Effects of fertilization and mulch treatment on growth and establishment of three seedling types of Norway spruce (*Picea abies* (L.)Karst.)

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Swedish University of Agricultural Sciences
Master Thesis no. 138
Southern Swedish Forest Research Centre
Alnarp 2009
Master Thesis in Forest Management SLU course code EX 0506 Advanced level (E) 30 ECTS (HEC)

Abstract

The effects of fertilization and mulch treatment on growth and establishment of three seedling types of Norway spruce [*Picea abies* (L.) Karst.] were examined in a study in southern Sweden. Three types of seedlings were used in the experiment: 2 years old hybrid seedlings (P+1, which means that during the first year the seedling is grown in a container and the second year grown in the field), 1,5 years old containerized seedlings and 10 weeks old mini seedlings.

The seedlings were planted under near optimal conditions or in control parcels. Fertilization treatment was applied by a drip irrigation system and plastic cover mulch was used as weed control to create near optimal conditions. Growth and vitality of seedlings were compared between optimized and control parcels. Growth parameters were measured after one and two growing seasons.

All seedling types were significantly affected by fertilization and mulch. Height and top increment was greater in fertilized plots compared to the control. Amount of biomass differed significantly between treatments after the second growing season. Nutrient content differed between treatments only after the first growing season.

Key words:

Norway spruce, fertilization, mulch, hybrid seedling, containerized seedling, mini seedling

1. Introduction

1.1 Background

Norway spruce (*Picea abies* (L.) Karst.) is one of the most important tree species in case of wood production, not only in Swedish forestry but also in other countries around the Baltic sea. The natural range of Norway spruce includes the northern hemisphere (Fig. 1). The western border of occurrence goes through south-eastern France (5°27' E, 44°51' N 1450 meters altitude) and the eastern limit is situated near southern Ural mountains around 55° S. The most northern stand is situated in Norway (30°04' E, 69°27' N, 40 meters altitude) and the most southern one in Greece (41°27' N, 24°16' E, 40 meters altitude) (Schmidt-Voght 1978).

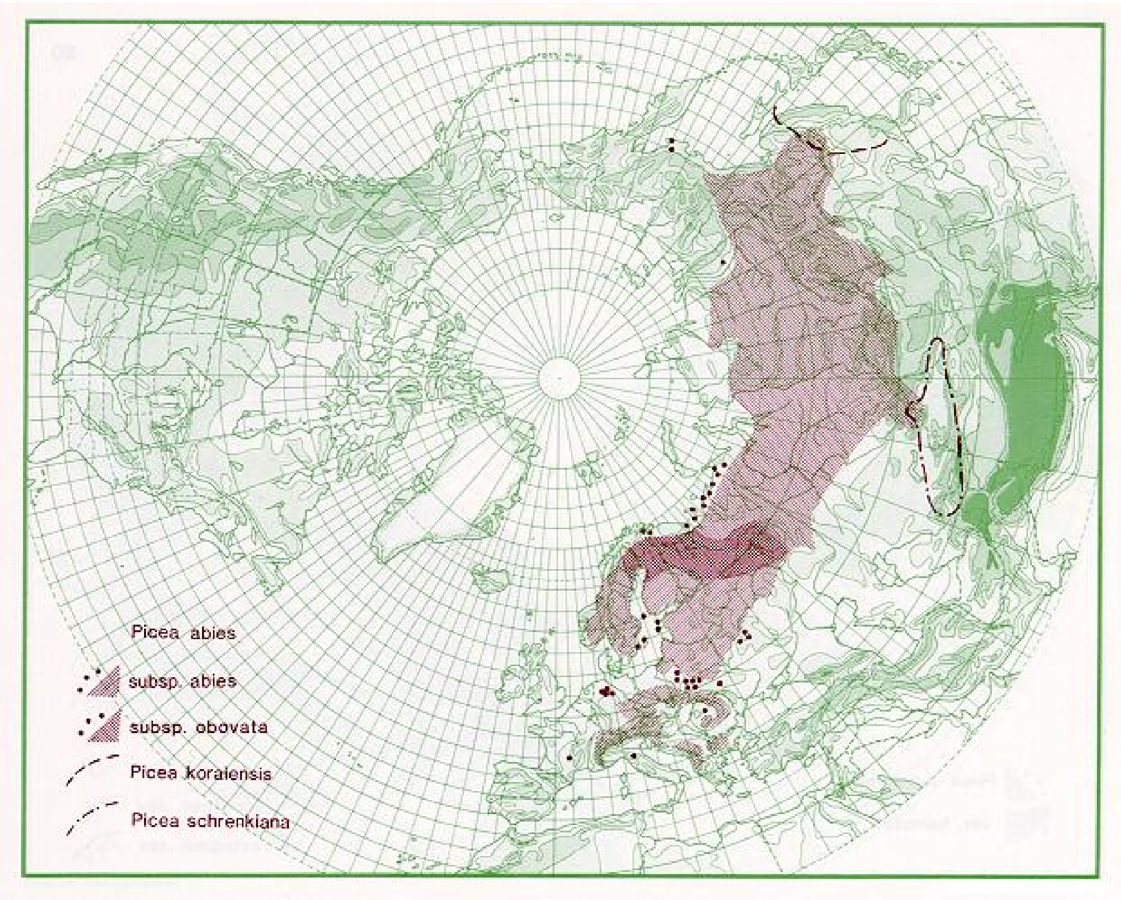

Fig. 1. Natural range of Norway spruce.

1.2 Ecological characteristics of Norway spruce

Ecological demands of Norway spruce are widely described. It requires high humidity and moist soils (Feliksik 1972). It can grow under shelter but reacts rapidly to an opening of the canopy. In case of light demands, Norway spruce has similar preferences as Hornbeam (*Carpinus betulus*), Douglas fir (*Pseudotsuga menziezi*), Little-leaf lime (*Tilia cordata*), but higher requirements than Fir (*Abies alba*), Beech (*Fagus silvatica*) and lower than Pedunculate oak (*Quercus petrea*), Sesile oak (*Quercus robur*), Sycamore maple (*Acer pseudoplatanus*), Swiss stone pine (*Pinus cembra*) and many other much more light demanding species (Puchalski and Prusinkiewicz 1990).

Rubner (1960) claims that Norway spruce can survive a vegetation period of 60 days with a temperature higher than 10° C in the north. Jurkevic and Perfonof (1967) say that in the southern regions the maximal vegetation period with a temperature over 10° C lasts 155 days.

In case of water, the demand of Norway spruce is similar to that of beech and fir, which are all among average demanding species. According to Schmidt-Voght (1978), one hectare of a Norway spruce forest transpires 19 tones of water per hectare during 24 hours on a dry site and 34 tones per hectare on a humid one. It is worth to notice according to this research that transpiration of coniferous trees is 300-400 times higher in summer time than in winter (Ivanoff 1924).

In case of soil preferences, Norway spruce is situated between middle demanding species. According to Obmiński (1977) Norway spruce grows in soils with a pH around 3,4 - 6,7, but the optimum is 5,4 - 6,0, which means that it is more demanding than Scots pine, Black alder or Birch but less demanding than Fir, Larch and much less demanding than Hornbeam or Oak (Puchalski and Prusinkiewicz 1990). The significant nutrient problem for Norway spruce is insufficient amount of nitrogen because of time demanding litter decomposition. According to Schmidt-Voght (1978), Norway spruce usually finds enough calcium, potassium and phosphorus. Since it does not need so much calcium there is always enough of this nutrient. Sometimes, especially on swamps or sands, there is not always enough potassium and phosphorus.

During the vegetation period even a small decrease of temperature to below 0° C can cause serious damages to fresh needles and shoots of spruce seedlings (Christersson 1985, Christersson and Fircks 1990). They found that under -3° C, half of the measured seedlings were seriously injured and at -4° C, all of them were damaged.

In southern Sweden the risk of low temperatures is much lower in the coastal areas than in the interior parts (Perttu 1981, Nilsson 1990). In the interior areas temperatures below zero occur frequently in spring and early summer, i.e. during periods when current-year shoots of Norway spruce are sensitive to freezing. The flushing of Norway spruce usually starts in mid or late May in southern Sweden, but there are large differences between individuals and provenances (Dormling 1982, Hannerz 1994b, Hannerz 1999). During the first period after bud burst, the shoots become more sensitive to low temperatures, and shoots 1-5 cm long seem to be most sensitive in both Norway spruce (Dormling 1982, Hannerz 1994a) and Black spruce (Bigras and Hebert 1996). Once the shoots have passed through this period of most intensive growth, frost hardiness improves (Repo 1992, Hannerz 1994a), but they do not become fully hardened until late autumn.

When producing Norway spruce seedlings it is necessary to balance the quality of the plants, their future strength and growth potential and costs. Not only height but also diameter is interesting from silvicultural point of view. Thicker seedling means lower risk of damages caused by pine weevil (*Hylobius abietis* (L.)).

The growth potential of seedlings is very much dependent on site conditions. In general, Norway spruce is planted on medium fertile soils. Poor growth of seedlings maybe caused by reduced amount of nutrients on the open clear cuts, especially nitrogen, which is moving with water to the deeper soil layers. Establishment of seedlings on fertile sites may be difficult since such sites contain dense field vegetation. The field vegetation competes with the seedlings for resources such as water, light and nutrients (Imo and Timmer 1999, Malik and Timmer 1996, Nambiar and Sands 1993). Field vegetation control with herbicides and soil scarification has been proved to increase initial growth and decrease damage of newly planted seedlings (Grossnickle and Heikurinen 1989, Imo and Timmer 1999, Örlander et. al. 1990). Soil inversion is a fairly new soil preparation method, which has been tested with good results due to the combination of bare mineral soil and retention of the humus layer (Örlander et al.1998). Compared with pure mineral soil, humus has shown to have a positive effect on seedling growth (Hallsby 1995).

Macronutrients play an important role in seedling growth. The most important is nitrogen (N). It is essential in the cell structure, as well as taking part in every physiological process inside living plants. Potassium (K) - although not being a component of plant structure – is the most important cation in plant physiology. Phosphorus (P) is important in germination as well as top increment.

In southern Sweden the most common seedling types used in regenerations, are large 3-year old bare root seedlings or large containerized seedlings. They seem to be less affected by competing vegetation, are more resistant to pine weevil damages and need less time to establish. But smaller seedling types can establish as good as the big ones when site preparation improves the soil characteristics, reduce competition from surrounding grass and damage by pine weevil. Moreover, small seedlings are less expensive to grow and plant and have a less disturbed root system in comparison with larger seedling types (Lindström 2003). Therefore, they may be financially attractive as a regeneration option for forest owners and companies if planting spots could be prepared in a way that provides successful establishment of small seedlings.

1.3 Aims

In this study, the aim was to investigate effects on establishment and growth of different seedling types of Norway spruce under near optimal conditions. The hypotheses are that: 1) growth and vitality of planted seedlings will be increased in fertilized plots compared with not fertilized ones, 2) growth will differ between seedling types and 3) allocation of seedling biomass will differ between seedling types and treatments. Moreover, I will try to find out why the initial growth of seedlings is so poor, how to reduce the competing vegetation, which seedling type is the most appropriate and how to reduce damages caused by frost and Pine weevil.

2.Materials and methods

2.1 Study design

The study site was located in southern Sweden at Asa Experimental Forest, about 40 kilometres north from Växjö (57°08'N, 14°47'E). Soil inversion was applied on the whole experimental site. The experiment was then divided into four blocks (Fig. 2). Each block was divided into five subplots, of which half of the plot was irrigated, mulched and fertilized (optimized treatment). The other half was without treatments (i.e. control). Fertilization was applied by using a drip irrigation system (Waterboys) and the fertilization used was Wallco (brand name) with a nutrient content of N-P-K 51-10-43 plus micronutrients. The dosage was 1 ml/l water. Plastic cover mulch (Mypex) was used as weed control.

Three different seedling types were planted in spring 2006 in each subplot:

1) 2 years old hybrid seedlings (P+1)
2) 1,5 years old containerized seedlings,
3) 10 weeks old mini seedlings

A total of 600 seedlings were planted, 100 seedlings per treatment combination. All seedlings were of the same Swedish origin (Maglehem).

Design of the experiment:

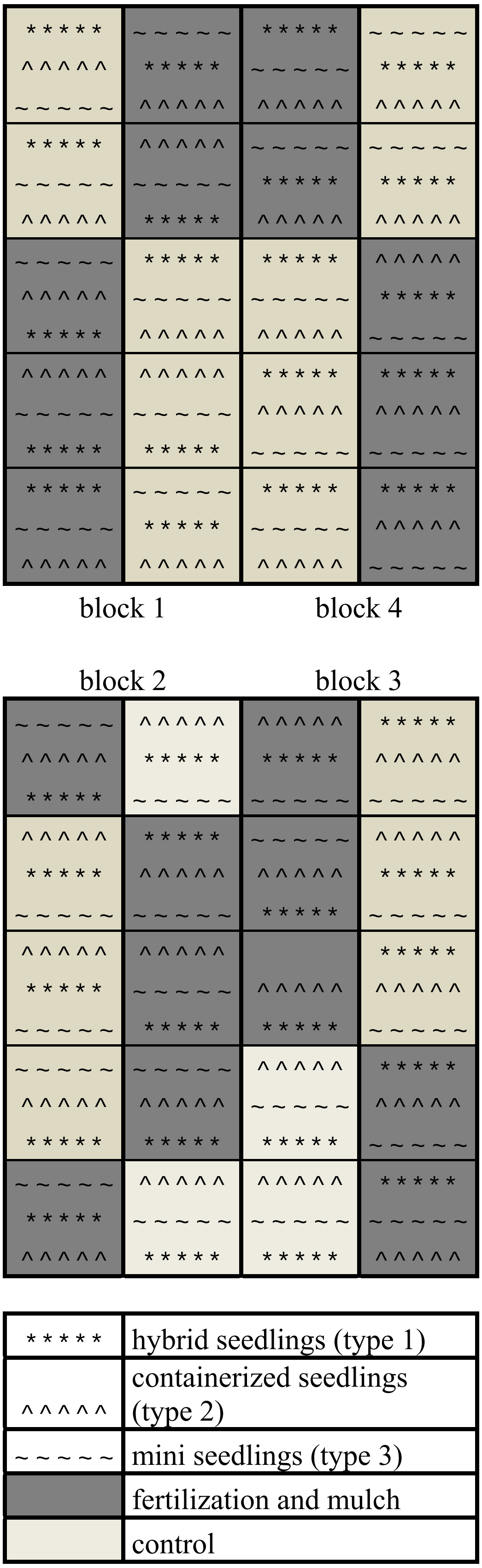

Fig.2. Experimental design

2.2 Site characteristics

Temperature on the study site was measured both in the air and in the soil. In the soil, four thermistors per treatment were used. Soil moisture was measured using gypsum blocks. Measurements were taken from 15 of June of 2006 until the 28 of September of 2006 with a frequency of 30 minutes.

2.3 Seedling growth

Height and root collar diameter was measured at planting. After the first and the second growing season (fall 2006 and fall 2007) height, length of current leader and root collar diameter were measured on all seedlings. If there were any damages they were written down. A number of 48 sample seedlings were harvested in fall 2006 and the same number in fall 2007.

The harvested seedlings were transported to the lab and cleaned. The roots were carefully rinsed with water to remove soil. Height and diameter of the stem of each seedling was measured. After that, stem and root system of each seedling was put in separate paper bags and hereafter put into a dryer. The seedlings were dried at 70° C until they remained at constant weight. Dry weight of the root systems, stems and needles was checked. The laboratory scale used in these procedures had an accuracy of 0,001 grams. Hereafter, research material from each seedling was prepared for nutrient content analyses. Needles from each seedling were minced to powder using a mincing machine and put to plastic capsules. Nutrient samples were pooled (treatment x seedling samples) and sent to a lab for analyses.

2.4 Statistical analyses

Statistical analyses were done using Statistica software and Microsoft Excel 2003. Mean values, standard errors and standard deviations for the growth parameters were calculated. Analysis of variance was performed using General Linear Model. For height, growth and diameter, mean values within the blocks were calculated. For biomass allocation there were $n=8$ samples per treatment combination (48 seedlings harvested after first growing season and the same number after second one). Where significant treatment differences were indicated by the ANOVA, means were separated by overall pairwise comparisons using Tukey's test. For all tests, an α-value of 0,05 was used to show significance.

3. Results

3.1 Soil temperature and soil moisture measurements

On the study site air temperature (data not shown) and soil temperature was measured during the vegetation period in fertilized and unfertilized subplots (Fig. 3). Temperature of soil seemed to be lower in the fertilized treatment in the beginning of the growing season. During this period early frosts were not noticed.

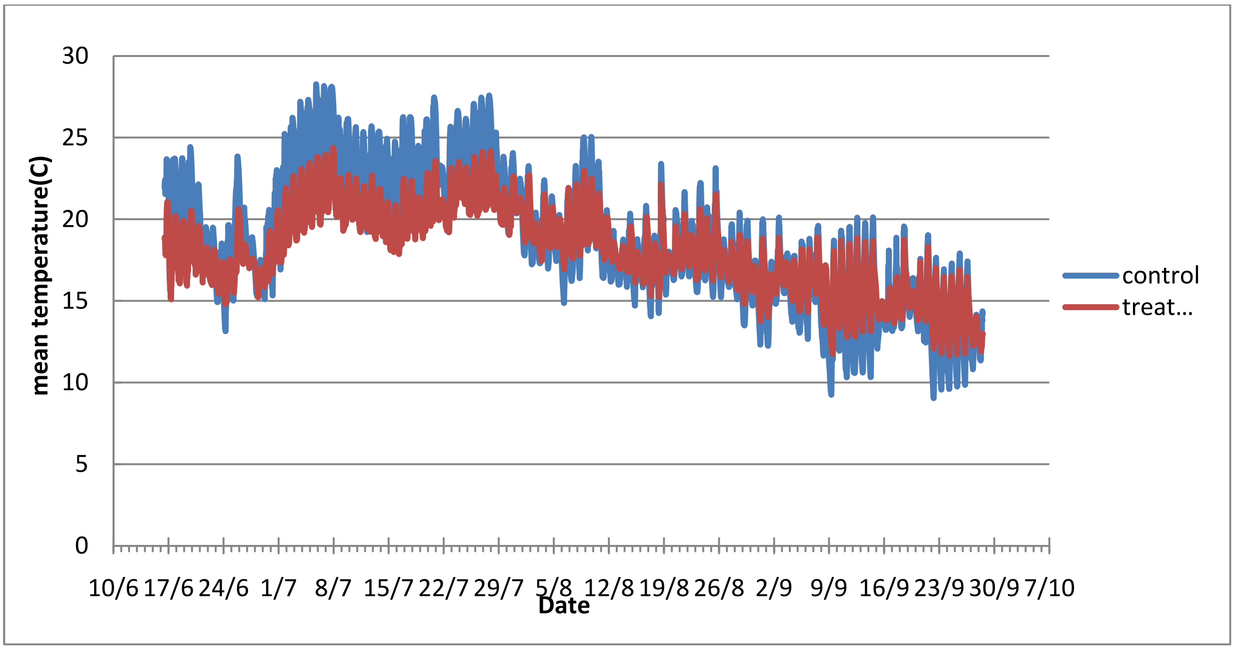

Fig. 3 Soil temperature fluctuation during vegetation period 2006

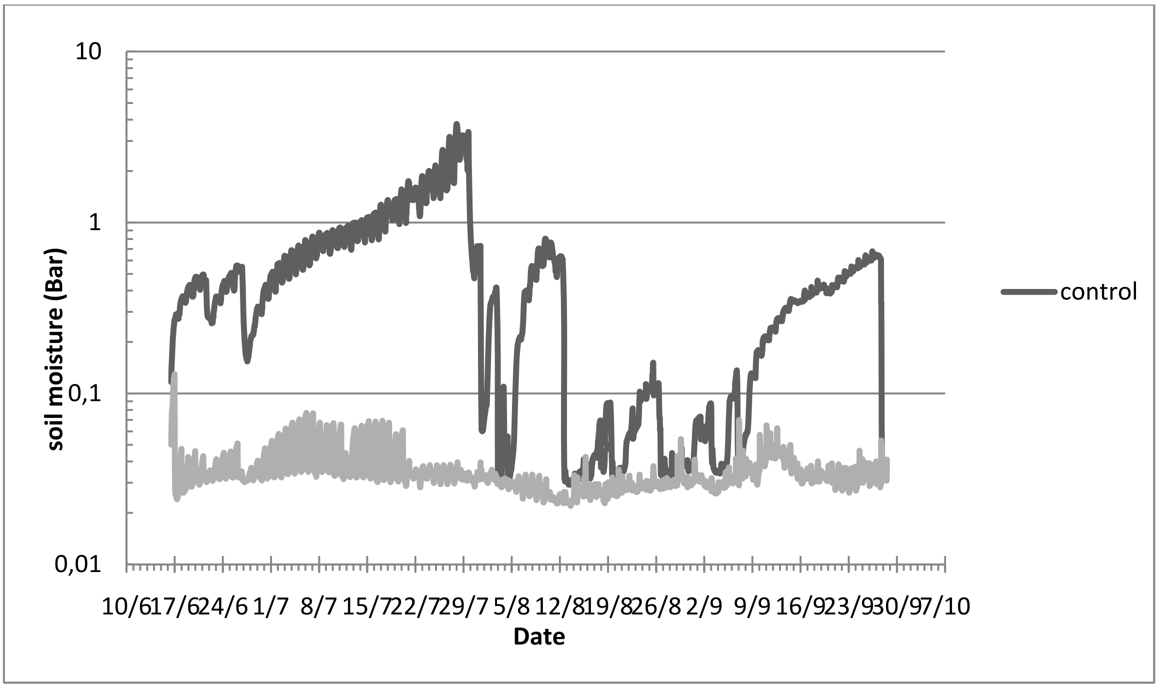

Fig. 4 Soil moisture during vegetation period 2006

. The soil moisture in control plots, which were not covered with mulch, was lower (Fig. 4). Not only low soil temperature but also low soil moisture may reduce the growth of new roots. As a consequence it can disturb the water balance of the seedling, which is very important for survival after planting in the forest.

3.2 Seedling growth and mortality

Mortality

The survival of seedlings was very high. Only one hybrid seedling died from all 200 which were planted, which means a survival rate of 99,5 %. Among containerized seedlings 3 died. One was from the edge of control subplot and two from the treatment subplot, which results in a survival rate of 98,5 %. The highest mortality was found among mini seedlings. In total 25 seedlings died, which means that 87,5% survived. In control subplot 6 seedlings died. In treatment subplot 19 seedlings died.

Height

In case of differences in height and growth, differences between fertilization with mulch treatment (optimization) and control were statistically significant for all seedling types (Table 1). Fertilized ones were bigger, thicker and more vital.

Table 1 Summary of results of Anova of treatment effects on seedlings

Parameter	Effect		
	Fertilization	Seedling	Fertilization x Seedling
height fall 06	**<0,001**	**<0,001**	**0,044**
height fall 07	**<0,001**	**<0,001**	**0,014**
height increment	**<0,001**	**<0,001**	**0,006**
diameter fall 06	**<0,001**	**<0,001**	**0,002**
diameter fall 07	**<0,001**	**<0,001**	**0,004**
diameter increment	**<0,001**	**<0,001**	**0,016**
top height fall 06	**<0,001**	**<0,001**	**0,002**
top height fall 07	**<0,001**	**<0,001**	**0,007**
top increment	**<0,001**	**<0,001**	0,121

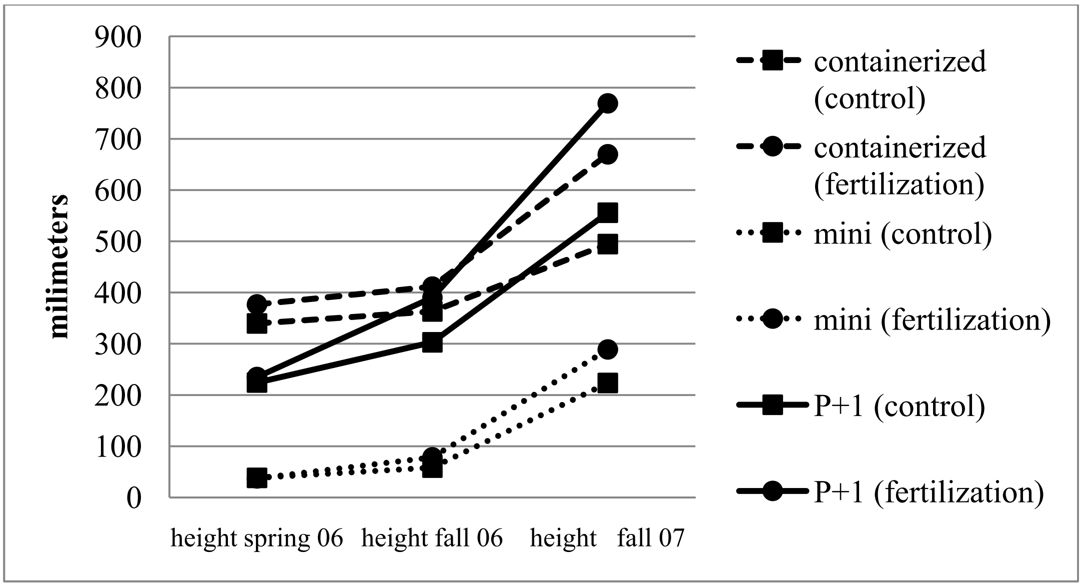

Fig.5 Height growth.

Height increment was strongly affected by treatment (Fig. 5). Growth of hybrid seedlings and containerized seedlings differed more between treatments than mini seedlings. The biggest difference in height growth the first growing season was between fertilized and controlled hybrid seedlings (Fig. 5). The other two seedling types were less affected by the treatment.

After the second growing season, the difference in height between treated and controlled hybrid and containerized seedlings were similar. Height of mini seedlings did not differ much between treatments.

Diameter

The differences in diameter were significant between treatments for every seedling type (Fig. 6). Diameter growth is important since the thicker the seedling, the bigger possibility to reduce damages caused by pine weevil (*Hylobius abietis* (L.))

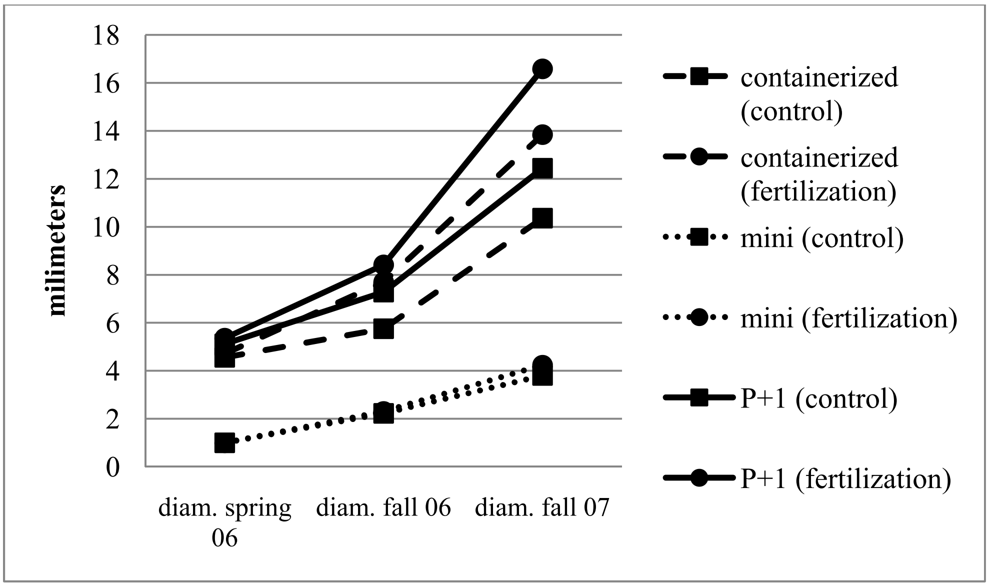

Fig. 6. Diameter growth.

3.3 Biomass growth and allocation

Table 2. Summary of results of Anova of treatment effects on seedling biomass

Parameter	Effect		
	Fertilization	Seedling type	Fertilization X Seedling type
weight of roots 06	0,177	**<0,001**	0,576
weight of roots 07	**<0,001**	**<0,001**	**0,015**
weight of stems 06	0,051	**<0,001**	0,248
weight of stems 07	**<0,001**	**<0,001**	**0,019**
weight of needles 06	0,161	**<0,001**	0,542
weight of needles 07	**<0,001**	**<0,001**	**0,022**

The influence of the fertilization and mulch treatment on weight of roots, weight of stems and weight of needles was not significant after the first growing season. This influence appeared after second growing season (Table 2) and was statistically significant.

Biomass growth differed between seedling types and treatments (Table 3):

Table 3. Biomass of all seedlings

Treatment	2006 fertilization and mulch	2006 control	2007 fertilization and mulch	2007 Control
weight of roots	4,59 a	3,80 a	30,44 a	11,79 b
weight of stems	5,25 a	3,86 a	37,83 a	16,65 b
weight of needles	4,69 a	3,75 a	27,24 a	13,33 b

Root growth

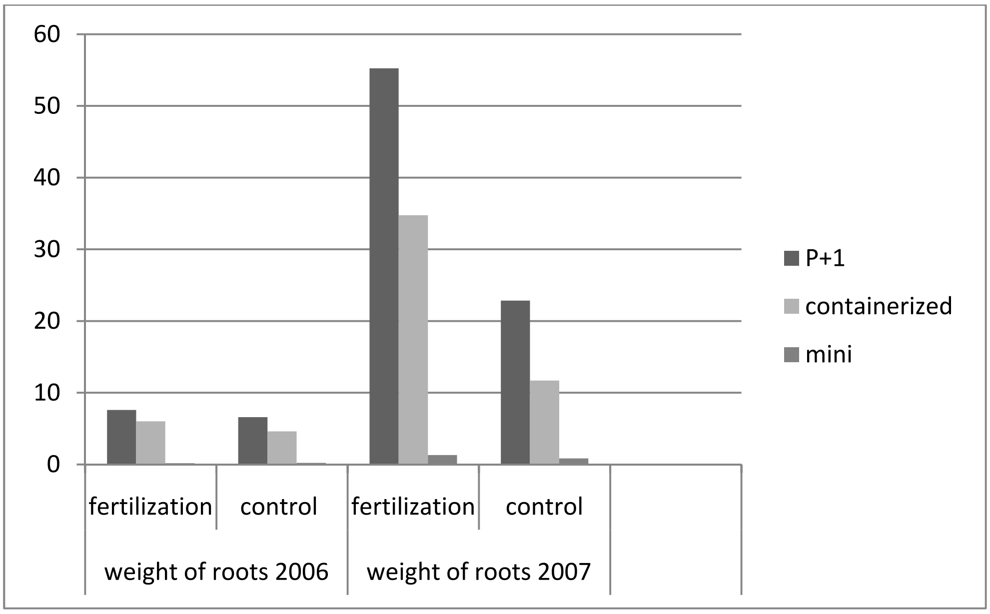

Fig. 7 Weight of roots 2006 and 2007 in grams.

Weight of roots was positively affected by the fertilized treatment (Fig. 7). It means that fertilized seedlings had greater root systems which helped them to establish and grow faster.

Stem growth

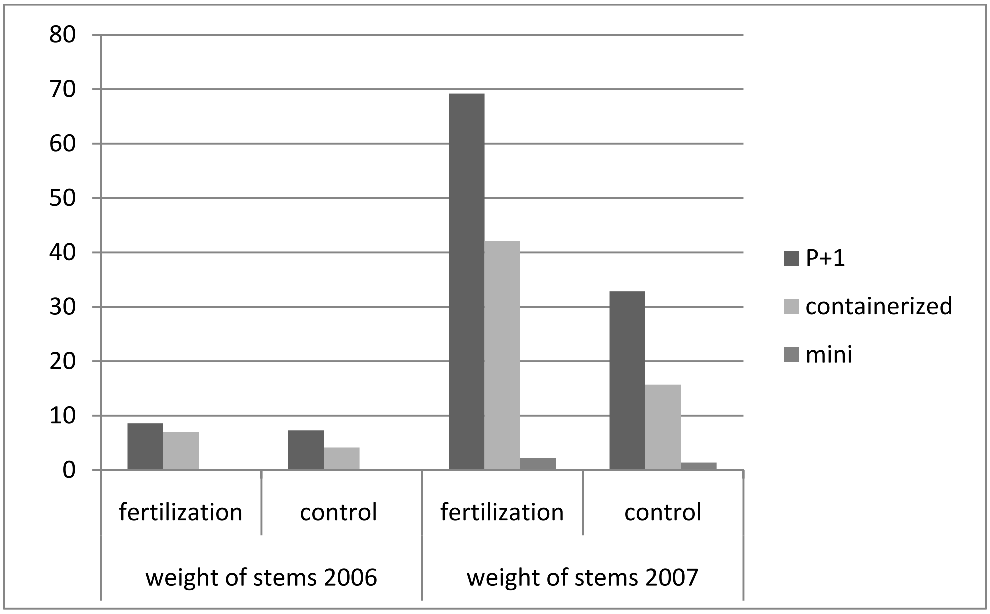

Fig. 8 Weights of stems 2006 and 2007 in grams.

For stem biomass, bigger relative differences were found between treated and controlled containerized seedlings than treated and controlled hybrid seedlings in 2006 (Fig. 8). In case of mini seedlings this difference was nearly noticed.

After the second growing season differences were similar to those between roots (Fig. 7). The biggest difference was found between treatment and control for the hybrid seedling type (more than two times). Also, containerized seedlings differed in stem weight between treated and untreated ones.

Needles:

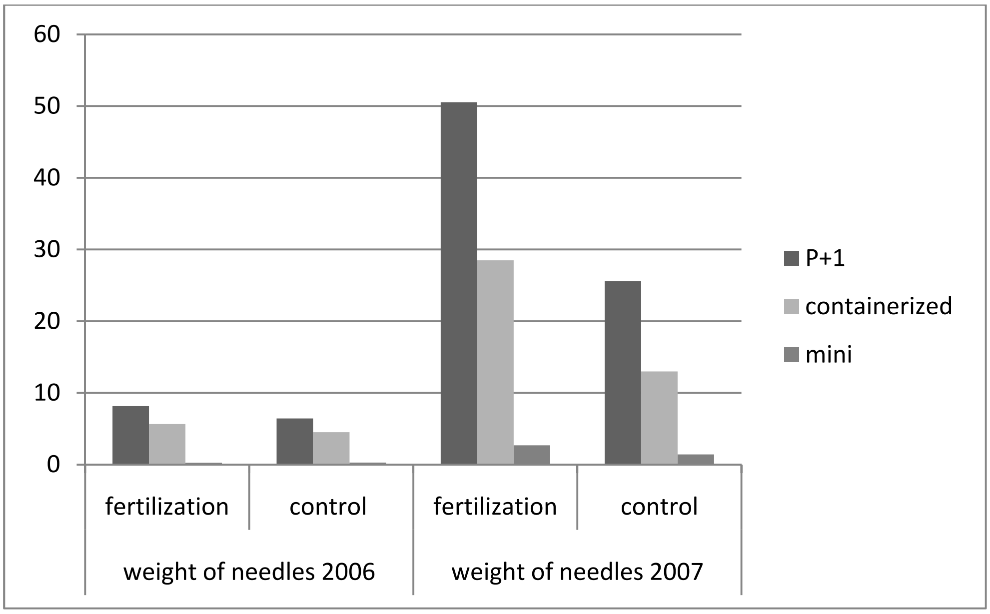

Fig. 9 Weight of needles 2006 in grams.

In case of needles the trend is similar to roots and stems (Fig. 9). Growth was greater in fertilized plots with containerized and hybrid seedlings than in the control. Similar to the roots, in case of mini seedlings (Table 4), differences appeared when comparing growth of needle biomass after the second growing season.

Table 4. Weight of the mini seedlings in grams.

	2006		2007	
	fertilization	control	fertilization	control
weight of needles	0,2575	0,29	2,68875	1,41625
weight of stems	0,14625	0,12125	2,235	1,3925
weight of roots	0,17625	0,20875	1,3025	0,8425

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Differences in allocation i.e. weight of roots, stems and needles as percentage of the whole seedling, were not convincing. Proportion between biomass allocated in different parts of the seedling was preserved and nearly the same for all three seedling types (Fig. 10 - 11).

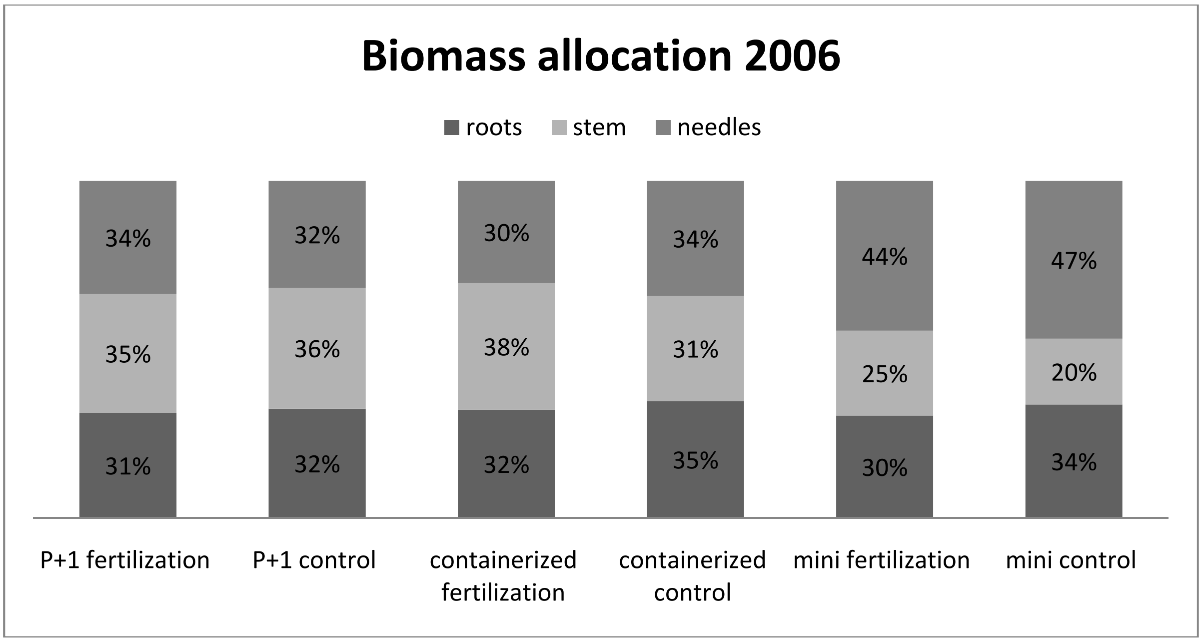

Fig. 10 Biomass allocation in roots, stems and needles of seedlings in 2006.

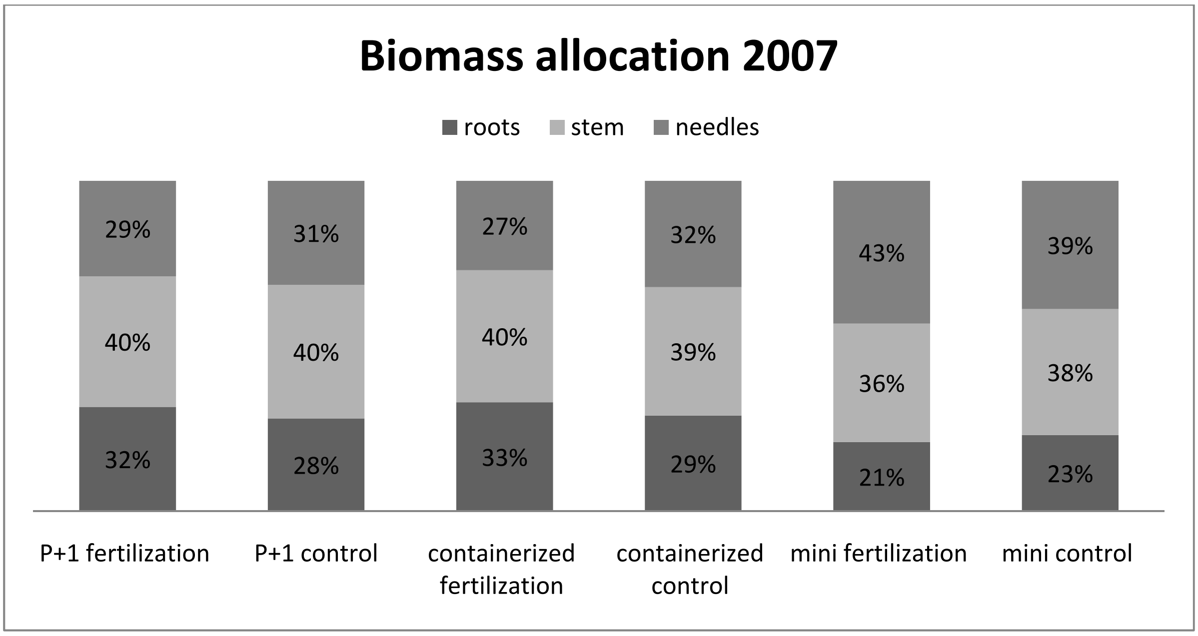

Fig. 11 Biomass allocation in roots, stems and needles of seedlings in 2007.

3.3 Nutrient content

Seedling nutrient contents are presented in tables 5 and 6. Macronutrient contents are presented in % of seedling dry weight and micronutrients in mg/kg seedling dry weight, except for sulfur, which is in % of seedling dry weight. Fertilized seedling types are named in fertilization column: 1 (treated) and 0 (control) First harvest was carried out in autumn 2006 and second harvest in autumn 2007.

Table 5. Nutrient content in three seedling types in relation to fertilization treatment (1st harvest)

Fertilization	seedling type	N	P	K	Ca	Mg	Na	Ma	Cu	Z	B	F	Al	S
1	hybrid	2,6	0,26	0,71	0,8	0,09	0,015	670	8,6	50	10	260	290	0,15
0	hybrid	2,2	0,24	0,69	1	0,08	0,02	780	16	54	2	780	840	0,14
1	containerized	2,7	0,25	0,82	0,89	0,12	0,015	540	7,9	61	18	180	140	0,16
0	containerized	1,9	0,21	0,72	0,69	0,08	0,015	350	7,1	34	6,7	280	290	0,12
1	mini	2,6	0,31	1	0,76	0,14	0,02	1000	10	73	14	340	380	0,15
0	mini	2,1	0,25	0,68	0,76	0,13	0,015	1500	21	84	14	1500	1600	0,13

Table 6. Nutrient content in three seedling types in relation to fertilization treatment (2nd harvest)

Fertilization	seedling type	N	P	K	Ca	Mg	Na	Ma	Cu	Z	B	F	Al	S
0	hybrid	2,2	0,31	0,78	0,87	0,07	0,015	670	6,8	100	4,1	170	230	0,13
1	hybrid	2,3	0,24	0,76	0,71	0,08	0,015	790	5,7	59	3,1	79	120	0,13
0	containerized	2,2	0,27	0,78	0,93	0,08	0,015	580	6,6	110	6,1	130	190	0,13
1	containerized	2,3	0,25	0,83	0,74	0,08	0,015	860	5,8	56	6,1	84	120	0,13
0	mini	1,9	0,31	0,77	0,71	0,1	0,015	930	12	130	4,9	370	440	0,12
1	mini	2,1	0,25	1	0,53	0,07	0,015	850	8,9	74	3,4	240	270	0,12

Differences in nutrient content among hybrid seedlings between treated and controlled samples in 2006 were significant only for nitrogen content.

Other nutrients did not differ that much, sometimes even not fertilized seedlings had bigger concentration of certain element than fertilized ones. The similar situation appeared among containerized seedlings. Differences in nutrient content of mini seedlings between treated and controlled samples in 2006 were significant in case of nitrogen content. However, the difference was less significant than in the case of hybrid and containerized seedlings. Nutrient content for mini seedlings after the second growing season did not differ significantly between fertilized and control samples.

4. Discussion

4.1 Height growth

Fertilization and mulch cover, the optimization treatment, affected seedling growth positively, which supports the hypothesis that growth and vitality of planted seedlings can be increased in fertilized plots compared with not fertilized ones. Especially hybrid and containerized seedling reacted in a similar way and were positively affected by the optimal treatment. Similar results were shown by Nilsson and Örlander (2003). They claim that nutrient availability seemed to be a limiting factor for seedling growth since seedling growth was positively affected by fertilization when it was combined with herbicides. In this experiment, the role of herbicide was taken by cover mulch and gave similar results.

Also, in this experiment growth was different for different seedling types, which supports the hypothesis that growth differs between seedling types. Mini seedlings seemed to be less affected by the treatments. The reason for that could be that hybrid and containerized seedlings were under lower stress at planting than mini ones. After the first growing season differences in height between the same type of seedling, comparing fertilizing with mulch to control, were less significant (hybrid and containerized seedling) than after the second season. The same situation was shown for top shoot length (data not shown), except for the mini seedlings, which did not have any first year shoot growth. The mini seedlings set bud after planting and some of them were covered by the mulch, which reduced growth further. The situation changed after the second growing season. The difference in height between treated and controlled seedlings was bigger, the difference in top length was also bigger with fertilization and mulch treatment. The top shoot increment appeared also on mini seedlings but the difference was not significant enough to say that they were affected by treatment. A first year of poor growth for Norway spruce seedlings seems to be common in boreal forests (Löf 2000), but the second year and the third year, the increment appears significantly (Örlander et al.1996).

The growth of some seedlings, located on the edge of subplot, could be reduced by surrounding vegetation, which due to bigger efficiency in capturing nutrients, was growing more aggressive. The seedlings from the edge were also put at risk of whipping by surrounding vegetation (not controlled with the mulch), which may have reduced growth. The fact that mulch reduces the amount of competing vegetation and therefore has a positive effect on seedling growth, has been observed before (Clemens and Starr 1985, Johansson at al. 2005). The importance of mulch could also play a role in preventing surface evaporation (Koshi and Stephenson 1962, Bulmer 2000, Johansson et al. 2005), and conserve soil water. Not without importance is also soil inversion, which increases growth of planted seedlings (Brand 1990, Allen and Wentworth 1993, Johansson et al. 2005), but in this experiment whole study site was prepared in this way so this can not be taken into consideration. Another explanation to poor growth without mulch and other types of vegetation control could be that seedlings had difficulties in competing for resources, because of low root growth caused by great amount of competing vegetation (Nordborg and Nilsson, 2003).

4.2 Diameter growth

Diameter growth showed that under optimal conditions Norway spruce is probably more resistant for damages caused by pine weevils. Bigger and thicker seedlings are usually more resistant to damages caused by those beetles, especially on fresh clear-cuts, since it is more difficult for the insect to bite in to the fresh wood and harm it.

4.3 Biomass growth and allocation

The study shows that with the fertilization treatment the biomass growth was increased in all seedling types. However, the allocation of biomass to roots, stems and needles, as percentage of the weight of whole seedling was preserved. This does not support my hypothesis that allocation of the seedlings biomass differs between seedling types and treatments. It may indicate that the seedlings were absorbing not only the correct proportion of nutrients, but also appropriate amount of it. This result is partly similar to earlier studies (Nordborg and Nilsson 2003, Johansson et al. 2007). The differences between sample seedlings around the same seedling type were more significant after the second growing season than the first one.

4.4 Nutrient content

Nutrient concentration differed between seedling types. Comparing treated and untreated samples, differences after the first growing season were much bigger than after the second one. That could be a result of bigger competition from surrounding vegetation, or small amount of samples to investigate. Maybe, which is reported by Nilsson and Örlander (2003), fertilization did not increase nutrient availability for the seedling instead the positive effects came from removing competing vegetation. Another explanation, probably more important, is that seedlings did not absorb more than they need (no luxury consumption) which may suggest correct proportion of nutrients in soil and good growth conditions.

5.Conclusions:

Poor seedling growth at the beginning may be caused by nutrient availability, which seems to be limiting factor for seedling growth. Moreover the competition from surrounding vegetation may strongly influence it as well. The solution to improve seedling growth could be soil inversion connected with fertilization which was shown in this experiment. Another thing, investigated in this experiment, was seedlings biomass.. A balanced proportion of nutrients is important, which was shown in the results. Earlier studies shows that small seedlings can establish quickly and grow better than larger seedlings when planted in favorable environment but this study does not confirm this fully.

Seedling types and practical considerations

The vitality of seedlings, planted in optimal conditions, was more than satisfying. Growth differed between seedling types. But we have to take under consideration economical calculations and technical possibilities. For forest owners and companies, the cost of establishment of new seedlings is very important. In case of Norway spruce plantations, problems such as frost damages, wind throw, browsing and damages caused by pine weevil exists., which demands from foresters to apply certain activities like scarification, feeding barriers or shelterwood cuttings to increase seedling survival.

Fertilization and mulch cover affected seedling growth positively. Especially hybrid seedlings reacted in a significant way with the best growth and vitality, good frost resistance, and less damages caused by pine weevil. But higher production and planting cost, risk of damages during planting and more difficult establishment have to be taken under consideration by forest owner. This study may indicate that investing in longer seedling production, bigger bare-root seedlings, gives bigger efficiency – survival and vitality – and allows to stint money on site preparation and problems caused by rocky and stony land, which is common in southern Sweden. But the process of planting is more labour-consuming, and knowledge demanding. There is also a threat of water stress when large bare-root seedlings are planted.

Mini seedlings reacted also positively but not as much as they might be expected to. They are cheap to produce, have good growth and good establishment, are easy to plant, and the roots of mini seedlings are less disturbed since they are being planted with the container soil. From this experiment it was possible to observe that majority of biomass, allocated in different parts of those seedlings, was in needles. It may not be without importance for future growth and increment. When planting mini seedlings site preparation is necessary to reduce competing vegetation, which can dominate them. However, in an open surface with good light conditions the risk of damages caused by pine weevils is increasing as well as the risk of frost. Investing in site preparation and competing vegetation reduction allows to plant smaller seedling, which are cheaper to produce and cheaper to plant due to using planting tools like tubes. The planting process takes less time and needs less labor. Another option might be to invest in a bigger amount of mini seedlings, since mortality was rather low, and stint the money on scarification. But more seedlings to plant means higher labour cost for planting.

Since Norway spruce is a widely cultivated tree species with big importance for timber production, there is no doubt that more research is needed to understand problems connected with establishment of newly planted seedlings.

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7. Acknowledgements

I would like to thank Ms. Karin Johansson from Southern Swedish Forest Research Center SLU in Alnarp and Skogforsk (Sweden) and Mr. Wojciech Wesoły from University of Life Sciences in Poznań – Department of Silviculture (Poland) for supervision, help and valuable comments. I would like also to thank Mr Piotr Łakomy from University of Life Sciences in Poznań – Department of Silviculture and Mr. Eric Agestam from Southern Swedish Forest Research Center SLU in Alnarp (Skåne) for evaluation. More over I would like to thank Mr. Piotr Robakowski from University of Life Sciences in Poznań – Department of Silviculture for help with data processing. I am grateful to Southern Swedish Forest Research Center SLU in Alnarp for access to laboratory facilities. The Swedish Institute participated in costs of the experiment. My dear Parents and Julia I would like to thank for mental support.

8. Streszczenie w Języku Polskim

Praca magisterska jest poświęcona badaniu wpływu nawożenia i maty anty chwastowej na wzrost i witalność sadzonek Świerka pospolitego. Nawożenie jako element produkcji sadzonek drzew leśnych jest dość szeroko dyskutowane na łamach wielu czasopism naukowych. Dużego znaczenia nabiera ono w przypadku produkcji sadzonek na szeroką skalę. Sadzonek, które mają być posadzone nierzadko w niesprzyjających warunkach. Dostarczenie w odpowiednim momencie optymalnej ilości składników odżywczych ma olbrzymie znaczenie dla jakości sadzonek, ich prawidłowego wzrostu i żywotności. To przekłada się później na zwiększenie przeżywalności sadzonek, a co za tym idzie udatności upraw oraz zmniejszenie kosztów ewentualnych poprawek i pielęgnacji. Dość powszechnym zjawiskiem jest słaby wzrost sadzonek w początkowym okresie zaraz po posadzeniu. Ma to związek ze zmiana otoczenia (tzw. szokiem) jak również niedoborem niezbędnych składników odżywczych. Innym problemem są przymrozki późne, które dziesiątkują młode sadzonki lub znacznie ograniczają ich wzrost, często uszkadzając je. Doświadczenie ma na celu sprawdzenie jak zachowują się sadzonki świerkowe poddane nawożeniu i nawadnianiu kropelkowemu oraz ochronie przed zachwaszczeniem przy pomocy specjalnej maty. Przyjęto następujące hipotezy badawcze:

1. Wzrost i witalność sadzonek będzie wyższa w optymalnych warunkach
2. Wzrost będzie się różnił w zależności od typu sadzonki
3. Alokacja biomasy zmieni się w zależności od sposobu nawożenia

Doświadczenie jest zlokalizowane w południowej Szwecji, regionie Småland, na terenie Leśnego Centrum Doświadczalnego Åsa, około 40 kilometrów na północ od Vaxjö (57° 08´ N, 14° 47´ E). Eksperyment ma układ blokowy. Powierzchnia badawcza jest podzielona na 4 bloki. Każdy z bloków jest podzielony na 5 poletek. Każde z poletek jest podzielone na 2 parcele, z których jeden jest kontrolą a na drugim zastosowano matę anty chwastową wraz z systemem nawożenia kropelkowego. W doświadczeniu zastosowano 3 typy sadzonek: (1) sadzonki dwuletnie (P+1), będące przez pierwszy rok w kontenerze a drugi w gruncie; (2) półtoraroczne sadzonki kontenerowe oraz (3) dziesięciotygodniowe mini sadzonki. Na każdym z parceli zostało posadzonych 15 sadzonek (po 5 każdego typu w 3 rzędach). W sumie 600 sadzonek tego samego pochodzenia zostało posadzonych wiosną 2006 roku na powierzchni badawczej. Po pierwszym i drugim okresie wegetacyjnym od posadzenia wszystkie sadzonki miały zmierzone: wysokość, długość pędu szczytowego oraz średnice powyżej szyi korzeniowej. Ponadto zebrano 48 próbnych sadzonek po zakończeniu pierwszego okresu wegetacyjnego i taką samą ilość po zakończeniu drugiego do analizy alokacji biomasy w igłach, łodydze i korzeniach jak również zawartości makro i mikroelementów w igłach. Sadzonki po wysuszeniu w temperaturze 70° C do stałej masy zostały zważone z dokładnością do 0,001 grama osobno igły, łodyga i korzenie. Analizy zawartości składników mineralnych dokonano na zmielonych igłach sadzonek jednak ze względu na wysoki koszt analizy jednej próbki zdecydowano się na oznaczenie średniej zawartości dla każdego typu sadzonki w zależności od tego czy była poddana nawożeniu czy nie. Analizę statystyczna przeprowadzono przy pomocy programu Statistica. Trzyczynnikowa analiza wariancji z interakcją w oparciu o model GLM (General Linear Model) została zastosowana. Następnie po analizie wariancji zastosowano test Tuckey'a. Aby ograniczyć błąd zostały wyliczone średnie dla każdego parametru w obrębie każdego bloku. Na potrzeby analizy alokacji biomasy zastosowano ten sam model w oparciu o wartości parametrów dla każdej z próbnych sadzonek. Ze względu na niewystarczającą ilość danych analiza statystyczna zawartości składników odżywczych nie mogła być przeprowadzona. Dokonano jedynie porównania średnich zawartości poszczególnych składników dla typów sadzonek w zależności od tego czy stosowano nawożenie czy nie.

W wyniku przeprowadzonych analiz udowodniono hipotezy badawcze. Dzięki nawożeniu i ograniczeniu zachwaszczenia przy pomocy maty wzrost wszystkich 3 typów sadzonek był korzystniejszy, sadzonki te miały lepszą kondycję co może mieć olbrzymie znaczenie w momencie posadzenia ich na uprawach. Najlepiej na nawożenie reagowały sadzonki dwuletnie (P+1) najgorzej mini sadzonki. Te ostanie również miały największą śmiertelność spośród wszystkich, użytych w doświadczeniu. Wpływ nawożenia na alokacje biomasy w poszczególnych partiach rośliny był widoczny dopiero po zakończeniu drugiego okresu wegetacyjnego. I tu również najlepiej reagowały sadzonki (P+1) oraz kontenerowe, a najsłabiej mini sadzonki, które były prawdopodobnie zbyt małe aby w pełni mogły być zastosowane do odnowień. Analizując zawartość składników odżywczych, szczególnie zawartość azotu, stwierdzono pozytywny wpływ nawożenia po pierwszym okresie wegetacyjnym natomiast ta różnica zanika po drugim okresie wegetacyjnym. Wpływ nawożenia został udowodniony w tym doświadczeniu. Wyniki te mogą posłużyć do rozważań na temat jaki typ sadzonki jest tym optymalnym i dającym najlepsze efekty. Nie wiadomo jednak czy sadzonki sprawdzające się w optymalnych warunkach tak samo zachowają się w praktycznym zastosowaniu. Dlatego istnieje potrzeba dalszych badań w tym zakresie dla lepszego poznania zależności sadzonek od różnych czynników i doskonalenia sposobów produkcji materiału odnowieniowego.