The Effect of Soil Scarification on Natural Regeneration in Forest Microsites in Estonia

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Abstract

Soil scarification is one of the main methods for enhancing natural regeneration and it is widely used before seeding and planting as well. The aim of this research was to assess the effect of soil scarification on natural regeneration in the 11-year-old forest regeneration areas in fertile mineral soil and peatland sites. After clear-cutting, these areas were disc-trenched with Donaren 190 and inventoried after the first growing season. The inventory was performed using rectangular sample plots ranging in size from 10x10 to 15x20 m. The number of all woody plants was determined by microsites – untreated area, furrow, slope, and ridge. The same inventory was redone 11 growing seasons later.

After 11 growth years, a large number of Scots pine trees (*Pinus sylvestris* L.) was found in *Vaccinium myrtillus, Vaccinium vitis-idaea,* and *Oxalis* site types and drained peatlands, with 2,600–5,300 trees per hectare. The number of pine plants on microsites on mineral soil was the greatest in furrows and on slopes (33.5% and 30.4%), and on peat soil on slopes and in untreated areas (38.3% and 52.1%). The number of naturally regenerated Norway spruce (*Picea abies* (L.) Karst) trees was the largest in *Oxalis-Vaccinium vitis-idaea, Vaccinium myrtillus* and *Oxalis* site types, with 2,000–3,000 plants per hectare. With regard to microsites, spruce plants were the most abundant in untreated areas and in furrows on mineral soil (23.2% and 34.6%) and in untreated areas and on slopes on peat soil (54.3% and 37.0%). Among deciduous trees, birches (*Betula pendula* Roth., *Betula pubecens* Ehrh.) and aspens (*Populus tremula* L.) as well as other deciduous trees (*Salix* sp. L., *Tilia cordata* L., *Alnus* sp L., *Sorbus aucuparia* L., *Prunus padus* L., *Fraxinus excelsior* L.) were mostly growing in untreated areas on both mineral and peat soil. Soil scarification increased consistently the number of conifer seedlings in the sites typical of Norway spruce and Scots pine ($p<0.05$), where no effect was detected in the number of deciduous saplings.

Key words: soil scarification, microsites, forest site types, natural regeneration

Introduction

Soil scarification is considered an effective method in the improvement of reforestation in boreal areas. Changes in woody plant growing conditions brought about by soil scarification in reforestation have been thoroughly explored all over the world.

Many research findings reveal that soil scarification can affect the entire system of growing conditions, such as the suppression of water and nutrient competitors for trees (Burgess et al. 1996, Nilsson and Örlander1995, Nilsson and Allen 2003), increase in soil moisture and temperature level (Kubin and Kemppainen 1994, Johansson et al. 2005), creation of better light conditions, reduction in soil density (Lähde 1978), increase in nutrient mineralisation (Raison et al. 1987, Persson and Wirén 1995, Stenger et al. 1995), and reduction in insect damage (Örlander and Nilsson 1999, Petersson et al. 2005, 2006). Thus, soil preparation improves the initial conditions for seed germination and woody plant growth in clear-cut areas. Mechanical soil preparation usually ensures the abundance of woody species (Newmaster et al. 2007). The short-term effect of soil preparation and scarification on soil characteristics and tree growth has been discussed in several studies (Graham et al. 1989, Schmidt et al. 1996, MacDonald et al. 1998, Kund et al. 2010), although the final outcome of regeneration is obtained over the course of a longer period.

Root development is the key factor in determining the germination and first-year growth of planted seedlings. Ground vegetation competition is also a problem during seedling establishment (Nilsson and Örlander 1999[2]). The results of the research by Johansson et al. (2007) revealed that competitive vegetation continues to remain a problem for spruce mini-seedlings (10-week-old seedlings) even after 3 years from planting; the same applies for naturally regenerated seedlings. In general, scarification has a beneficial effect on the number of deciduous trees, although according to Nilsson et al. (2006) shelterwood reduces natural regeneration because young plants are usually suffering from light deficiency.

A number of research papers have also explored the long-term effects of soil scarification on forest regeneration (Seemen 1997, Mattson 2002, Mattson and Bergsten 2003, Karlsson and Nilsson 2005, Boateng et al. 2006, Hawkins et al. 2006, Nilsson et al. 2006, Hope 2007). Their findings reflect the generally positive effect of soil preparation on the growth of young stands. Most of the studies discuss the effect of soil preparation on woody plant survival and growth. There are fewer studies which examine the outcome of natural regeneration and the related impact of soil scarification. These studies rather, analyse changes (water regime, nutrient concentration, and leaching) in the soil of various microsites caused by soil scarification with disc trenchers (Nohrstedt 2000, Smolander et al. 2000, Heiskanen et al. 2007, Piirainen et al. 2007).

In 1994, the new hydraulic disc trencher DONAREN 190[1] was introduced in Estonia, following the example of the Nordic countries, as a supplement to traditional machinery (mounders, excavator mounders, ploughs and disc cultivators). The disc trencher is used to scarify clear-cut areas in forests on both mineral and peat soil, especially in relatively low fertility growing sites where reforestation conditions are not contributing to regeneration. In the course of soil scarification, the distance between the discs is 2.0–2.5 meters and the distance between the furrows is 2.0–4.5 meters, depending on the directions of movement of the trencher, number of stumps on clear-cut areas, and placement of logging residual. The machine is regarded as suitable for the enhancement of natural regeneration (Seemen 1995).

In a previous study, Seemen (1997) reported that the relative proportion of disturbed and untreated soil area was considered important for contributing to natural regeneration. The relative proportion of untreated and treated soil varied to some extent in examined forest site types (Table 1), 26-44% and 56-74%, respectively. The results were considered acceptable in terms of silviculture. With regard to reforestation and natural regeneration, the greatest value (number of trees) in treated soil was attributed to furrows. In the forest site types, furrows made up 20-30% and ridges 16-34% of the area of scarified clear-cuts. On average, slopes made up 12% of the area. Thus, growing conditions in clear-cut areas scarified with the disc trencher were radically altered on ridges and in furrows, which made up an average of 52% of the area of clear-cuts. In Sweden, the percentage of disturbed soil was approximately 54% (Mattsson and Bergsten 2003); therefore, a scarification technology similar to that used in Sweden was used in Estonia.

Earlier research results (Seemen 1997, Seemen and Pikk 1997) showed that ground vegetation recovered relatively quickly on treated microsites; within 1-2 years in areas of rich growth of ground vegetation. Abundant natural regeneration of deciduous trees (*Betula pendula* Roth.*, Betula pubecens* Ehrh.*, Populus tremula* L.) occurred on untreated soil, 8,200 trees per ha on average. On treated soil, natural regeneration was at its early stage and hence the number of woody plants was small (1,000 woody plants per ha in furrows, 1,450 woody plants per ha on slopes, and 1,400 woody plants per ha on ridges). It is very difficult to evaluate the relative importance of natural regeneration, that is, the number of operational units left to regenerate naturally, in Estonia due to insufficient statistical data. At the same time, systematic data on the improvement in natural regeneration by years are available. Estimably, the proportion of forests left to natural regeneration is about 40-50% of all clear-cut areas in Estonia (Metsakaitse- ja metsauuenduskeskus 2009).

The objective of this study was to determine the success of natural forest regeneration 11 years after clear-cutting and disc trenching. The study was conducted on microsites (untreated, furrow, slope, and ridge) in mineral and peat soils in fertile forest site types.

Materials and methods

The inventory of regeneration results was taken after 11 years in all previously studied clear-cut areas. The areas were clear-cut in the winter of 1993–1994 and inventoried in 1995 and 2005. The representation of forest site types (Lõhmus 2004) among clear-cut areas in Estonia scarified in 1994 was taken into account in the selection of research sites (Table 1). Table 1 presents descriptions of the site and soil type, soil group in study areas, range of the site index and humus layer thickness, which were determined in 1995. The number of areas and sample plots, and the main tree species were determined in 2005. The first clear-cut areas (*Aegopodium, Oxalis-Vaccinium myrtillus, Vaccinium myrtillus*, etc.) were selected to be scarified with the disc trencher; however, the natural regeneration was not considered. The research sites also included fertile site types subject to variation in tree species. Inspection of the performance of the disc trencher along with the determination of the results of regeneration took place in the autumn of 2005 on 28 sites (Figure 1) with a total area of 93 ha. For eve-

[1] The disc trencher was manufactured in Bräcke, Sweden by Robur Maskin AB, which is now Bracke Forest AB.

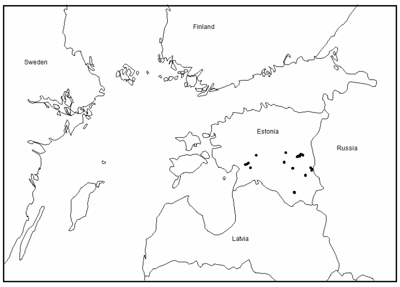

Figure 1. Locations of study areas

ry site 3-6 sample plots were established, a total of 95 plots with an area of 1.59 ha, including 22 sites on mineral soil and 6 on peat soil. The size of the clear-cut units ranged from 0.3 to 9.5 ha. Measured areas in the units remained between 110 m^2 and 942 m^2.

The disc trencher used scarifies the soil to form three types of microsites with different growing conditions – furrows, slopes, and ridges. In addition, a part of the soil remains untreated, which was considered the reference area in this research. Among the microsites, furrows are the deepest compared to the surrounding surface level and have the most unvarying growing conditions, whereas somewhat poorer conditions for seed germination prevailed on slopes due to several shrub layer roots, signs of humus accumulation, and forest litter occurring in the vertical cross-section of the soil. In terms of moisture deficiency in mineral soil, ridges had the most unfavourable (quickly dried soil, because of slightly pressed surface in ridges) growing conditions and the inverted part of the soil was occasionally spread unevenly with regard to the surface. No forest management activities (no seeding and no planting) had been carried out on the study areas after soil scarification.

Regeneration results in clear-cut areas were inspected according to the sample plot method. Three to four rectangular sample plots were established on clear-cut units, the corners were marked with stakes and trees on the surveying lines were cut on borders. Sample plots in sizes from 10x10–15x20 m (depending on regeneration density) were systematically arranged on the clear-cut units. The distances between the sample plots were 25-35 m, which depended on the size and shape of the clear-cut units. Measurements were made on new sample plots, not on the ones established 11 years ago. Plots located on logging residual or in other unsuitable places were moved. All woody plants by tree species and microsites were counted on all sample plots (Table 2); there was no size limit for woody plants.

Measurement data were analysed with the statistics software R (R Development Core Team 2011). For comparing differences in numbers of woody plants in different microsites, T-test was used. Results were analysed using a one-way ANOVA between-groups design (Hatcher and Stepanski 1994).

Results

Development of Scots pine young stands

Forest site types naturally most suited for Scots pine among the researched site types include *Vaccin-*

Table 1. Soil and site properties of the study areas (Estonian classification)

Site type	Number of areas/ sample plots	Soil type	Soil group	Site index (m)	Humus layer thickness (cm)	Main tree species before harvesting
Oxalis-Vaccinium vitis-idaea	¼	Mineral	Gleyi-umbric Podzols	25-29	4	Pine
Vaccinium myrtillus	3/12	Mineral	Humic Podzols	21-25	10	Pine, spruce
Vaccinium vitis-idaea	½	Mineral	Podzols	21-25	4	Pine
Oxalis-Vaccinium myrtillus	3/11	Mineral	Gleyed soddy podzolic	25-29	6	Spruce
Oxalis	2/9	Mineral	Pseudo-podzols	25-33	4	Spruce, birch
Hepatica	3/10	Mineral	Typical brown soil	21-29	1	Spruce
Aegopodium	7/21	Mineral	Gleyed brown lessive soil	25-29	1	Birch, spruce
Filipendula	½	Mineral	Gley	21-25	10	Birch, aspen
Drained Vaccinium uliginosum	¼	Mineral	Gley podzols	13-17	20	Pine
Drained transitional bog	2/7	Peatland	Transitional mire soil	13-17	>30	Pine
Drained peatland	4/13	Peatland	Rised bog soil	9-13	>30	Pine

Table 2. Average numbers of naturally regenerated trees on sample plots per hectare by forest site types in 1995 and 2005

Site type	Pine		Spruce		Birch		Aspen		Deciduous tree	
	1995	2005	1995	2005	1995	2005	1995	2005	1995	2005
Forest site types on mineral soil										
Oxalis-Vaccinium vitis-idaea	0	0	0	2202	3300	5224	0	0	12600	2442
Vaccinium myrtillus	180	2658	1620	2697	36020	8368	380	2622	2070	2818
Vaccinium vitis-idaea		5339				7594				
Oxalis-Vaccinium myrtillus	0	0	0	976	2890	11144	1500	78	5460	577
Oxalis	0	4661	0	2228	1550	8994	0	0	14410	0
Hepatica	0	0	570	0	4470	1390	21810	1450	3640	6983
Aegopodium	0	208	300	499	14070	5302	5090	5247	1995	12084
Filipendula	0	0	0	0	4240	9556	1420	1179	11030	3452
Drained Vaccinium uliginosum	3815	0	0	183	2060	1648	0	0	100	0
Forest site types on peat soil										
Drained transitional bog	110	365	100	255	4720	1976	0	0	370	0
Drained peatland	0	1600	760	794	6480	13971	1210	191	125	0

ium myrtillus, Vaccinium vitis-idaea, *Vaccinium uliginosum* and transitional bog forest site types, although the survival of woody plants is also affected by specific growing conditions (Table 2).

After the first inventory in 1995, sporadic pine plants were only found in clear-cut areas of *Vaccinium myrtillus* and transitional bog forest site types, except the clear-cut area in drained *Vaccinium uliginosum* site type with 3,800 naturally regenerated pines per hectare. Few pine plants were growing in the areas left to natural regeneration also after 11 years from soil preparation. More pines had appeared only in *Vaccinium myrtillus* and *Oxalis* site types. Natural regeneration of Scots pine was missing in *Oxalis*-*Vaccinium vitis-idaea*, *Oxalis*-*Vaccinium myrtillus*, *Hepatica* and *Filipendula* and was very low in *Aegopodium* and transitional bog forest site types (Table 2). A noteworthy fact is that the rich pine regeneration that occurred in *Vaccinium uliginosum* site type had perished during the 11 years following the soil preparation.

One year after soil preparation, most of the pines (72%) in clear-cut areas on mineral soil were growing in furrows, 23% of pines on ridges and 5% on untreated soil; no pines were found on slopes (Fig. 2).

After 11 years, the distribution of trees on mineral soil had become more homogenous by microsites: 22% of trees were growing on untreated soil and the relative number of trees was practically equal in furrows and on slopes (34% and 30%, respectively); pines had also appeared on ridges (14%). After one year, sporadic naturally regenerated pines (110 pine plants per hectare) could be found on slopes in clear-cut areas in transitional bog forests and drained peatland forests. Scots pine natural regeneration was also low after 11 years; trees on slopes had perished and new pine plants had started growing on untreated soil and in furrows (Figure 2). In 2005, a significantly higher ($p<0.05$) number of pine plants per hectare was growing on disturbed area compared to undisturbed area. A total of 78.3% of the plants were growing on 60.9% of the total clear-cut units, which reflects the positive effect of soil preparation on pine natural regeneration.

Density of pine and spruce plants increased in the disc-trenched microsites, especially in furrows and on slopes, in both the 1995 and 2005 inventories. The respective number was the largest in furrows and on slopes both in 1995 and 2005 (Figure 3). For example, in the clear-cut area in *Vaccinium myrtillus* site type with 1,500 pines per ha, 52% of the trees were found on untreated soil and 48% on slopes; no pines were growing in furrows and on ridges.

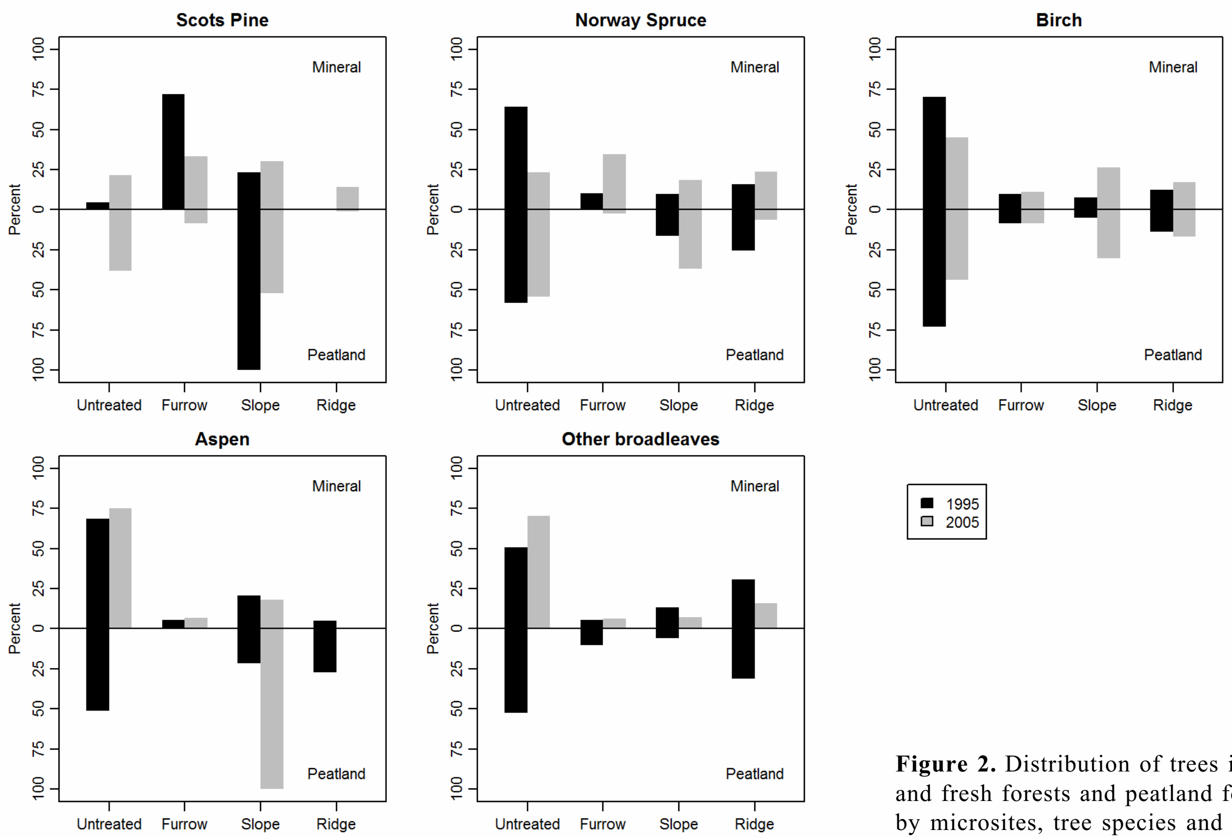

Figure 2. Distribution of trees in dry and fresh forests and peatland forests by microsites, tree species and years

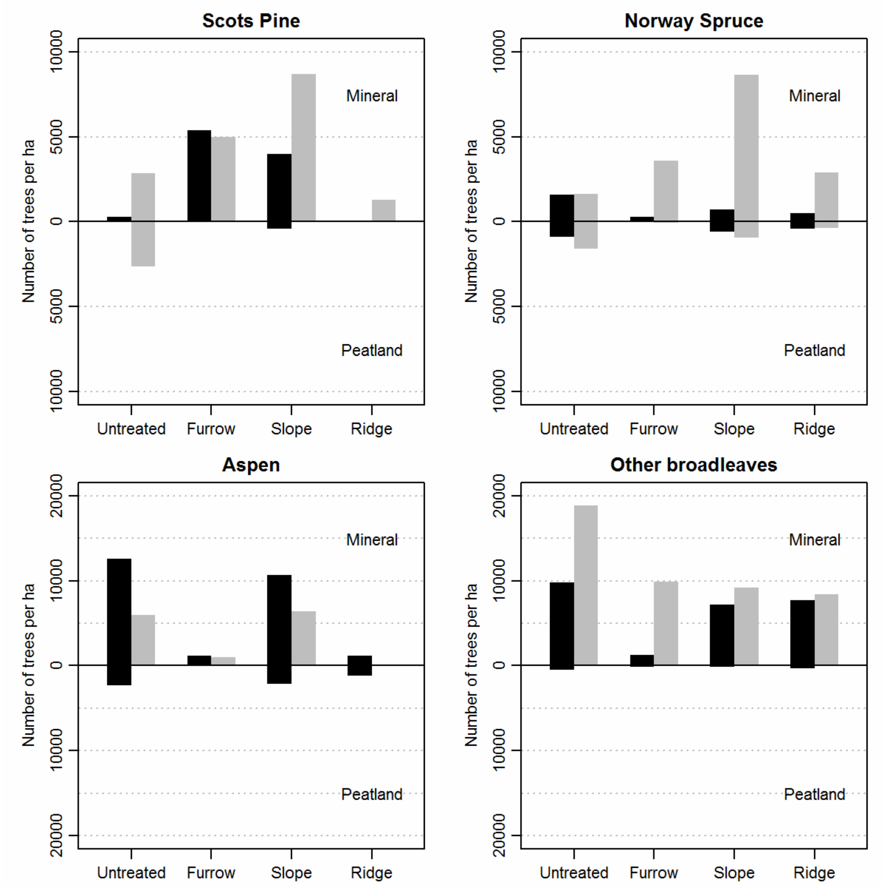

Figure 3. Mean stand density in dry and fresh forests and peatland forests by microsites, tree species and years

Development of Norway spruce young stands

The outcome of Norway spruce natural regeneration is generally the same as that of Scots pine, although it varies significantly by forest site types and plots. In the end of the first growing season following soil scarification, naturally regenerated spruce plants were growing on half of the clear-cut areas of the researched site types. The largest number of spruce plants was found in *Vaccinium myrtillus* site type. Spruce plants also occurred in *Hepatica* and *Aegopodium* site types as well as in the clear-cut areas in drained peatlands and transitional bog forest site types. During the following 11 years, the number of spruce plants had significantly increased in clear-cut areas in *Oxalis-Vaccinium vitis-idaea Vaccinium myrtillus* and *Oxalis* site types, with over 2,200 plants per hectare (Table 2). In the case of such spruce numbers, the composition of stands with a majority of spruce without cultivation may be expected.

Among naturally regenerated spruce plants, approximately 60% were growing on untreated soil on both mineral and peat soil in 1995. Depending on soil type, 16–26% of the spruces were growing on ridges; few plants occurred in furrows and on slopes. In 2005, 23% of the spruces were growing on untreated soil; the number of trees on slopes had increased to some extent. Data on the density of trees also reflected a greater number of spruces on untreated soil and slopes compared to furrows and ridges. Therefore, the obtained results showed that soil scarification had a significant ($p<0.05$) effect on the natural regeneration of Norway spruce; 76.8% of spruce plants were growing on 55.5% of the total clear-cut units.

Soil scarification had a significant effect on the abundance of the natural regeneration of Norway spruce – the numbers of plants were significantly different on untreated soil and on disturbed soil in mineral and peat soils (Figure 4). On average, 550 trees per hectare were growing on untreated and 4,260 trees per hectare on scarified soil.

Development of Silver birch young stands

Compared to coniferous trees, the number of Silver birches in clear-cut areas was already high at the end of the first growing season following soil scarification (Table 2). In *Vaccinium myrtillus* and *Aegopodium* clear-cut areas, 36,020 and 14,070 plants, respectively, were growing per hectare. In other site types, the number of birches reached 1,550–6,480 per hectare. In half of the site types, the number of birches rose

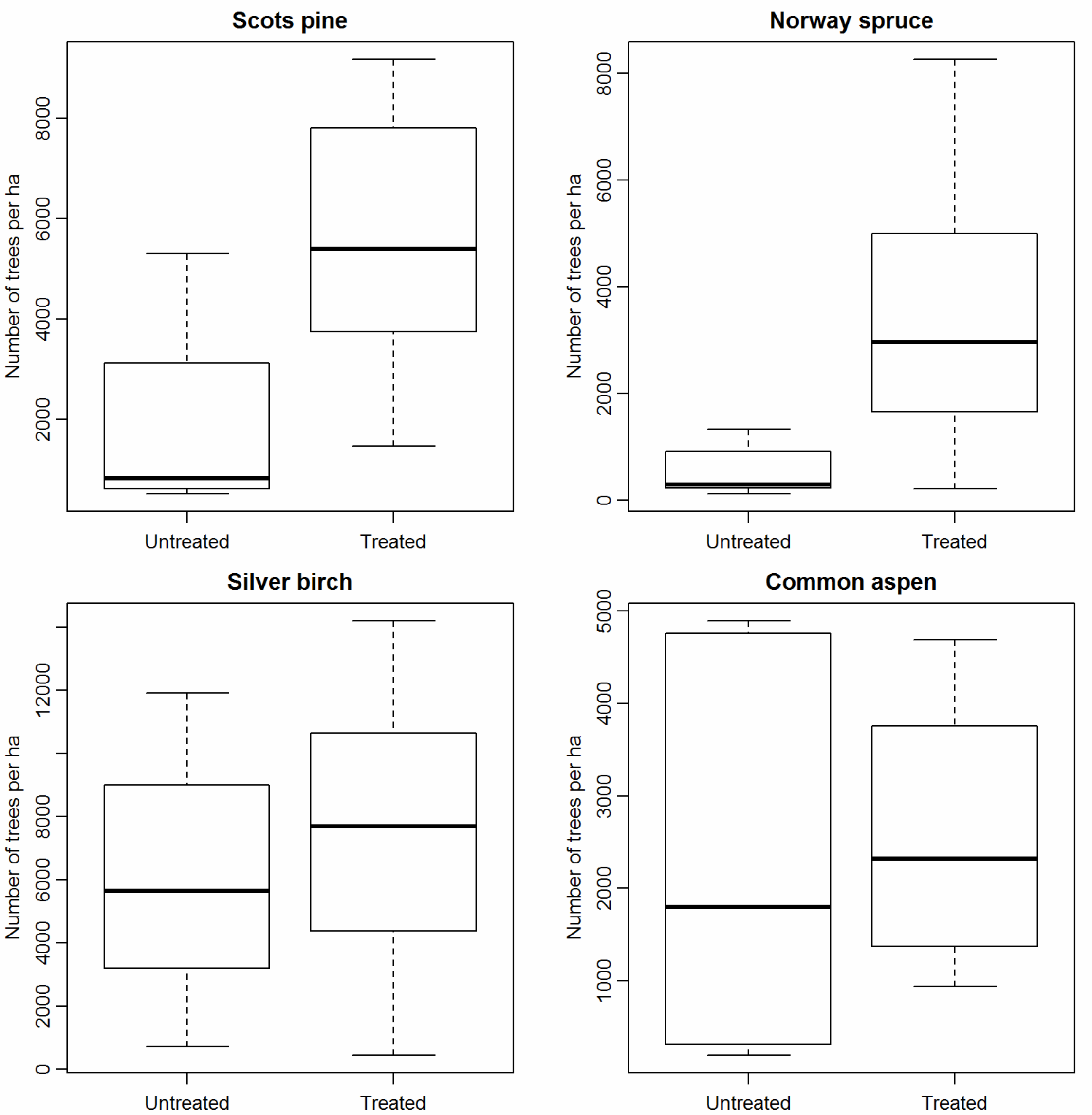

Figure 4. Distribution of stand density in mineral soil by tree species in year 2005

2-4 times during 11 years from soil scarification, reaching a maximum of 13,971 trees per hectare in drained peatlands. In the rest of the site types, there was a slight decrease in the number of birches; the smallest number of birches had remained in the clear-cut areas of *Hepatica* site type. A year after soil scarification, 1,550–36,020 birches per ha were growing in researched clear-cut areas depending on site type (Table 2). On mineral and peat soil 70% of birches were growing on untreated soil after the first year of soil scarification. More than 40% of the birches were growing on untreated soil 11 years later, approximately 10% in furrows, 30% on slopes and 20% on ridges. The efficiency of scarification in Silver birch dominated stands was low % 54.9% of birch plants were growing on disturbed areas, which formed 56.3% of the total clear-cut units.

Development of European aspen and other deciduous tree young stands

The number of European aspens in researched areas was, in general, smaller than that of birches and the distribution more uneven by site types. After the first inventory, the density of aspens was greater in *Hepatica* and *Aegopodium* site types. No aspens were found in *Oxalis-Vaccinium vitis-idaea, Oxalis, Vaccinium uliginosum* and transitional bog forest site types. 69% of aspens on mineral soil and 51% of aspens on peat soil were growing on untreated soil. After the second inventory, the number of aspens had considerably increased in *Vaccinium myrtillus* sites, whereas in the rest of the site types, the relative importance of aspen had declined (Table 2). The regeneration of aspen also differed significantly between site types. 75% of aspens were growing on untreated soil, 18% on slopes and 7% in furrows. The growing density of aspens was also the highest on untreated soil. During the time between the two inventories, aspen had mostly fallen out of the composition on peat soil; only a few trees had survived.

In addition to birch and aspen, numerous other deciduous trees (*Salix* sp.*, Tilia cordata, Alnus* sp.*, Sorbus aucuparia, Prunus padus, Fraxinus excelsior*) were growing in some clear-cut areas – 14,410 plants per ha in *Oxalis* sites, 12,600 plants per ha in *Oxalis-Vaccinium vitis-idaea* sites, and 11,030 plants per ha in *Filipendula* sites. During the following 11 years, the number of other deciduous trees decreased in most of the site types, whereas the opposite trend occurred in *Hepatica* and *Aegopodium* site types. A rich number of other deciduous tree species (*Salix* sp.*, Tilia cordata, Alnus glutinosa, Alnus incana, Sorbus aucuparia, Prunus padus*) were growing on fertile mineral soils in addition to birch and aspen (Table 2). One year following soil scarification, 50% of them were growing on untreated soil and 31% on ridges. Eleven years later, 71% of deciduous trees were growing on untreated soil and stand density was also the highest on this microsite (Figure 2). The natural regeneration of deciduous trees was low on peat soil and during the 11 years they fell out of the composition of young stands.

Discussion

On peat soil, furrows formed by the disc trencher seemed to function as soil drainage ditches rather than habitats. Both slopes and ridges proved to be the best growing sites. Within 11 years, growing conditions in the microsites had changed greatly, especially on peat soils, with moss and the shrub layer growing in furrows. Excessive moisture occurring in the furrows of some sites on mineral and soil could reduce the speed of regeneration (Mäkitalo and Hyvonen 2004)

Nowadays, great attention is focused on promoting the diversity of tree species with deciduous trees. Increasing their importance in coniferous stands facilitates nutrient intake from the soil, reduces risks in forest management (storms, butt rot fungus), diversifies forest production, etc. About half of the clear-cut areas in Estonian forests regenerate naturally (Metsakaitse- ja metsauuenduskeskus 2009), mainly with deciduous trees. In order to maintain the current proportion of coniferous stands, we are forced in this situation to reforest pine stands (35% of total forest area) and spruce stands (17% of total forest area) by planting and seeding. Although planting and sowing are the fastest and most reliable methods of reforestation in coniferous stands, it has proved relatively expensive, because it requires the development of a nursery network. In Sweden, for example, almost 80% of planting costs are related to the seedlings (Johansson et al. 2007). Natural regeneration involves several shortcomings, the consequences of which are alleviated by using methods contributing to natural regeneration; soil preparation being one of the most widely used techniques. It is used to create as favourable germination and growing conditions as possible for seeds fallen from trees. Certainly, the abundance of the seeds depends on the specific seed year.

Recently planted spruces may suffer from or even perish due to water stress, which is caused by vegetation competition in dry periods (Nilsson and Örlander 1995). A study conducted in southern Sweden showed that more than 70% of the root biomass of ground vegetation can be found in the upper 15 cm thick layer of the soil profile where the main part of the root system of planted or naturally growing young spruces is situated. Competition between herbaceous and woody plants can be more clearly seen during the first two years following planting (Nilsson and Örlander 1999[2], 1999[3]) In this study, the number of pine plants was significantly larger and their growth better on sample plots on treated mineral soil than on untreated mineral soil (Figure 4) after 11 years.

Root development is the key factor in determining the germination and first-year growth of planted seedlings. The results of the research by Johansson et al. (2007) revealed that competitive vegetation continues to remain a problem for spruce mini-seedlings (10-week-old seedlings) even after 3 years from planting; the same applies for naturally regenerated seedlings during the first growing weeks.

Water stress caused by vegetation competition may lead to woody plants perishing in dry periods (Nilsson and Örlander 1995), whereas the elimination of ground vegetation ensures excellent germination and fast tree growth (Burgess et al. 1996). Water stress on seedlings is also heightened by low soil temperature (Lopushinsky and Max 1990). This can be raised by soil scarification, by up to 2 ţC according to research conducted in Estonia (Valk 1957). Natural regeneration and its later development depend on many factors. In Estonia, the surface is of great importance upon the germination of seedlings. Rich vegetation obstructs tree seeds from reaching the soil. The germination of seedlings is also hindered by a thick and dense raw humus layer.

Soil scarification affected the natural regeneration of pine the most in site types favourable for pine, whereas it had a lower effect on Norway spruce and hardly any effect on deciduous trees. After the first inventory, among direct soil preparation methods furrows had the least effect in terms of both the total number and growing density of trees, whereas slopes had the greatest effect. 11 years following soil preparation, the growing density of birches on slopes on mineral soil was significantly higher than on untreated soil. Seed trees were usually not left growing in clear-cut areas (before the year 1998); only a few (5-10) of them were kept in pine stands. Thus, it is difficult to evaluate the effect of seed trees on natural regeneration. However, clear-cut areas in Estonia are usually no wider than 100 m and a possible spread of seeds should therefore be quite successful.

Scots pine

The results of the research carried out in Sweden indicated that the number of naturally regenerated pine plants in clear-cut areas scarified by a disc trencher had almost doubled (ca 5,000 plants per ha) compared to untreated clear-cut areas (<2,500 plants per ha) after 4–7 years from scarification. Naturally regenerated pine plants alone are not enough for the formation of ordinarily closed pine young stands; however, a relatively rich natural regeneration of pine supports planting and therefore the initial density of plantations can be reduced in some site types (Nilsson et al. 2006).

The findings of the research by Hyppönen and Kemppe (2001) also showed the positive effect of soil preparation on the natural regeneration of pine: 12 years after scarification, the number of pine plants in the untreated area was 3,500 per hectare, 7,200 in the disturbed area and 10,100 in the disturbed+sowing area, of which 1,100, 2,300 and 2,700 plants per ha, respectively, were capable of developing. In addition to these, 2,000 spruce plants per hectare occurred in microsites. It was also pointed out that an exceptionally good pine seed year followed the scarification. According to another, similar study (Hyppönen et al. 2001), the number of pine plants in the area scarified by the disc trencher was a little higher after the 18th growth year than in the untreated area (2,400 and 2,300 plants per ha, respectively).

Karlsson and Nilsson (2005) generalised the results of earlier research and concluded that soil scarification has a positive influence on the natural regeneration of pine, spruce, and birch. However, according to the research conducted by the above-mentioned authors themselves (Karlsson and Nilsson 2005), soil scarification significantly increased the density of pine seedlings and spruce seedlings. These results coincide closely with the outcome of this research, according to which soil scarification gave the best results in pine stands on mineral soil – the number of pines increased in furrows, on slopes as well as on ridges. The two main success factors for natural regeneration are the abundance of seeds spreading across the reforested area and weed invasion. Pine seed years reoccur quite often (the interval in Estonia is 3–4 years) and weed invasion on disturbed soil is relatively slow in pine stands. Thus, soil preparation produces desired results. In Sweden (Nilsson et al. 2006), it is suggested that dry or mesic site types on nutrient deficient or moderately fertile soils should be left to pine natural regeneration. From the viewpoint of advanced regeneration retention, scarification often has a negative impact, because seedlings are damaged or destroyed in the course of scarification (Nilsson et al. 2006). It would be useful to also follow similar recommendations for enhancing pine natural regeneration in site selection in Estonia. Although the abundance of pine natural regeneration in the first years following scarification may also be great on damper soils, for example in furrows in the *Vaccinium uliginosum* site type, the regeneration will perish within the next few years due to periodic excessive moisture. The research conducted in Sweden observed moisture conditions and pine seed germination capacity in four substrates (feather moss, mineral soil, humus and organic material on soil). It appeared that the germination capacity of pine seeds is the highest in the humus layer (40%) and in a moderately moist and warm environment (Oleskog and Sahlen 2000).

Our research results reflect the significant impact of soil moisture level on the development of the outcome of natural regeneration after soil scarification with disc trenchers in clear-cut areas. Research results proved the positive effect of soil preparation on pine natural regeneration in pine stands. The expedience of using disc trenchers for promoting natural regeneration on peat soil requires further research.

Norway spruce

The reason for the different numbers of plants in the relative distribution of the natural regeneration of Norway spruce is the somewhat different rate of weed invasion in mineral and peat soils. The microsites formed in scarification become largely weed-invaded in fertile spruce areas within 1-2 growing seasons, whereas on mineral soils, weed invasion in furrows is more modest since they are covered by the herbaceous layer falling from ridges.

According to this research, the impact of soil scarification on the natural regeneration of spruce on mineral soils was moderately positive, especially on slopes. Similar results have also been obtained in Sweden where the number of naturally regenerated spruce plants (ca 1,000 plants per ha in untreated clear-cut areas) was significantly smaller than that of pine, with scarification having no remarkable effect compared to the existence of shelterwood (Nilsson et al. 2006). Soil scarification did not increase the density of spruce plants also according to Karlsson and Nilsson (2005). One of the reasons for such results is the rapid post-scarification weed invasion of fertile soils in spruce stands. During the years following clear-cutting, competition between underground vegetation and naturally regenerated spruce seedlings was not studied. In Finland, the effect of soil scarification on the natural regeneration of spruce is positive in boreal forest site types (*Empetrum nigrum, Vaccinium vitis-idaea* site types), ensuring a larger number of trees (approximately 500 plants per ha more), which will secure good formation of the regeneration after 12 growth years (Hyppöne and Kemppe 2001). Valkonen and Maguire (2005) found that the number of spruce germinations on a unit of area was positively related to herb cover and yet negatively to general vegetation. Moss domination or the occurrence of relatively light-demanding plants in the microsite was dependent on the small number of germinations. During the first growing years, germination capacity in scarified conditions was 4.3–6.9 times higher than in unscarified conditions (Valkonen and Maguire 2005). The growth of coniferous trees is also hindered by the natural regeneration of deciduous trees in clear-cut areas (Piatek and Allen 2000).

The reason for the differences in the relative distribution of the natural regeneration of Norway spruce is the somewhat different rates of weed invasion on mineral and peat soil. The microsites formed in scarification become largely weed-covered in fertile spruce stands already within 1-2 growing seasons, whereas on mineral soil, weed invasion in furrows is more modest because they are covered by the herbaceous layer falling from ridges (Seemen and Pikk 1997).

Deciduous trees

Data were also collected on the dynamics of the changes in the number of plants over 12 years. For instance, the number of birches in boreal forest decreased after 12 growth years in the scarified site from 7,000–10,000 plants to 2,000–3,000 plants per hectare but increased in the untreated area from 1,000 plants to 2,000 plants per hectare (Hyppönen and Kemppe 2001).

According to Finnish forest researchers, the number of pines, spruces and birches started to decrease after the 10th year following soil scarification (Hyppönen and Kemppe 2001). Consequently, furrows provided more unfavourable conditions for the survival of both coniferous and deciduous trees, as did ridges for the growth of deciduous trees, compared to slopes. The decrease in the number of plants in furrows was most probably caused by soil compaction in furrows and excessive moisture in lower areas. It is likely that plants perished on ridges due to low soil density and percolation. However, Heiskanen et al. (2007) show that water retention and air-filled porosity were significantly higher and the density lower in ridges than in the untreated area. Results indicated that changes in the physical characteristics and organic substance content of soil may affect the water regime in the soil and, thus, also preconditions for forest growth after over 20 years from soil scarification in Lapland (Heiskanen et al. 2007).

Soil scarification probably has no significant effect on the survival of regeneration in the increased leaching of nutrients as a result of soil scarification, because ultimately, it influences soil fertility only slightly (Piirainen et al. 2007) or not at all (Nohrstedt 2000).

An analysis of research results by microsites actively scarified in Estonia showed that in the year following the scarification, furrows and slopes were relatively rich in pine seedlings, whereas spruce seedlings appeared sparsely in furrows, on slopes as well as on ridges; numerous deciduous trees sprouted in furrows, on slopes and also on ridges.

Conclusion

Soil scarification has a positive effect in typical sites for pine rather than spruce. Deciduous trees regenerate sufficiently without any intervention. The number of naturally regenerated coniferous trees was small because the composition of deciduous tree stands in most researched site types involves a small number of coniferous trees. Spruce stands containing deciduous trees are likely to form in *Vaccinium myrtillus, Oxalis* and *Oxalis-Vaccinium vitis-idaea* site types. After 11 years, the number of coniferous and deciduous trees had diminished in furrows, yet considerably risen on slopes. The number of pines and spruces on ridges had slightly increased, but still, the regeneration was dominated by deciduous trees.

For sites where deciduous trees and conifers grow together and natural conifer stands are preferred, it is important to carry out soil scarification and later pre-commercial thinning to contribute to the growth of conifers.

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ВЛИЯНИЕ ПОДГОТОВКИ ГРУНТА НА ЕСТЕСТВЕННОЕ ОБНОВЛЕНИЕ ЛЕСА 11 ЛЕТ ПОСЛЕ НАЧАЛА ИСПОЛЬЗОВАНИЯ ДИСКОВОГО ПЛУГА В ЭСТОНИИ НА ТИПАХ УСЛОВИЙ МЕСТОПРОИЗРАСТАНИЯ МИНЕРАЛЬНЫХ И БОЛОТНЫХ ПОЧВ

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Резюме

Подготовка грунта, или т.н. минерализация, является одним из основных методов содействия естественному обновлению, в то же время он широко используется в целях обновления леса. Основной целью данного исследования является выяснение, какое влияние имеет подготовка грунта на естественное обновление леса по истечении 11 лет после начала применения дискового плуга на имеющихся на минеральных и торфяных почвах типах условий местопроизрастания. После сплошной рубки использовался дисковый плуг Donaren 190, и первая инвентаризация участков проводилась после первого периода роста. Повторные измерения проводились в той же местности по истечении 11 лет после начала применения дискового плуга. Данные измерений были собраны с временных пробных участков, длина сторон которых составляла 10x10 до 15x20 м.

Число древесных растений было определено по элементам грунта: нетронутый участок, борозда, скат и гребень. Результаты измерений сравнивались с полученными 11 лет назад, и было выявлено изменение числа древесных растений на различных элементах грунта, как на минеральных, так и болотных почвах. После 11 лет роста больше всего встречалось сосновых растений в типах условий местопроизрастания *Vaccinium myrtillus, Vaccinium vitis-idaea* и *Oxalis* и на осушенных болотных почвах, в среднем 2600–5300 дерева на гектар. На минеральной почве встречались сосновые растения чаще всего в бороздах и на скатах – 33,5% и 30,4%. На торфяных почвах встречались сосновые растения также на скатах, но и на нетронутых участках, соответственно 38,3% и 52,1%. Естественно обновленной обычной ели было больше всего на *Oxalis-Vaccinium vitis-idaea, Vaccinium myrtillus* и *Oxalils* типах условий местопроизрастания, 2000–3000 дерева на гектаре. В отрезке элементов грунта деревья обычной ели встречались на минеральной почве больше всего на нетронутых участках и в бороздах – 23,2% и 34,6%. На торфяной почве естественно возникшие ели встречались больше всего также на нетронутых участках, а также на скатах – 54,3% и 37,0%. Из лиственных пород деревьев, как осина, так и береза поникшая, росли на минеральной и торфяной почве, прежде всего, на нетронутых участках. Подготовка грунта имела положительное влияние на рост численности обычной сосны и обычной ели, а на численность лиственных деревьев подготовка почвы существенно не повлияла. Хвойные породы деревьев росли в изобилии на естественных для них местопроизрастаниях.

Ключевые слова: подготовка грунта, элементы грунта, типы условий местопроизрастания, естественное обновление