Thibault Charlois

Influence of soil preparation on the success of Norway spruce plantation on fine-grained soil

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Thesis Abstract

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Author: Thibault Charlois

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Soil preparation before regeneration, in forestry, is very common and widely used in Finland. It improves the outcomes of reforestation and it is one of the critical parameter of the future stand quality. However, different soil types exist, with different properties, and planting results may vary. On fine-grained soils, plantations do not succeed as well as on coarser soils, despite the improvements brought by soil preparation.

This study goes through different soil preparation methods – spot mounding and light ditch mounding with variable mound heights, and inverting –, as well as unprepared control plots with and without herbicide application, tested on a fine-grained soil, planted with Norway spruce, in Central Finland. Particularly, seedlings development and broadleaves competition are examined and interpreted.

Obtained outcomes show that the mounding methods favor spruce seedlings development. The competition was the lowest among the plots prepared with the light ditch mounding method. Inverting and unprepared plots did not show encouraging results and the damages that seedlings have experienced during the first growing season (pine weevil, vole, frost heave) had a noticeable impact on their development. Herbicide application on unprepared plots did not confer any advantage to the seedlings, and on the contrary, the postplanting outcomes from those plots are poorer than on control plots without herbicide application.

Keywords: fine-grained soil, forest regeneration, frost heave, glyphosate, *Hylobius abietis*, inverting, light ditch mounding, mounding, Norway spruce, *Picea abies*, pine weevil, soil preparation (forestry), spot mounding.

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Maanmuokkaus ennen uudistamista on hyvin yleinen ja laajalti käytetty metsänhoitomenetelmä Suomessa. Se parantaa metsänuudistamisen tuloksia, ja se on yksi tulevan puuston laadun ratkaiseva tekijä. Kuitenkin, eri maalajeilla on erilaisia ominaisuuksia, ja uudistamisen tulokset voivat vaihdella. Hienojakoisilla kangasmailla istutus ei onnistu samoin kuin karkeammilla maalajeilla, huolimatta maanmuokkauksen tuomasta parannuksesta.

Tässä tutkimuksessa vertailtiin eri maanmuokkausmenetelmiä: laikkumätästyksen ja naveromätästyksen erikorkuisia mättäitä sekä kääntömätästystä. Koealoihin kuului myös muokkaamattomia kontrolliruutuja, joista osa oli käsitelty herbisideillä ja osa oli käsittelemättömiä. Hienojakoiselle kangasmaalle (hietamoreeni) perustetuille koealoille istutettiin kuusta Pohjois-Savossa, Suonenjoella. Taimien kehitys ja lehtipuiden kilpailu olivat tärkeimmät tutkittavat muuttujat.

Saadut tulokset osoittavat, että mätästysmenetelmät edistävät kuusen taimien kehitystä. Kilpailu oli vähäisintä naveromätästyksellä käsitellyillä koeruuduilla. Kääntömätästys ja muokkaamaton kontrolli eivät tuottaneet rohkaisevia tuloksia. Näillä koeruuduilla esiintyneillä tuhoilla, jotka kuusen taimet ovat kokeneet ensimmäisellä kasvukaudella (tukkimiehentäi, myyrätuhot, rouste), oli huomattava vaikutus taimien kasvuun. Glyfosaattikäsittely muokkaamattomilla aloilla ei tuonut etua taimille, ja istutuksen tulokset olivat päinvastoin huonommat kuin muokkaamattomalla kontrollialalla jossa kasvinsuojeluainetta ei käytetty.

Keywords: glyfosaatti, hieno hieta, *Hylobius abietis,* kuusi, kääntömätästys, laikkumätästys, naveromätästys, maanmuokkaus (metsätalous), metsänuudistaminen, mätästys, *Picea abies,* rouste, tukkimiehentäi.

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Definitions

Mounding	In Finnish: *mätästys*. Soil preparation method consisting of taking a scoopful of soil with an excavator and putting it upside down nearby, in purpose of planting a seedling container on afterwards.
Light ditch mounding	In Finnish: *naveromätästys*. Mounding soil preparation method consisting of digging 30-40 cm ditches to form mounds.
Spot mounding	In Finnish: *laikkumätästys*. Mounding soil preparation method consisting of removing a single spot of soil to form a mound.
Inverting	In Finnish: *kääntömätästys*. Soil preparation method consisting of putting upside down a scoopful of soil with an excavator at the same position, preserving an even soil and resulting in an inverted patch of humus and mineral soil.
Patch scarification	In Finnish: *laikutus*. Soil preparation method consisting in removing patches of humus to uncover the mineral soil. It is used on dry sites and can be suitable for both artificial and natural regeneration, if the competition is expected to be weak.
Disc trenching	In Finnish: *äestys*. Also known as harrowing. Soil preparation method consisting of removing deep patches of humus to uncover the mineral soil. This method is adapted to dry and coarse soils and suits for both artificial and natural regeneration. The competition has to be weak.

1 Introduction

1.1 Norway spruce facts

According to the Finnish Statistical Yearbook of Forestry (2012), Norway spruce (*Picea abies*) is the main species to be planted in Finland. It only represents the second growing stock volume currently – 698 million m^3 – after Scots Pine (*Pinus sylvestris*) – 1 145 million m^3 –, but the future of Finnish forest will be different. Indeed, what was considered as a secondary species until the 1990's, has now the favor of forest owners in artificial regeneration. In 2011, 52 047 hectares have been planted with Norway spruce, while 21 486 hectares have been planted with Scots pine (Figure 1).

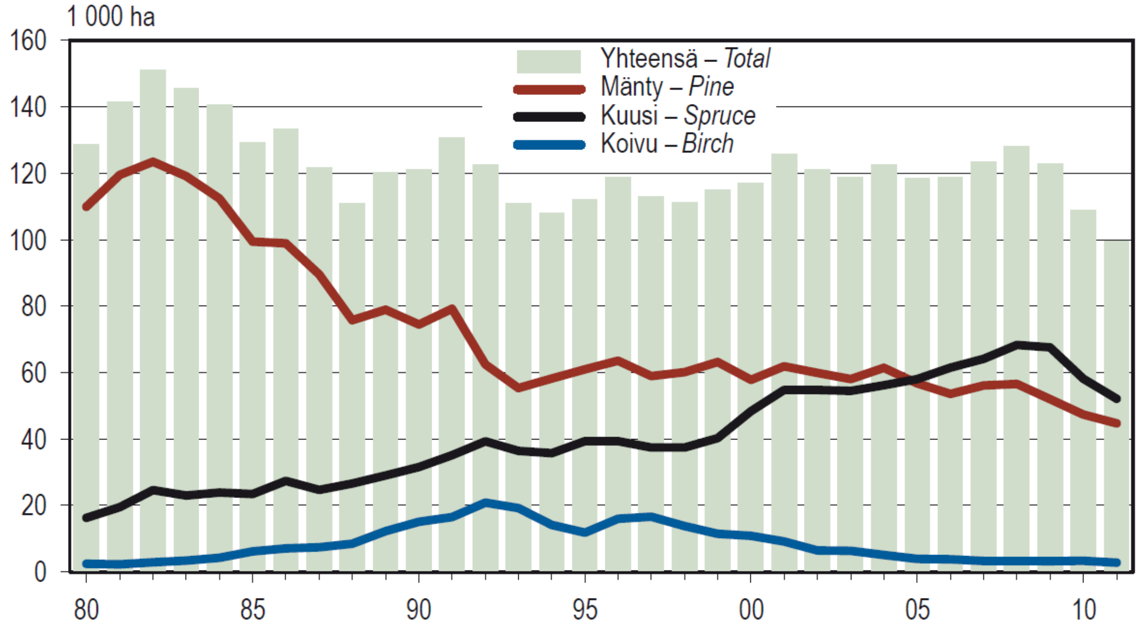


Figure 1. Artificial regeneration by tree species, 1980-2011 (Finnish Statistical Yearbook of Forestry 2012).

In Sweden, Norway spruce also tends to increase its presence. During the year 2012, 217 million of spruce seedlings have been delivered. In comparison, the amount of scots pine seedlings was 128 million and lodgepole pine seedlings (*Pinus contorta*) was 18 million. The standing volume of spruce has slowly developed though, during the last decades, as it was 1 263 million m^3 in 2000 and

1 282 million m^3 in 2010 (+ 1.5%), while the standing volume of Scots pine evolved from 1 181 million m^3 in 2000 to 1 293 million m^3 (+9.5%) (Swedish Statistical Yearbook of Forestry 2013).

1.2 Soil preparation facts

Soil preparation indubitably eases the plantation operation and enhances the growth performance. Mounding methods – light ditch mounding, spot mounding and inverting – are the most commonly used and efficient (66 751 ha in 2011), more than patch scarification (13 773 ha) and disc trenching (29 153 ha) in Finland (Finnish Statistical Yearbook of Forestry 2012). Indeed, they have a positive influence on soil temperature, on nitrogen availability, on vegetation competition and on scourges damages like the European pine weevil (*Hylobius abietis*) (Luoranen, Saksa & Uotila 2012; Örlander & Nilsson 1999; Heiskanen & Viiri 2005). Despite those mounding methods are more expensive operations, compared to lighter methods as patch scarification and disc trenching, they involve lesser cleanings costs and generate a higher quality stand, leading to a better economic performance (Uotila, Rantala, Saksa & Harstela 2010).

1.3 Fine-grained soil

Finnish soils may be classified in two distinct types: mires and mineral soils. The mire type consists of peat soils and covers 34% of the Finnish national surface. The other 66% are mineral made and represent 17 159 000 hectares in Finland (Finnish Statistical Yearbook of Forestry 2012).

Among mineral soils, three main categories appear after visual and tactile observation (Luoranen, Saksa, Finér & Tamminen 2007; Mälkönen 2003):

- Coarse soil (gravelly)

- Medium-grained soil (sandy)

- Fine-grained soil: median particles smaller than 0.06 mm, including silt and at least 5% of clay (< 0.002 mm).

The study site is a fine-grained till soil (*hietamoreeni*). A fine-grained soil has known properties. It is quite impermeable and let a part of the running water to flow at its surface. It stores water for a long period and, in this state, it is soft ground. When it dries, it becomes particularly hard. A terrain categorized as fine-grained is also known to cause frost heave that is frost of the wet upper layer of the soil, which increases the density and push seedling containers up, out of the ground, leading the plant to drought and death (Luoranen et al. 2012).

1.4 The previous study and the present study

Metla, the Finnish Forest Research Institute, has launched a study reported by Heiskanen et al. (2013). In this document, it is described how soil preparation methods have been tested on fine-grained soil planted with Norway spruce, on two locations, one in Pieksämäki, another in Suonenjoki.

The present document is the continuation of the previous study done by Heiskanen et al. (2013), adding to the study new data collected in 2012 from the Suonenjoki plot, notably seedlings' heights and diameters, herbaceous and broadleaf vegetation competition, as well as cleaning need.

I have searched to continue the previous study by answering those following interrogations.

Has the spruce growth been ameliorated by any soil preparation method? Regarding the soil type, soil preparation methods, which decrease the water content, increase temperature and provide more protection against scourges (pine weevil, vole and frost heave notably) are the most likely to present the more successful growth of seedlings.

What are the differences of results, among the different methods applied, in vegetation control need? Broadleaf establishment on a forest stand is favored by soil moisture and fertility. Both factors occur on the study plot. Therefore, a certain level of competition was expected. However, soil preparation offers less growth potential for broadleaves. The immediate vicinity of seedlings planted on mounds should be clearer of competitive vegetation.

2 Materials and methods

2.1 The Suonenjoki plot

Metla has started its study in Suonenjoki, in the province of Keski-Suomi (latitude 62.65 N, longitude 27.10 E), in Finland. It is a sloppy terrain, measuring 0.8 ha (Figure 2), classified within the Myrtillus type, where soil preparation has been done in spring 2007. Artificial regeneration led to the plantation of 1 692 seedlings, nearly 2 000 seedlings per hectare.

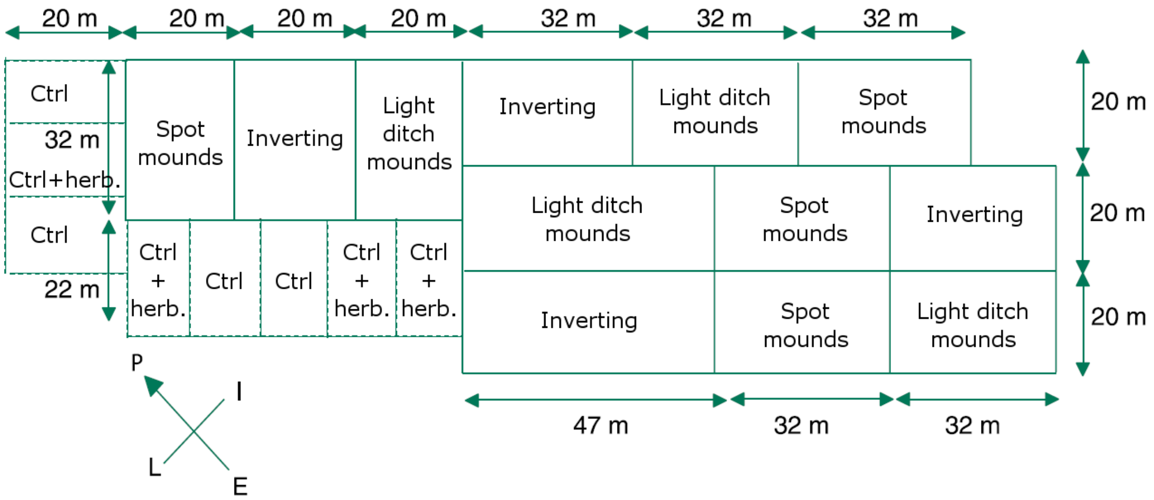


Figure 2. Map of the Suonenjoki plot (source: Juha Heiskanen, Finnish Forest Research Institute).

Three different methods of soil preparation have been implemented on different test plots, as well as two control test plots with undisturbed soil. On the half of the control plots, herbicide has been applied (glyphosate, 1.2% concentration, Glyfonova Bio, Cheminova A/S, Lemvig, Denmark), sprayed 50 cm around seedlings with a protection onto them, during the second growing season; the second half has been left without herbicide application.

The soil preparation methods are the following.

Spot mounding. An excavator passes and digs holes. The taken ground is put upside down nearby (mineral soil up, humus down), in a way that seedlings planted on the top can accede to a double layer of humus (Figure 3). There, three different heights of mounds have been used: low (5 cm of mineral soil above humus), medium (13 cm) and high (18 cm).

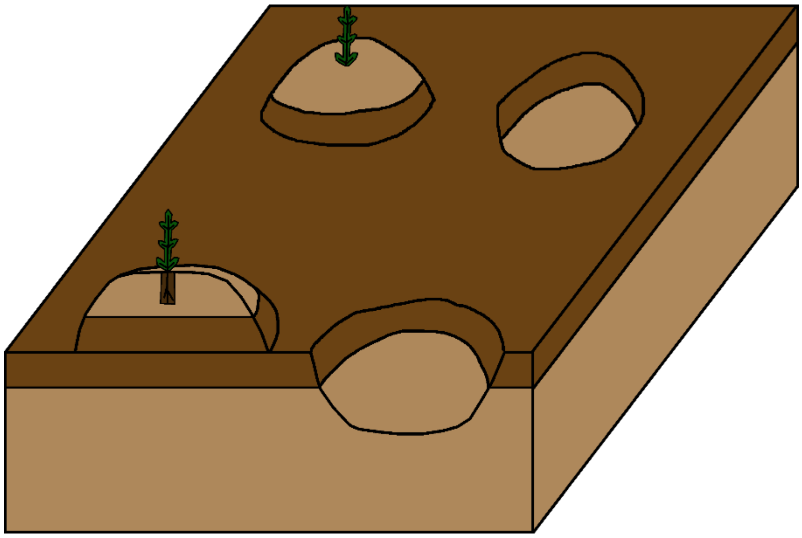


Figure 3. Spot mounding method.

Light ditch mounding. The excavator creates mounds put upside down by taking ground in a way to create a ditch, about 30-40 cm deep, which collects the upper layer of running water, though they are short in range and do not lead the water away from the plot (Figure 4). Likewise, three different heights of mounds have been done: low (5 cm of mineral soil above humus), medium (13 cm) and high (18 cm).

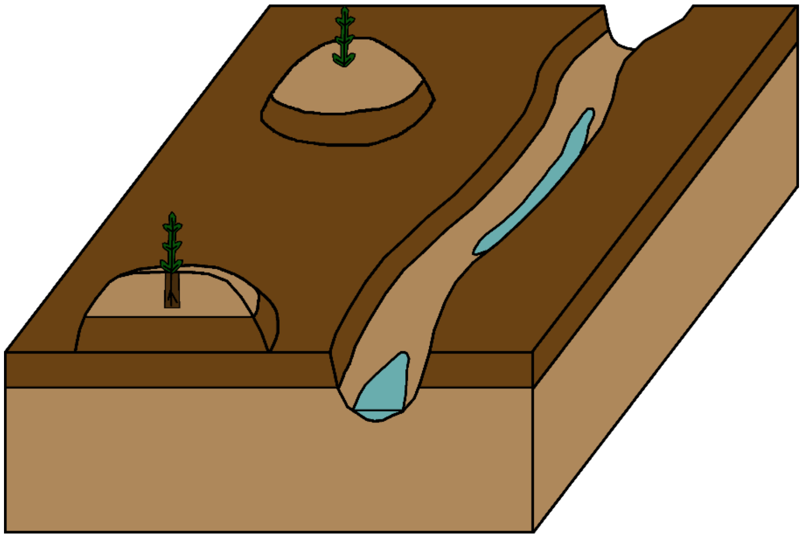


Figure 4. Light ditch mounding method.

Inverting. The soil is dug up by the excavator and returned upside down within the same pit (Figure 5).

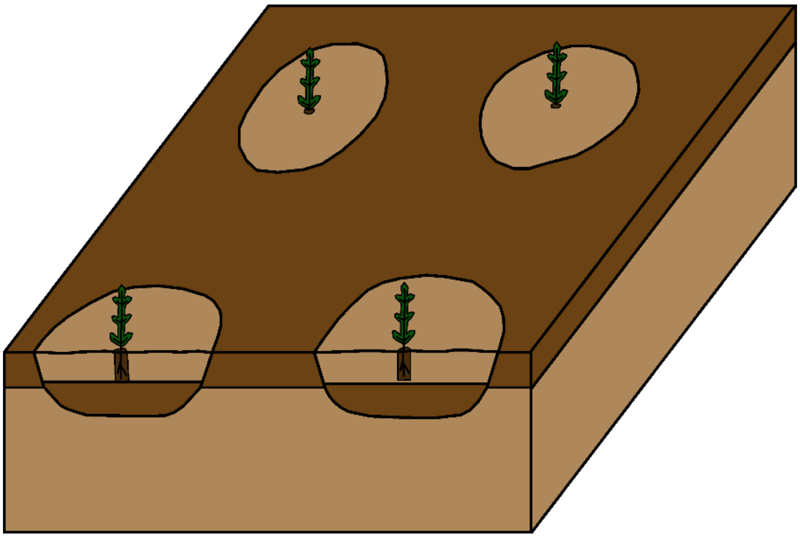


Figure 5. Inverting method.

The slope of the terrain has been taken into account when dividing the plot into test plots. Quadrangle test plots measure 640 m^2 each and the selection of the soil preparation method has been made randomly. There were then three preparation methods, with three different heights for spot and light ditch mounding, plus two control plots, resulting in twelve test plots altogether. Different heights of mounds have been tested to study the temperature and the moisture of the soil (Heiskanen et al. 2013). Mounds tend to subside with time and their positive effect is noticeable in the early development of seedlings.

Seedlings of Norway spruce were in Plantek 81F containers (produced by Lannen Plant Systems, BCC Oy, Säkylä, Finland), grown in a forest nursery in Suonenjoki, aged of 2 years, treated against pine weevil (submersion in deltamethrin, 0.05% concentration, Decis 25 EC, Bayer Crop Science AG, Manheim am Rhein, Germany) before shipping. The Pottiputki model of planting tube has been used for plantation operation, aiming 4 to 6 cm planting depth. After planting, in spring 2007, seedlings mean height was 25.8 cm and their root collar mean diameter was 3.3 mm.

The first cleaning operation has been done in 2011. This has been processed on half surface of each plot, leaving therefore half of plants from every test sample cleaned from broadleaves competition, and the other half uncleaned as a control. This cleaning operation consisted of a regular silvicultural intervention; spruces had their immediate competitors removed and remaining broadleaf stems, which were not disturbing the spruces' growth, have been left untouched.

2.2 Data collection

The present study has the same basis as the previous study reported by Heiskanen et al. (2013).

All spruce seedlings have been measured in 2010, 2011 and 2012. Have been registered the following data:

- Height of spruce seedlings (with measuring tape) in centimeters.
- Base diameter of spruce seedlings (with caliper) in millimeters.

Conditions of seedlings' environment have also been taken into account in 2012, to study the competition parameters:

- Herbaceous stratum cover has been estimated visually. A percentage rounded to 5 has been given for every seedling.
- Height, base diameter and amount of broadleaves, on the same basis as spruce seedlings measurement, one meter radius around each seedling.
- Cleaning need, estimated visually for each spruce seedling and rated within four classes (1- no need; 2- cleaning needed in 3 to 5 years; 3- immediate cleaning needed; 4- cleaning in late).

2.3 Data treatment

All calculation have been done under the spreadsheet application Microsoft Excel. For every soil preparation method (light ditch mounding, spot mounding, inverting, control, control with herbicide), the data previously described have been reported, separating plots where cleaning has been done from plots where it has not been. Since uncleaned plots do not add any pertinent information, as they do not represent the evolution of a young spruce stand under normal forest management, they are not reported in the present study. The collected data have been compiled. Mean and median results have been calculated. The results shown here exclude the vigour and mortality parameter, as it is described by Heiskanen et al. in the previous study (2013).

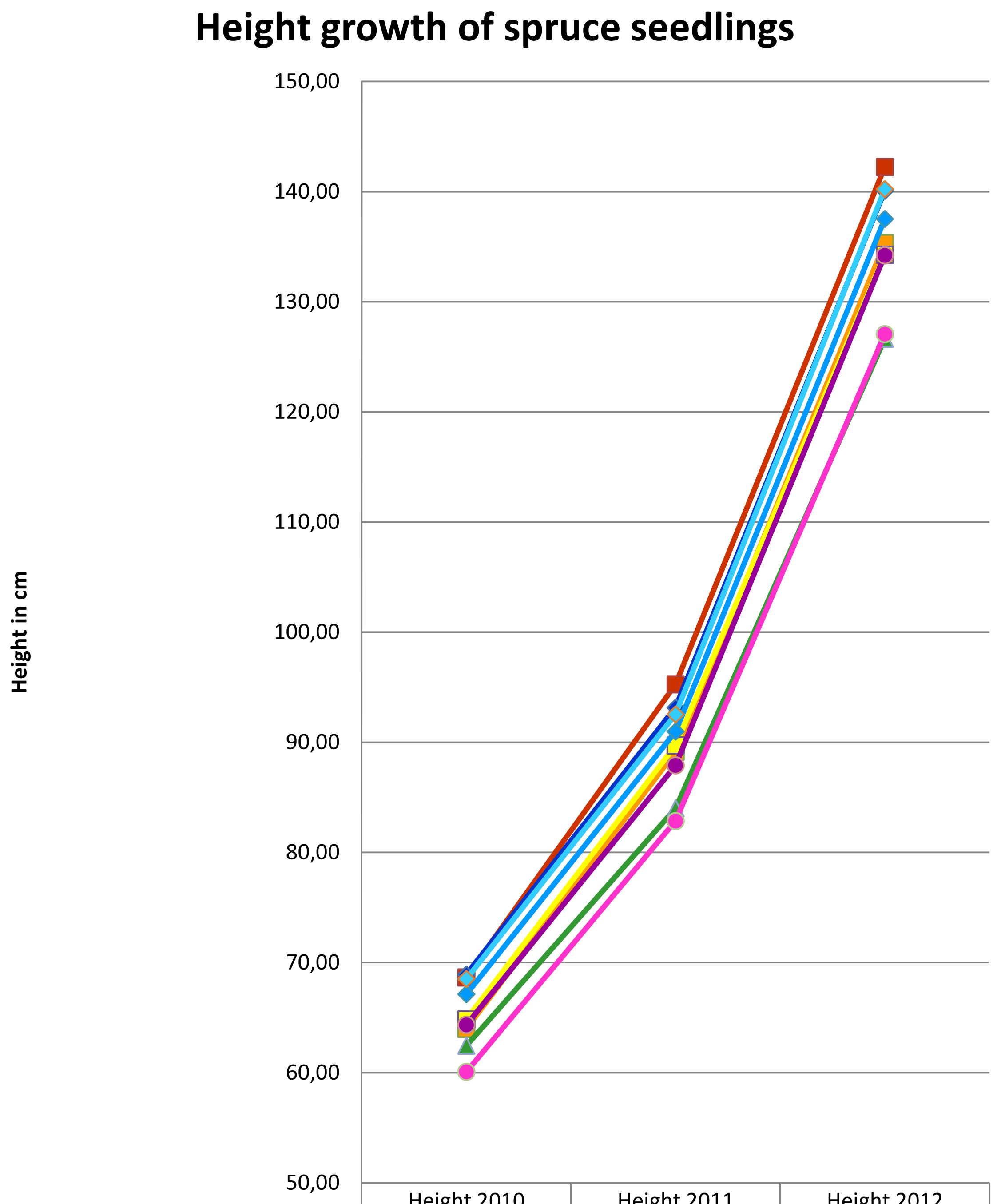
3 Results

3.1 Spruce growth

3.1.1 Spruce seedlings height

Trees' height is considered as paramount importance in forestry. Dominance in this matter will assure the better access to light and fast development, with more spaced out and smaller branches, straighter and higher stem and lower diameter metric decreasing (in other words, the stem will look closer from a cylinder than a cone). The growth in height is influenced by vegetation competition.

The heights of spruce seedlings have been growing according to the same pattern, as it is visually noticeable on the graph (Figure 6). Nevertheless, the most successful preparation method for the height growth appears to be the low spot mounding, which shows a slightly better height in 2010, 2011 and 2012. The two other spot mounding methods, medium and high mounds, registered much lower results. The three light ditch mounding methods show good performances too. Medium mounds, for both spot mounding and light ditch mounding, don't present as good results though, as low and high mounds. Inverting results are definitely not encouraging, since control plots gave similar or better growth output. Herbicide application might have a bad influence on seedlings, despite seedlings were covered and protected from direct contact with the herbicide during the application. Heiskanen and Viiri (2005) suggested that roots could be in contact with herbicide, which is a hypothesis to keep in mind.



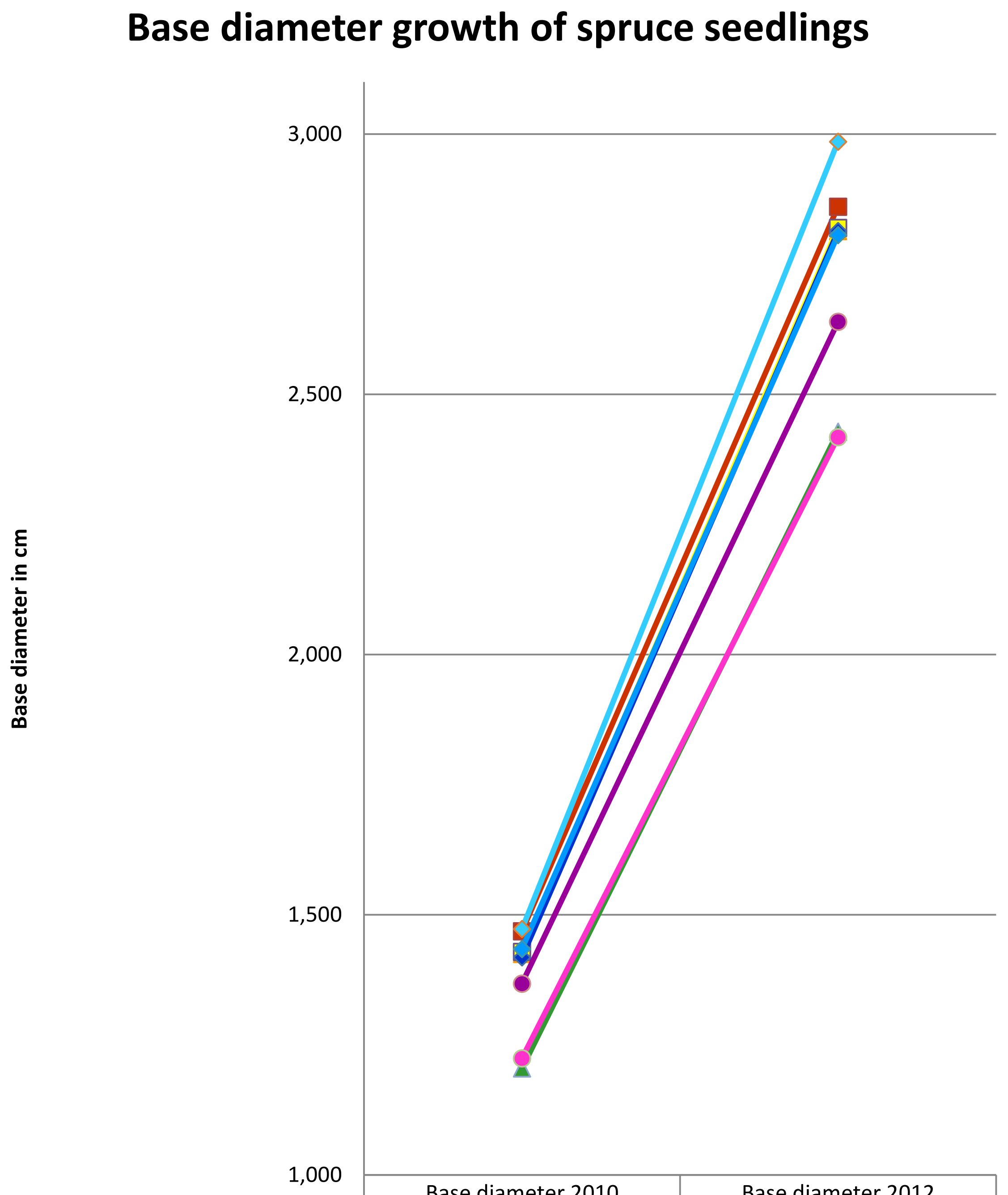
	Height 2010	Height 2011	Height 2012
Low spot mounding	68,64	95,25	142,25
Medium spot mounding	63,97	89,14	135,33
High spot mounding	64,83	89,71	134,26
Low light ditch mounding	68,90	93,15	140,09
Medium light ditch mounding	67,11	90,96	137,52
High light ditch mounding	68,51	92,52	140,23
Inverting	62,43	84,00	126,64
Control	64,33	87,89	134,22
Control + herbicide	60,07	82,84	127,05

Figure 6. Height growth of spruce seedlings in 2010, 2011 and 2012.

3.1.2 Spruce seedlings base diameter

This parameter has its interest to indicate the stability of the stand. The height growth is of course a sign of plantation success and quality. But a too fast sprint to the light makes the stem weaker at its base. In boreal forest, the snow cover, notably, generates a weight on branches and thus tensions within the stem, leading to breaking if the diameter is too thin. In case the pressure from surrounding vegetation happens to be too strong, the spruces will tend to struggle to dominance, neglecting their diameter growth and therefore jeopardizing the stand stability.

Base diameters have been measured in 2010 and 2012 (Figure 7). High ditch mounding method shows the best performance for both years. Low spot mounding is slightly below it, still with good results. Medium and high spot mounds, as well as low and medium light ditch mounds, obtain all very similar results, under the score of the two first methods said. Inverting method is here also similar or under the control plot results.



	Base diameter 2010	Base diameter 2012
Low spot mounding	1,468	2,861
Medium spot mounding	1,425	2,814
High spot mounding	1,429	2,820
Low light ditch mounding	1,418	2,813
Medium light ditch mounding	1,434	2,806
High light ditch mounding	1,472	2,985
Inverting	1,204	2,428
Control	1,367	2,639
Control + herbicide	1,224	2,417

Figure 7. Base diameter growth of spruce seedlings in 2010 and 2012.

3.2 Vegetation competition

3.2.1 Amount of broadleaves around seedlings

The number of broadleaf stems has been counted one meter around the seedlings in 2012, to estimate the impact of soil preparation methods on their amount (Figure 8).

Light ditch mounding is indubitably the most successful in this domain. Slightly more than one stem is found generally in the immediate surroundings of a spruce. It is much better than spot mounding, with more than two competitive stems around a spruce, and inverting, with more than three stems around a spruce. Inverting method shows again some lower result than the control plot. Herbicide application seems to favor the installation of a dense broadleaf competition (almost five stems around a spruce).

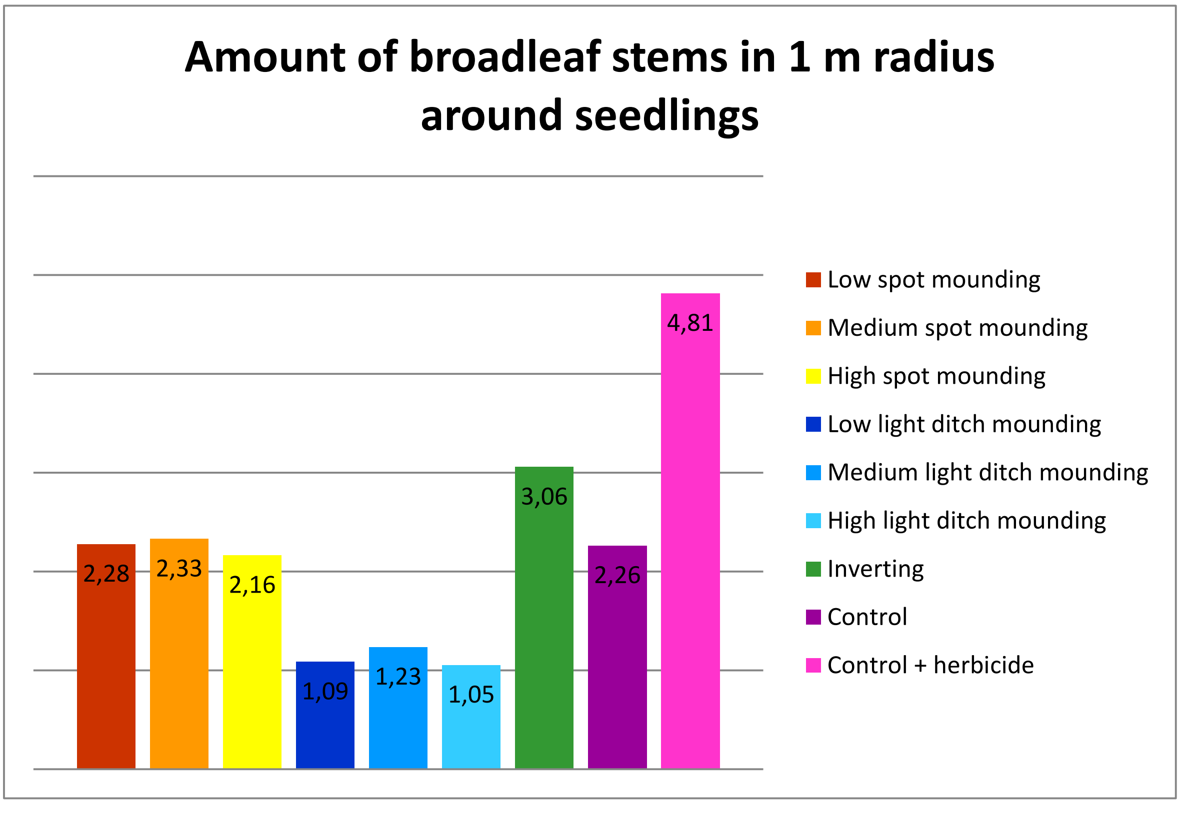


Figure 8. Amount of broadleaf stems in 1 m radius around seedlings.

3.2.2 Dominant height of competitors

In 2012, the dominant height of broadleaf stems, located within one meter around spruce seedlings, has been measured (Figure 9).

Results seem to show similar outcomes, heights from about 93 cm to 122 cm. This difference is roughly representing a growing season though and it must not be underestimated. In this matter, the light ditch mounding methods appear to be the most efficient (93 to 97 cm high only) and the spot mounding methods present the highest competition (108 to 122 cm high). Inverting is situated between them (about 104 cm high). Control seedlings outcomes, without herbicide application (about 97 cm), which are supposed to demonstrate the natural norm for comparison with soil preparation results, show that light ditch mounding does not decisively influence the height of the competition. On the contrary, the comparison between controls and spot mounds indicates a notable difference: the broadleaf stems are 10 to 25 cm higher for the spot mounding methods.

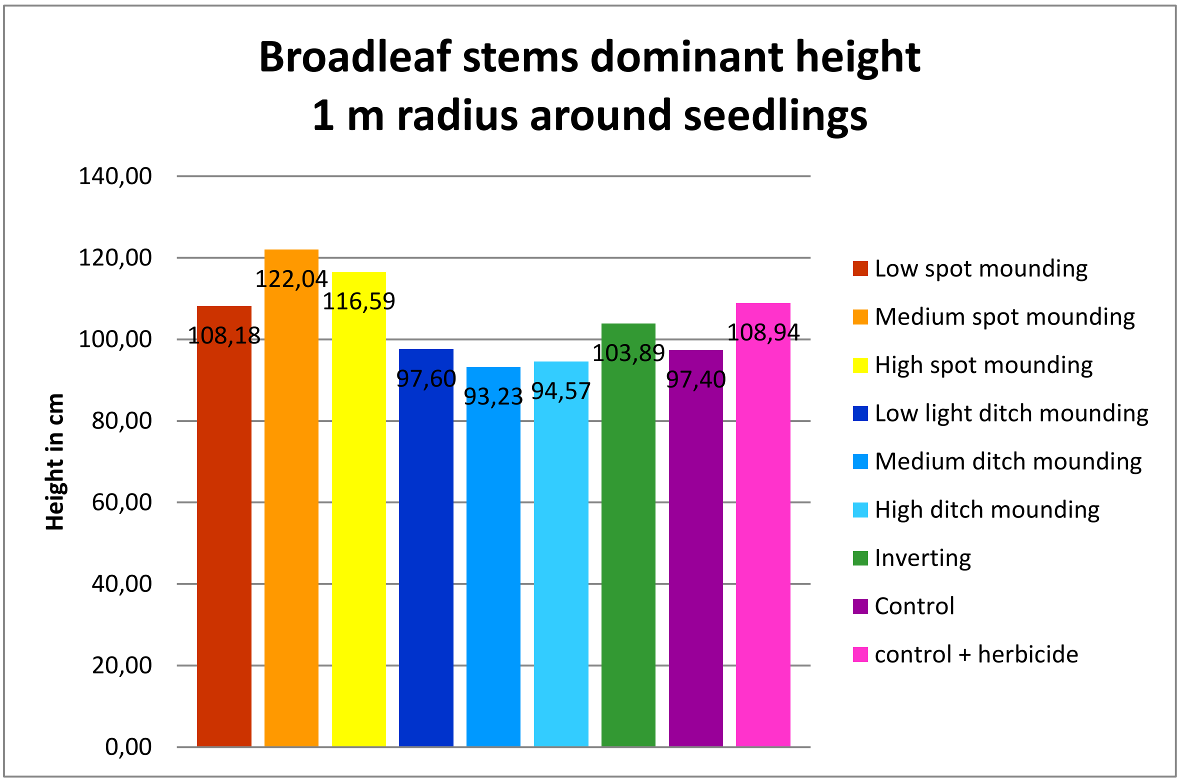


Figure 9. Broadleaf stems dominant height in 1 m radius around seedlings.

3.2.3 Dominant base diameter of competitors

The statistics following (Figure 10) show the same pattern as the previous ones, for the dominant height of broadleaves one meter around seedlings.

Base diameters are in average much lower in light ditch mounding than a spot mounding. Inverting and controls have slightly bigger dominant base diameters, but stay close to the light ditch mounding methods outcomes.

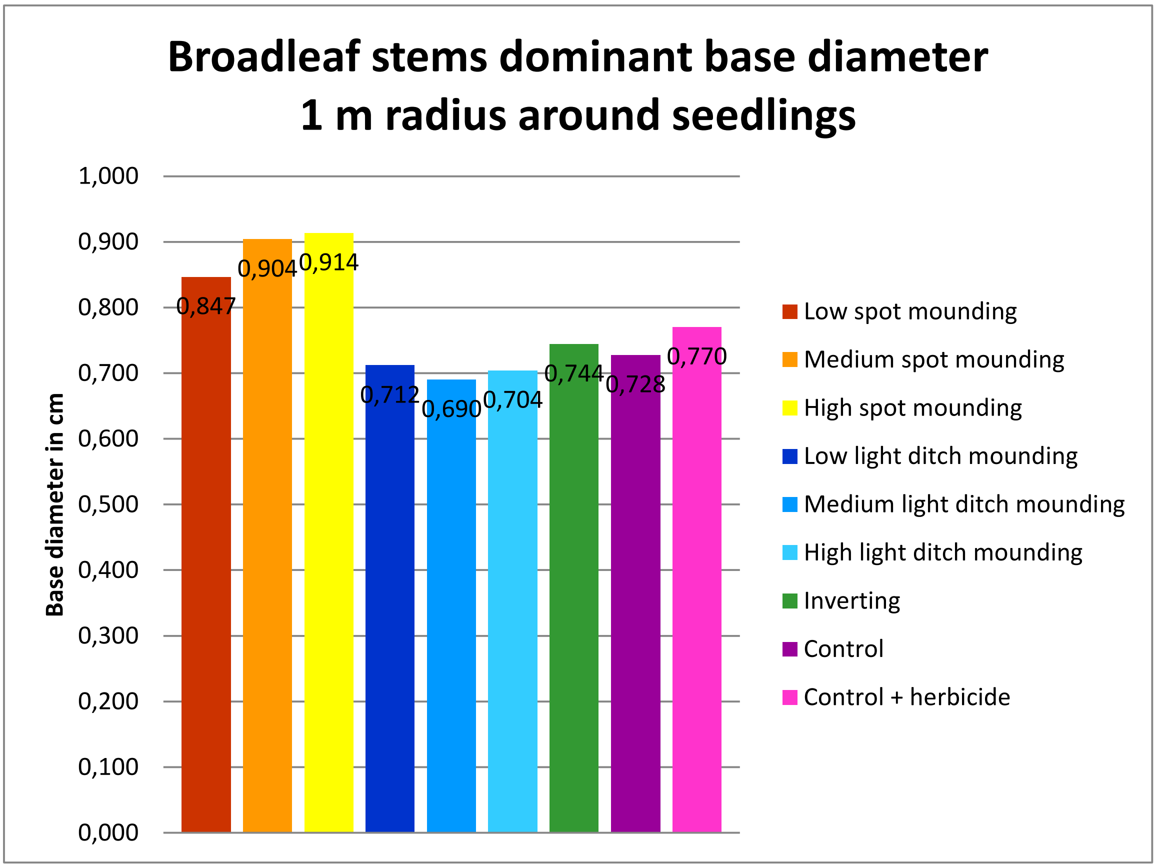


Figure 10. Broadleaf stems dominant base diameter in 1 m radius around seedlings.

3.2.4 Herbaceous stratum cover

The herbaceous cover may not be a trustworthy indicator of pine weevil damage risk (Örlander & Nilsson 1999). It has been estimated visually in 2012. An approximated percentage of the surface has been given, rounded to 5, one meter around each seedling (Figure 11).

The spot mounding methods present the lesser herbaceous cover, around 24% cover. Among the light ditch mounding, it varies from 33% for low mounds, to 36% for medium mounds, to 43% for high mounds. Controls have 47% of their surface covered by the herbaceous stratum. Herbicide application shows some light effect after years: 42%. Inverting is the grassiest, with 52%.

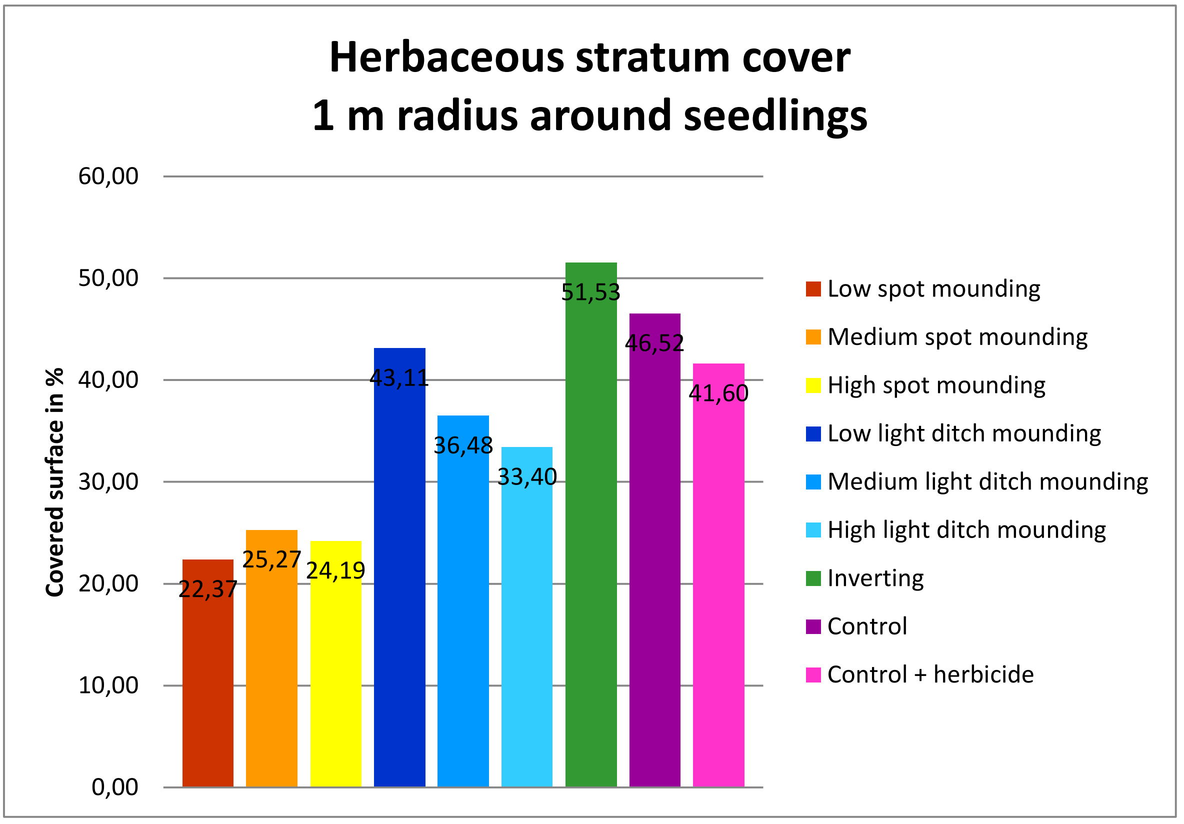


Figure 11. Herbaceous stratum cover in 1 m radius around seedlings.

3.2.5 Cleaning need

The cleaning need has been estimated according the visible pressure of the competitive vegetation to the spruce seedlings (Figure 12). Each has been classified in one of the four classes, depending of the urgence of a cleaning intervention:

- No need: No competition. A new estimation after five years is necessary to assess the pressure again.

- Cleaning in 3 to 5 years: The vegetation competition is developing, but is not prejudicial yet.

- Immediate cleaning: A silvicultural intervention has to be planned at the moment. The cleaning would be then done the same year or following year.

- Cleaning in late: The vegetation competition has started to have a negative influence on the spruce seedlings. Therefore, the cleaning operation is in late.

The vegetation competition is the weakest within the light ditch mounding method, particularly for its higher mounds. Inverting shows a mitigated urge, slightly higher than the control. On the other hand, spot mounding did not succeed to keep the competition low, in comparison.

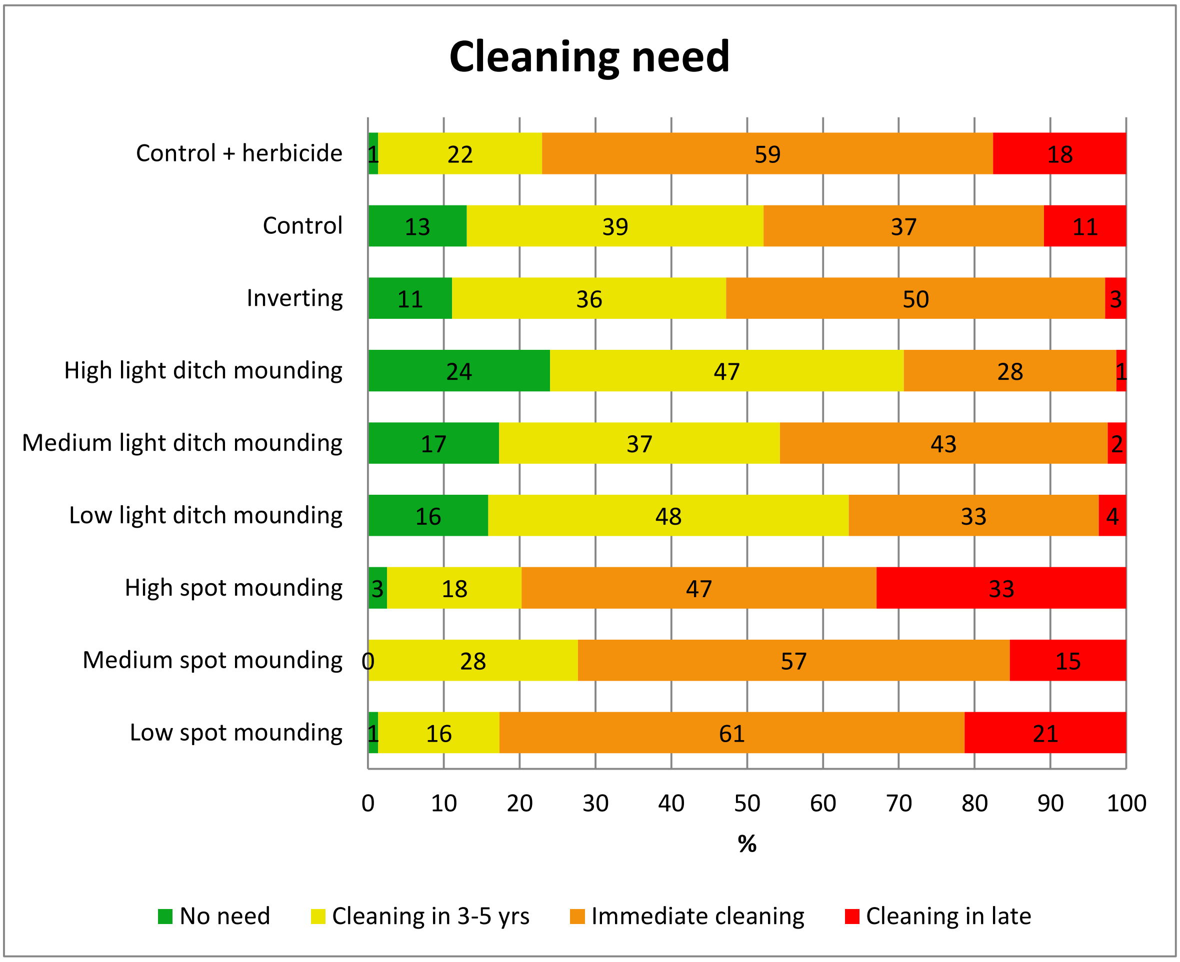


Figure 12. Cleaning need estimation from 2012.

4 Discussion

Spot and light ditch mounding methods have shown from similar to better results than controls, due to the lower moisture and therefore lower frost. Heights of seedlings vary from 0.04 to 8 cm more in average. This demonstrates a positive, but limited influence compared to the height growth of spruce seedlings on mounds in general (Saksa et al. 2005). On the other hand, the base diameters of spruce plants vary from +2 to +4 mm roughly, compared to controls. It can be partially explained by the greater height, but it also shows a better ratio height-diameter, which can be considered as a positive influence. Moreover, in their study, Petersson, Örlander and Nordlander (2005) point out that pine weevil damages are the lowest where bare mineral soil surrounds the crops, which is the case on mounding, and that could also have been a factor of better success.

The broadleaf regeneration was clearly weaker within the light ditch mounding method. Indeed, the density of broadleaves was the lowest, as well as their dimensions. Dominant heights were found to be about 95 cm, which can be compared with the 140 cm average height of spruces planted on light ditch mounds, the same year. The cleaning need estimated as low, also in 2012, indicates a link with these outcomes. Light ditch mounding appears to be the most positive method on spruce regeneration success on fine-grained soil.

Spot mounding differed notably from light ditch mounding in the competition development question. Indeed, this study shows a higher growth of broadleaf stems, similar to more than the control samples, in number, in height and in diameter. According to Uotila, Rantala and Saksa (2012), mounding on a fine-grained soil is the most performant soil preparation method to delay the early cleaning. In the present situation, where different mounding methods have been applied, it has to be noticed that the cleaning needs are rather different between spot mounding and light ditch mounding. This last one has the critical advantage to lower the water content of the soil, as it appears, and therefore to reduce the broadleaf growth and pressure to the spruce plants. Spot mounds have also been markedly less covered by herbs, which can explain the easier growth of broadleaves.

Mounding heights had somewhat an influence on seedlings growth from 2007 to 2010. Outcomes obtained by Heiskanen et al. (2013) shown a slightly better development of spruces on higher mounds, but the outcomes of seedlings growth, in height and base diameter, from 2010 to 2012, are more variable. For instance, seedlings height is slightly better on low spot mounds than on high spot mounds. Therefore, higher mounds represent a development advantage to seedlings only during the three or four first growing seasons, to resist against the early age damage risks.

Inverting method is found to be particularly inefficient, and even counterproductive for the spruce plantation establishment. This is explained by pine weevil disturbance during the early growth, by the high moisture and the low temperature, leading to frost heave on fine-grained soil (Heiskanen et al. 2013), by the quick development of the broadleaves and also by the single layer of humus the roots can have access to, contrarily to other mounding methods.

Herbicide application on the control samples has decreased the herbaceous stratum cover, but did not confer the spruce seedlings any growth advantage, all in all. Pine weevil pressure doesn’t seem to be anyhow impacted by grass control with chemical treatment, as Örlander and Nilsson (1999), as well as Heiskanen and Viiri (2005), suggested. The application of glyphosate is somewhat positive the first year, as the grass does not disturb the growth of seedlings anymore (herbs fall and flatten in autumn and seedlings are too light to resist to their weight combined with the snow). Nevertheless, the pine weevil had the most negative impact on controls, with and without herbicide application, on this study site, as demonstrated by Heiskanen et al. (2013). The poor performance of the control plots treated with herbicide, compared to untreated ones, could suggest that spruce seedlings have suffered from glyphosate too, probably through the roots (Heiskanen & Viiri 2005), since the seedlings vigor decreases during the second growing season (Heiskanen et al. 2013), though it would need a chemical analysis to prove it. Örlander and Nilsson (1999) pointed out that, the presence of humus only would be a critical element to pine weevil attraction, instead of grass cover. Moreover, the vigorous broadleaf sprouts and coppices have taken the dominance. Their establishment on control plots has been the densest and the strongest.

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