 3). A significant increase in the total density of mites was recorded on plots where mulching with forest ectohumus was applied compared with the variants with no mulching (HSD Tukey test). A significant increase in the effect of both of the factors under study – organic fertilisation with compost and mulching – was recorded in the next vegetation season of a three-year cultivation of beech. The largest size of the mite gathering was recorded in the OE variant (11,470 individuals m^{-2}). No effect of organic fertilisation on the occurrence of mites was observed in an earlier study carried out in the same nursery during 2-year study cycles in the cultivation of larch and pine, but a positive effect of mulching on the arthropods was demonstrated (Klimek *et al*. 2011, 2012). Those observations showed that a positive effect of organic fertilisation alone, without mulching, on the occurrence of mites did not appear until the third year after the procedure.

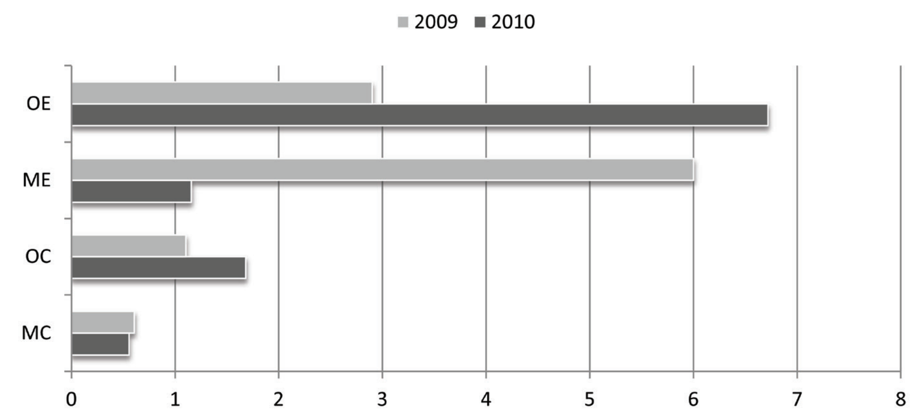
Table 3. The density of mites (*N* in 1000 individuals m^{-2}) in studied variants

Taxon	Year	Variant of the experiment				Fertilization effect (p)	Mulching effect (p)
		MC	OC	ME	OE		
Actinedida	2009	0.84[a]	1.14[a]	1.35[a]	2.77[b]	0.098	0.015
	2010	0.27	0.66	0.96	0.75	0.063	0.058
Mesostigmata	2009	0.15[a]	0.33[a]	1.08[b]	0.63[a]	0.633	0.002
	2010	0	0.24	0.18	0.39	0.013	0.081
Oribatida	2009	0.51[a]	1.26[a]	8.13[b]	8.04[b]	0.948	0.000
	2010	0.15[a]	1.11[a]	1.11[a]	5.06[b]	0.000	0.000
Tarsonemida	2009	0	0	0.03	0.03	1.000	0.161
	2010	0.03	0.09	0	0	0.386	0.010
Acari (total)	2009	1.51[a]	2.74[a]	10.60[b]	11.47[b]	0.615	0.000
	2010	0.45[a]	2.11[b]	2.26[b]	6.20[c]	0.000	0.000

Explanations: [a,b,c] – data with the same letter do not differ significantly ($p<0.05$)

The largest gathering was that of oribatid mites and they dominated among mites during both seasons in variants: OC, ME and OE. Only on MC plots were mite gatherings dominated by *Actinedida*. Oribatid mite domination among mites populations is typical of forest soils – they usually account for 70% of all mites (Klimek 2000).

The ratio of gathering densities of mites of the *Oribatida* and *Actinedida* orders may indicate the quality and biological balance of the soil environment (Werner and Dindal 1990, Gulvik 2007). Werner and Dindal (1990) claim that a ratio below 1.0 is observed on arable land, and above 1.0 – in more stable ecosystems with a lower degree of disturbances, e.g. on semi-natural meadows, i.e. in soil with a considerable proportion of organic matter. The methods of soil enrichment in a forest nursery, applied in this experiment – fertilisation with compost and mulching – caused the ratio to increase (Fig. 1). A particularly high *Oribatida*/*Actinedida* ratio (6.72) was calculated in the third year of nursery cultivation on the plots where mulching and organic fertilisation were applied in combination.



	MC	OC	ME	OE
2009	0.61	1.11	6.00	2.90
2010	0.56	1.68	1.16	6.72

Figure 1. The density ratio *Oribatida* to *Actinedida* in the years 2009 and 2010 in studied variants

CONCLUSIONS

The beech seedlings on the plots where compost was used as fertiliser were significantly taller in the second and the third year of nursery cultivation than those growing on the plots where mineral fertilisers were applied. Mulching increased the height of the seedlings significantly only in the last (third) year of the study. The tallest three-year-old seedlings were found on plots where both of the tested procedures had been carried out. Neither of the factors under study had a significant effect on the diameter of the root neck in the second year of the nursery cultivation, but they increased it significantly in the third year. Fertilisation with compost with an addition of pine-tree bark increased the number of leaves per plant and a leaf area in two – and three-year-old seedlings. A beneficial and significant effect of mulching on these parameters was found in the third year of cultivation.

A significantly positive effect of mulching on the mite gathering density was recorded in the second year of the nursery cultivation. However, both of the experimental factors had a positive effect on the occurrence of those arthropods in the third year of the study. Oribatid mites were the most numerous mite order and they were found in the greatest density on plots where mulching was applied. Fertilisation and mulching increased the *Oribatida*/*Actinedida* ratio, which may indicate an improvement in the biological balance in the soil environment.

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