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Effect of soil preparation method on root development of *P. sylvestris* and *P. abies* saplings in commercial forest stands

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Abstract Soil preparation is a common practice that precedes outplanting of Norway spruce (*Picea abies*) and Scots Pine (*Pinus sylvestris*) in boreal forests. It has been proven to enhance the survival and early growth of seedlings. Containerized *P. abies* and *P. sylvestris* saplings were excavated 1–3 years after outplanting in clear cut forests across Latvia. The excavated saplings were grown in forests that had been prepared either using site mounding or disc trenching soil preparation method. The aim was to determine the effects of soil preparation method used on the root depth, dry mass and orientation. Saplings are forming deeper root system that expand evenly when planted on mounds, yet the root dry mass was not affected by soil preparation method or soil type. Seedlings planted in trenched sites formed two-sided root system, parallel to the furrow. No correlation between roots growing direction and cardinal points was found.

Keywords Mounding · Disc trenching · Root orientation · Forest regeneration

Introduction

Initial site conditions and early management greatly influence growth, health and productivity of a stand. Therefore it is important to choose management methods that are economically viable and lead to highest productivity in each particular case. Soil preparation prior to planting or sowing is a widely used method to improve seedling survival rate and growth. Soil preparation has shown to improve soil aeration, increase average soil temperature, boost nutrient availability, decrease soil bulk density, decrease competition with surrounding vegetation, as well as reduces the need for tending and to some extent can prevent *Hylobius abietis* damage (Löf et al. 2012; Luoranen and Viiri 2012; Petersson et al. 2005; Goulet 1995; Örlander et al. 1990). Preparation is typically done

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the year before planting. Disc trenching is currently the most widely used soil preparation method in Latvia. With the help of a disc trencher a furrow is created and soil is pushed to one side, creating a berm on one side of the furrow (Fig. 1). Seedlings are then planted on the hinge of the created microsite. Trenched microsites are believed to be more suitable for forests soils prone to drying out. The positive effect of disc trenching can be enhanced by choosing appropriate trench orientation and planting position which can be either on top of the berm, on the hinge or in the furrow (Burton et al. 2000).

In recent decades mounding has become a more widely used soil preparation method in Northern countries. Mounding is done by excavating soil and turning it over next to the newly made pit. This creates a microsite where mineral soil is exposed on the top of the mound and a double layer of organic soil is created at the bottom. In some cases this can create air pockets between both organic layers, if debris, such as branches, is not properly removed after clearcutting (Haeussler 1989). The pit collects excess water which is often present under climate conditions in Latvia. Due to increasing precipitation in Northern countries water excessiveness can become a problem of wider scope. The mound pit also serves as a water reservoir during dry periods, although if the recommended size of the mound is exceeded the risk of drought increases, especially in humus rich conditions (Gemmel et al. 1996). Compared to unprepared soil, mounding has proven to promote tree growth by creating a favourable microclimate for seedlings in cool regions (Heiskanen et al. 2013; Nieminen et al. 2012; Pearson et al. 2011; Pennanen et al. 2005; Sutton 1993). Forest stands on mounded sites have also shown to fix more carbon than stands on unprepared soil (Mjöfors et al. 2017). Other authors have found that trees grown on mounds tend to grow taller than the ones planted in trenched sites (Uotila et al. 2010; Saksa et al. 2005). In some cases, trenching has shown to be just as effective as mounding (Luorenen and Rikala 2013). In such cases disc trenching can be favoured over mounding due to the lower initial costs. Planted trees are easier to spot and distinguish from naturally occurring trees in mounded sites, due to the elevation of the microsite. This factor alleviates tending, especially during the early years of a stand.

Picea abies and *Pinus sylvestris* are the two most economically viable planted tree species for regeneration of forests in Latvia. Different growing condition are requirements for each species and should be taken into account when choosing the most appropriate soil preparation method. The objective of this study was to evaluate early root growth response of *P. abies* and *P. sylvestris* to soil preparation method.

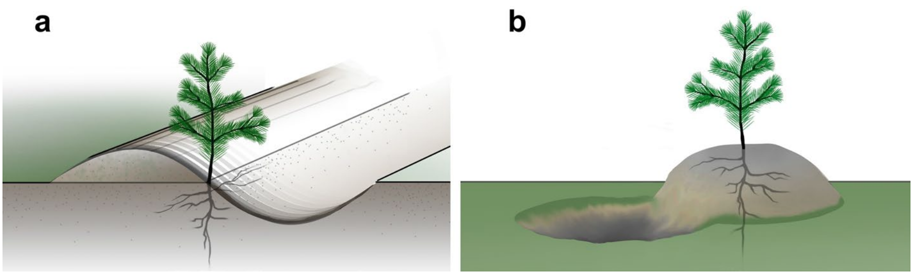

Fig. 1 Planting position when using disc trenching as a soil preparation method (**a**) and the mounding method (**b**)

Materials and methods

Study sites

Pinus sylvestris and *Picea abies* containerized seedlings were measured in forest stands on wet mineral soils (WS) and on drained mineral soils (DS) according to Latvian forest classification system (Zālītis and Jansosns 2013).

All of the studied sites had been prepared for planting by either using mounding (M) or disc trenching (DT) method. Seedlings had been manually planted in the spring of 2013, 2014 and 2015. Respectively—seedlings had spent three, two or one growing season in the planting sites at the time of survey. All study sites were located in the humid continental climate area according to the Köppen climate classification system. Annual total mean precipitation of the region is 667 mm (of which approximately only 50% evaporates) and mean temperature is + 5.9 °C.

Containerized seedlings of *P. abies* and *P. sylvestris* were excavated from 45 productive managed forest regeneration sites (Fig. 2). Stands of the same tree species and age were selected in pairs of one trenched and one mounded site of the same forest type. 26 *P. abies* and 19 *P. sylvestris* stands were surveyed. The study sites were young, regenerated stands managed by Latvian State Forests company and had not been created for research purposes, therefore sites were paired to be as close to each other as practically possible in each particular case. The average distance between sites was 16.2 with a maximum distance of 75.8 km.

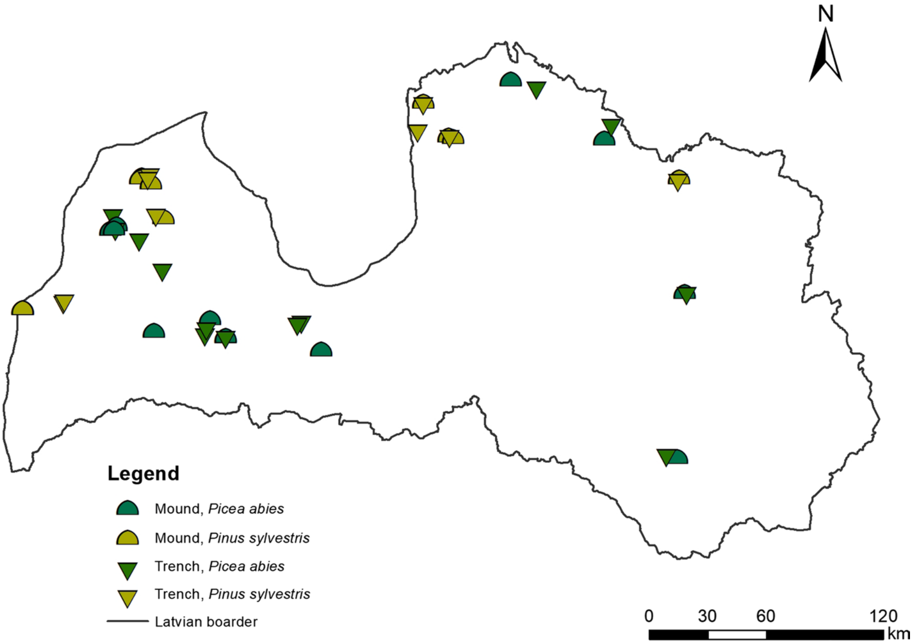

Fig. 2 Location of study sites

For both soil preparation methods requirements of quality are set by Latvian State Forests. Minimal acceptable width of a mound is 0.50 m, length-0.60 m and height-0.15 m. Mound physical dimensions fit quality requirements in 86.9% of cases.

Trench furrow quality requirements are depth of 0.15–0.30 m and width of 0.50–0.70 m. 76.0% of furrows fit the requirement for depth and 65.0% fit the width requirement (49.4% of trenches fit both dimension parameters). In most cases where trenches did not fit the requirements, the furrows were shallower and wider than required by standard most likely due to weathering.

Data collection

Data collection was carried out during the summer of 2016. Five circular plots of 25 m^2 (radius = 2.82 m) were selected in each study site. Plots were evenly distributed diagonally or in a straight line and the distance between plots was dependant on the dimensions of each individual site.

Tree location in relation to trench or mound pit was noted. In the 2nd and 4th plot of each site five healthy trees were carefully excavated (total 10 trees per site). One large, one comparably small and three medium sized trees were manually excavated in order to survey root growth. The root depth and orientation of 1st and 2nd order coarse roots in relation to the trench or mound pit was determined. Root area was represented as circular projection that was divided into eight segments (Fig. 3). If any roots fell in such segment, it was noted as 1, if not, as 0. Roots falling into each segment were summed up and represented as percentage of total measured tree count. Two of average sized seedling in the 2nd and 4th plot were taken to LSFRI Silava to determine seedling root dry mass. The seedlings were dissected at the root collar (where first root starts) and then oven dried after which the root was weighed. Trees that had been notably damaged by grazing or other causes were not used in data analysis. Overall survival of young saplings was high (above 90%) regardless of soil preparation method. To determine survival dead and alive trees were counted, however, survival rates were not further studied due to empty planting spots that could be a result either of tree dying or due to tree not being planted.

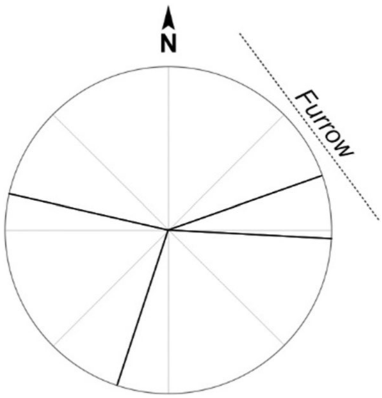

Fig. 3 Schematic representation of root orientation recording method (bold lines in the circle represent roots)

Statistical analysis

In this study R (R Core Team 2017) version 3.4.1. F and lme4 (Bates et al. 2015) was used to perform a linear mixed effects analysis of the relationship between root depth, root mass and soil preparation method. Planting year and soil preparation method (without interaction) were used as fixed effects in the model. Study site was set as random effect. To compare models and evaluate effect significance ANOVA was used (Fox and Weisberg 2011). Forest type was initially set as fixed effect, but was excluded from the model, since there was no significant difference between model with this effect and a model without the effect in question. Each tree species was looked at separately.

Homoscedasticity of the residuals was determined with Levene Test and visual inspection (Fox and Weisberg 2011), and normality was determined using Shapiro–Wilk test. Data was not normally distributed, therefor it was log-transformed to fit normality assumption.

Results

Root mass and depth

Linear mixed-effects model showed that soil preparation method affected root depth of *P. sylvestris* ($P=0.001$) increasing it in mounded sites (Table 1 and Fig. 4). Soil preparation method did not affect *P. abies* root depth ($P=0.44$).

There was no correlation between dry root mass and root depth (*P. abies* $R^2=0.08$, *P. sylvestris* $R^2=0.28$). Linear mixed-effects model showed that soil preparation method had no significant effect on dry root mass of both *P. sylvestris and P. abies* ($P=0.60$ and $P=0.09$, respectively).

Root orientation

No correlation between tree root growth direction and cardinal points was found regardless of tree species, forest type and soil preparation method used. However, it was found that when using disc trenching method both *P. sylvestris* and *P. abies* roots showed a tendency to grow parallel to the furrow (Fig. 5). This was evident already 1 year after outplanting and in later years roots had held this direction and also penetrated deeper into the berm. This does not support the hypothesis that trees develop one sided root system in the direction of berm. It also contradicts an old made claim that furrows would accumulate soil fast enough and therefore provide space for tree roots to grow and establish radial root distribution (Pontey 1808).

Table 1 Results of analysis using general linear mixed effects model with root depth and root dry mass as responsive variables and year and soil preparation method as fixed effects

		Estimate	SE	*df*	*P*
P. sylvestris depth	Year	−0.347	0.045	18.768	<0.001
	Soil preparation method	0.264	0.069	18.821	0.001
P. sylvestris mass	Year	−1.763	0.177	18.034	<0.001
	Soil preparation method	0.147	0.279	18.100	0.603
P. abies depth	Year	−0.260	0.075	24.169	0.002
	Soil preparation method	0.068	0.088	24.577	0.44
P. abies mass	Year	−1.131	0.200	25.321	<0.001
	Soil preparation method	−0.407	0.235	25.200	0.946

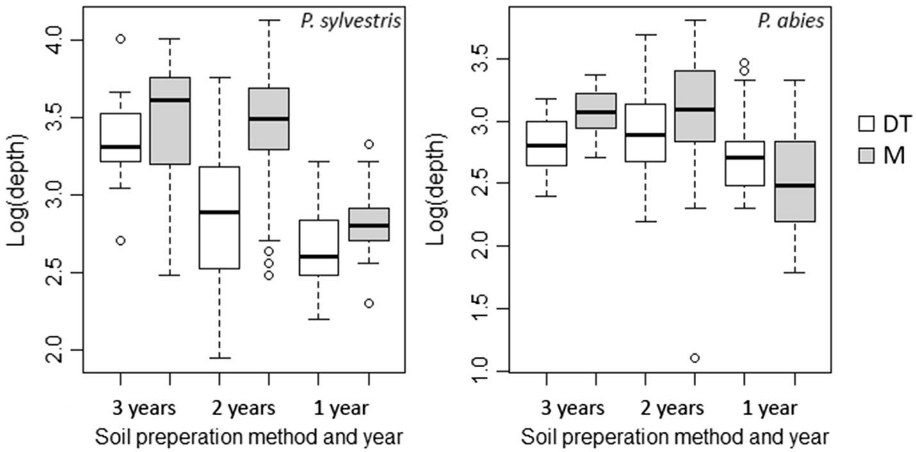

Fig. 4 *Pinus sylvestris* and *Picea abies* root depth (log transformed) in disc trenched (DT) and mounded sites (M) depending on tree age (1, 2 and 3 years old)

When planted in mounds, tree roots tended to be more evenly radially distributed. Combined with greater root depth, this should lead to more wind resistant forest stands in future. Coarse roots that develop in early age serve as basis for further root development as well as determine their shape and structure.

Discussion

Already 1 year after outplanting different growth responses of studied trees to soil preparation methods can be observed. Mounding leads to significantly deeper root system of *P. sylvestris*. Mounded sites have less competition for sunlight than trenched sites, and also provide dryer soil conditions. These factors could be the cause of roots reaching deeper for water in mounds. The most important finding of this study is that coarse roots are more evenly radially oriented when planted in mounds thus providing more stable further development. In addition, this study has shown that already during the first years after planting tree roots penetrate through the mound, therefore securing the tree in the soil underneath it. This has been one of the concerns regarding mounding. Due to different species specific properties, *P. sylvestris* roots grow through the mound slightly faster than *P. abies*.

When planting in disc trenched sites to provide most beneficial conditions for tree development it is crucial to choose advantageous direction of the furrows in relation to cardinal points (to maximize sunlight accessibility) and dominant winds (Burton et al. 2000). This study emphasizes the importance of the latter factor. Orientation of coarse roots determines tree resistance to strong winds and storms, therefore, given the unevenly distributed roots found in trenched sites, it would be advised to consider leading wind direction when making furrows. This is especially crucial when regenerating forests with species susceptible to windfalls, such as *P. abies* (Pellikka and Järvenpää 2003). These root distribution and wind resistance relations require further study in older forest stands. There are three main positions where a tree could be planted in disc trenched site—in the base of the furrow, in the hinge or on the berm (Burton et al. 2000). The distribution of roots of trees planted at the base or on berm of the trench could result in different root distribution than found in this study. These planting positions offer space in all directions for roots to expand more

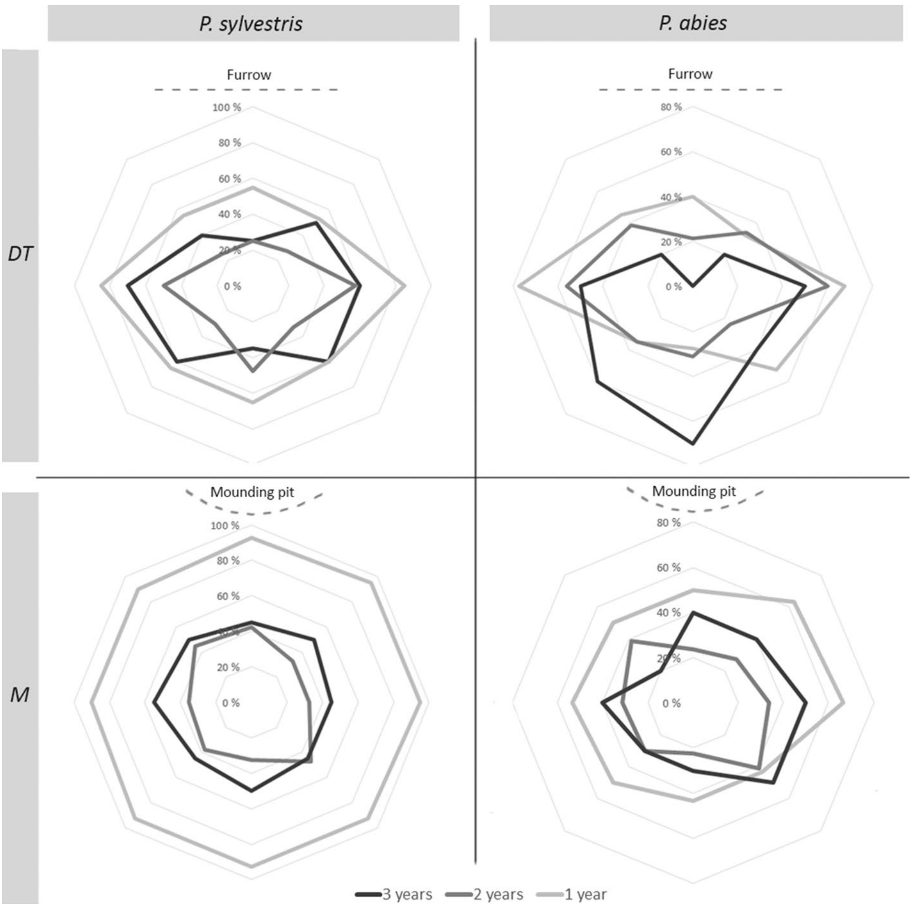

Fig. 5 *Pinus sylvestris* and *Picea abies* coarse root orientation in relation to furrow direction after 1, 2 and 3 growing seasons. ("Furrow" and "Mounding pit" represent the location of furrow and mounding pit in relation to tree). Percentage shows trees with roots in particular direction out of all measured trees

radially. Planting on the berm provides similar conditions as planning on mounds. However, planting depends on trenching machinery used and planting on the hinge provides more drought resistance in early years of growth (Mangalis 1989).

Concerning the interaction between tree species and soil preparation method, it seems that development of *P. sylvestris* is more responsive to soil preparation method.

This study found that, in the early stages of forest stand development, the main influence of soil preparation method used is evident in root development of seedlings.

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