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USE OF COMPOSTED SLUDGE AND FOREST ECTOHUMUS TO ENRICH SOIL IN TWO – AND THREE-YEAR CULTIVATION OF SCOTS PINE IN A FOREST NURSERY

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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 for two – and three-year-old Scots pine trees and on the incidence of mites (*Acari*) in the 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.

Organic fertilisation with compost prepared from hygienised sludge with an addition of pine-tree bark resulted in a significant increase in the plant height and the diameter of the root neck in two-year-old pine trees. The effect of mulching on these parameters was not significant. The synergistic effect of the factors on the plant height and the diameter of the root neck was not significant. Organic fertilisation significantly increased the height of 3-year-old pine trees, whereas it did not have a significant effect on the root neck diameter. Mulching increased the plant height significantly, but no statistical effect on the diameter of the root neck was demonstrated. Although no significant interaction of either experimental factors in their effect on the plant height and the diameter in the root neck was observed, the parameters tended to increase in the experimental option, which included organic fertilisation and mulching. Mulching had a significant effect on the presence of soil mites, especially oribatid mites (*Oribatida*). Their density increased greatly after the procedure. This growth, as well as an increase in the ratio of *Oribatida* to *Actinedida* could be a sign of improvement of the biological balance of the soils under study and their biological activity.

Key words: forest nursery, Scots pine, ectohumus, reintroduction of soil fauna, *Acari*.

INTRODUCTION

Frequent supply of organic matter to soil is a condition for successful tree production in the majority of forest nurseries (Szołtyk and Hilszczańska 2003). Soil in nurseries is enriched in humus by the addition of compost, less frequently crude peat, bark or sawdust. Another option is to use hygienised, composted sludge (Klimek *et al*. 2008, Rolbiecki *et al*. 2009). Composting sludge requires mixing it with a structure-forming agent, which supplies additional organic mass and ensures the optimum C:N ratio of about 30:1 (Siuta and Wasiak 2001). In practice, different compost additives are used, such as straw, sawdust, bark and green plant mass.

The soil of forest nurseries can also be enriched with organic matter by mulching. Apart from supplying valuable organic matter to soil, the procedure supplies it with live microorganisms and fauna, which is typical of forest soil. 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 the soil (Leski *et al*. 2009).

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 applied during the first year of cultivation, and mulching with fresh forest ectohumus on selected growth parameters for two – and three-year-old pine trees and on the occurrence of soil mites (*Acari*).

MATERIAL AND METHODS

The experiment. The experiment was carried out in 2009-2010 in the Białe Błota forest nursery (Bydgoszcz Forest District) on proper rusty soil in the second and third years of nursery cultivation of Scots pine (Photo 1 and 2). The soil conditions were characterised in an earlier paper (Klimek *et al*. 2011).

The experiment was set up in a two-factor dependent arrangement in four replicates. Fertilisation in the following two options was the first factor: M – mineral fertilisation – as per recommendations for forest nurseries, O – 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.

Photo 1. The three-year-old Scots pine tree cultivation in a forest nursery

Photo 2. Interrows of 2-year-old Scots pine tree cultivation mulched with ectohumus

Pine 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%). It was applied at 100 t ha^{-1} in the spring and mixed with the surface layer of the soil down to a depth of 10 cm before pine 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. The material contained numerous live organisms.

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

Climatic conditions during the vegetation period and the course of irrigation. The rainfall and irrigation during the vegetation periods during the years of study were presented in a different paper (Rolbiecki *et al*. 2016).

Plant growth. The growth of two – and three-year pine trees was determined after their vegetation was completed – in October 2009 and 2010, respectively. The height of the above-ground part (cm) and the diameter of the root neck (mm) 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.

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 cm2 and down 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. Mites were classified into orders. A total of 1.117 mites were classified. The average mite density (N) was given per 1 m2 of soil. Before the statistical analysis, the figures were converted into logarithms – ln(x+1) (Berthet and Gerard 1965). The statistical calculations were done with the Statistica 10 software by means of the two-way ANOVA analysis of variance. The significance of variances was verified by Tukey's HSD post hoc test.

RESULTS AND DISCUSSION

Characteristics of the plant growth. The experiment with two-year-old pine trees in Białe Błota carried out in 2009. Organic fertilisation resulted in an increase in the height of two-year-old pine trees (Table 1). The pines growing on plots where organic fertilisation was applied were higher – on average for the mulching options – by 5.9 cm (i.e. by 20%) compared to plants grown without organic fertilisation. The other factor examined – mulching – did not have a significant effect on the growth of pine trees. The greatest height (35.4 cm) was recorded for the pine trees grown on the plots where organic fertilisation and mulching was applied, which indicates that both of these factors have a synergistic effect on this feature of plant growth.

Table 1. Effect of fertilisation and mulching on the height of two-year-old pine trees (cm)

Fertilisation (I)	Mulching (II)		Mean
	C	E	
M	28.6	29.9	29.2
O	35.1	35.4	35.1
Mean	32.2	32.6	32.4

$LSD_{0,05}$: I – 4.055; II – ns.; Interaction: II/I – 1.201; I/II – 4.135

For comparison: in an earlier experiment carried out in 2004-2005 in the same forest nursery (Rolbiecki *et al*. 2007), the height of 2-year-old pine trees grown on plots where an organic fertiliser was applied, made from sludge (80%) and peat (20%) – in 2004 and 2005, respectively – was 33.6 cm and 38.2 cm. The plants that grew on plots where this fertiliser was applied were – on average during the study – higher by 8.6 cm than those grown in the control conditions. In another study – on post-agricultural soil, with the same organic fertilisation and micro-sprinkling – the height of 2-year-old pine trees was 31.6 cm in Lipnik near Stargard Szczeciński and 16.2 cm in Kruszyn Krajeński near Bydgoszcz (Rolbiecki *et al*. 2008).

Table 2. Effect of fertilisation and mulching on the diameter of the root collar of two-year-old pine trees (mm)

Fertilisation (I)	Mulching (II)		Mean
	C	E	
M	7.6	8.8	8.2
O	10.9	10.5	10.7
Mean	9.2	9.7	9.4

$LSD_{0,05}$: I – 0.670; II – ns; Interaction: II/I – ns; I/II – ns

Pine trees grown on plots where an organic fertiliser was applied had – compared with those that grew on the plots with only mineral fertilisation – a greater (by 2.5 cm, i.e. by 30%) root neck diameter (Table 2). The effect of mulching on this parameter was not significant. The synergistic effect of the factors on the diameter of the root neck was not significant.

In an earlier experiment carried out in 2004-2005 in the same forest nursery (Rolbiecki *et al*. 2007), the root neck diameter of 2-year-old pine trees grown on plots where an organic fertiliser was applied – in 2004 and 2005, respectively – was 8.9 mm and 8.8 mm. In an experiment carried out on post-agricultural land with the same organic fertilisation and microsprinkling, the diameter of the root neck in 2-year-old pine trees was smaller and it was 7.1 mm in Lipnik near Stargard Szczeciński and 4.8 mm in Kruszyn Krajeński near Bydgoszcz (Rolbiecki *et al*. 2008).

An experiment with three-year-old pine trees in Białe Błota, carried out in 2010. Organic fertilisation (O) – regardless of mulching – significantly increased the height of 3-year-old pine trees by 6.18 cm (i.e. by 18%) compared to the option with mineral fertilisation alone (M) (Table 3). Regardless of the fertilisation option, mulching significantly increased the pine tree height by 2.5 cm (7%). The tallest pine trees were recorded on plots where organic fertilisation and mulching were applied – the height of the above ground was 43.52 cm and it was greater by 8.67 cm (26%) compared to the pine trees in the control plot (MC) – grown with no organic fertilisation or mulching. However, a synergistic effect of both the factors (organic fertilisation and mulching) on the pine tree growth (interaction) was not statistically proven.

Table 3. Effect of fertilisation and mulching on the height of 3-year-old pine trees (cm)

Fertilisation (I)	Mulching (II)		Mean
	C	E	
M	33.85	36.7	35.27
O	40.37	42.52	41.45
Mean	37.11	39.61	38.4

$LSD_{0,05}$: I – 2.031; II – 1.478; Interaction: II/I – ns; I/II – ns

In a parallel experiment with small-leaved lime, organic fertilisation significantly increased the height of three-year-old lime trees (by 18% on average) and mulching did it to a statistically significant extent – by 12% (Klimek *et al*. 2013).

Neither of the experimental factors had a significant impact on the diameter of the root neck in the pine trees (Table 4). However, it is noteworthy that – as an average for the mulching options – there was a growing tendency in the pine trees on plots where the organic fertiliser was used. Furthermore – on average for the fertilisation options – mulching also increased this parameter. Although no significant interaction of both the experimental factors was observed in their effect on the trees diameter, it was found to be the largest in pine trees growing on plots where organic fertiliser and mulching was applied (OE).

In the experiment with the small-leaved lime tree mentioned above (Klimek *et al*. 2013), mulching significantly increased the diameter of the root neck of three-year-old trees.

Table 4. Effect of fertilisation and mulching on the diameter of the root collar of 3-year-old pine trees (mm)

Fertilisation (I)	Mulching (II)		Mean
	C	E	
M	10.7	11.97	11.34
O	12.3	14.8	13.54
Mean	11.5	13.4	12.44

$LSD_{0,05}$: I – ns; II – ns; Interaction: II/I – ns; I/II – ns

Occurrence of soil mites. Mites, especially oribatid mites, are very common in forest soils – several hundred thousand individuals per 1 m^2 of the soil area (Klimek 2000) – and they play a range of important roles: they have a positive effect on soil-forming processes, they stimulate spreading of bacteria and fungi and – indirectly – the formation of endo – and ectomycorrhiza (Klironomos and Kendrick 1996, Behan-Pelletier 1999, Remén *et al*. 2010, Schneider *et al*. 2005). They are also regarded as good bioindicators of soil biological activity (Behan-Pelletier 1999, 2003, Gulvik 2007, Klimek 2000).

In spring 2008, immediately after this experiment was set up (before mulching), the total density of mites was low – 1.080-1.990 individuals m^{-2} (Klimek *et al*. 2011). It increased many times in the following vegetation seasons 2009-2010 following mulching (Table 5). The ANOVA analysis showed only mulching to affect the total density of mites. Statistically significant differences were found in both seasons between the MC-OC and ME-OE options. The gathering of mites in non-mulching options was usually dominated by mites of the *Actinedida* order. Furthermore, oribatid mites dominated in the plots where forest ectohumus had been applied. Gatherings of *Mesostigmata* and *Tarsonemida* mites were considerably less numerous – no effect of the experimental factors on their occurrence was observed.

Depending on the experiment option, the density of oribatid mites ranged from 90 to 11.830 individuals m^{-2}. A statistically significant effect of mulching on the total density of mites was observed in 2009 and 2010. Statistically significant differences were observed in both seasons between the plots where mulching was applied (ME, OE) and those where it was not (MC, OC).

Table 5. 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	1.32^{a}	0.75^{a}	1.90^{b}	3.40^{b}	0.752	0.013
	2010	0.66^{a}	0.27^{a}	0.90^{b}	1.02^{b}	0.746	0.007
Mesostigmata	2009	0	0.33	0.21	0.72	0.038	0.154
	2010	0	0.03	0.03	0.00	1.000	1.000
Oribatida	2009	0.09^{a}	0.09^{a}	2.35^{b}	4.45^{b}	0.724	0.000
	2010	0.57^{ac}	0.30^{a}	11.83^{b}	2.17^{bc}	0.450	0.000
Tarsonemida	2009	0	0.03	0.03	0.03	0.565	0.565
	2010	0	0.03	0.06	0.03	0.645	0.169
Acari (total)	2009	1.41^{a}	1.20^{a}	4.48^{b}	8.61^{b}	0.921	0.000
	2010	1.23^{a}	0.63^{a}	12.82^{b}	3.22^{b}	0.350	0.000

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

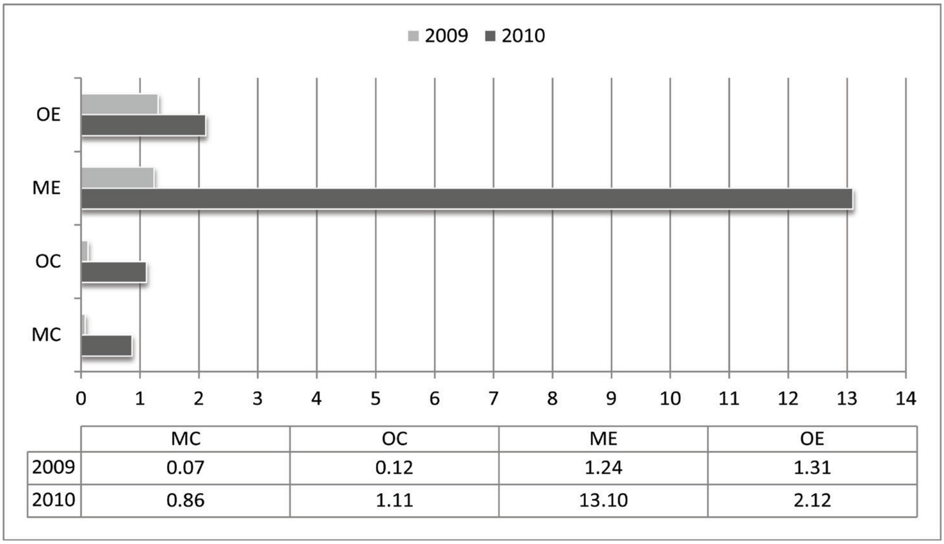

Figure 1. The density ratio *Oribatida* to *Actinedida* in the years 2009 and 2010 in studied variants

The density ratio of *Oribatida* to *Actinedida* is an indicator used in acarological studies; it indicates 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. In this experiment, the index was seen to increase after mulching was applied, especially in the second year of the study (Fig. 1). It is noteworthy that the index exceeded 1.0 after compost with bark was applied in 2010, i.e. in the third year after the pine nursery was set up. This may indicate that the process of soil restoration had been initiated, but it was slower than when mulching was applied with fresh ectohumus containing live organisms.

CONCLUSIONS

Two-year-old plants. Organic fertilisation with compost prepared from hygienised sludge with an addition of pine-tree bark resulted in a significant increase in the plant height and the diameter of the root neck in two-year-old pine trees. The effect of mulching on these parameters was not significant. The synergistic effect of the factors on the plant height and the diameter of the root neck was not significant.

Three-year-old plants. Organic fertilisation significantly increased the height of 3-year-old pine trees, whereas it did not have a significant effect on the root neck diameter. Mulching increased the plant height significantly, but no statistical effect on the diameter of the root neck was demonstrated. Although no significant interaction of both experimental factors in their effect on the plant height and the diameter in the root neck was observed, the parameters tended to increase in the experimental option which included organic fertilisation and mulching.

Occurrence of mites. Mulching had a significant effect on the presence of soil mites, especially oribatid mites (*Oribatida*). Their density increased greatly after the procedure. This growth, as well as an increase in the ratio of *Oribatida* to *Actinedida* could be a sign of improvement of the biological balance of the soils under study and their biological activity.

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