ESTABLISHMENT OF FOREST PLANTATIONS WITH CONTAINER TREE SEEDLINGS






Russian-Finnish cooperation

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Preface

In general, forestry plantation establishment is broadly divided into three management phases: seed collection and handling, nursery practices and plantation establishment, and young stand management. The guidebook «Fundamentals of container tree seedling production» published in 2011 was devoted to the technology used for growing tree seedlings in containers in Finland and Russia. This guidebook is continuation to that work and provides guidelines for establishment and management of forest plantations with container tree seedlings.

In order to get best profit from the use of containerized seedlings, the whole chain of reforestation operations – from seedling production to establishment and tending of young stand – must be in good shape. Small, good quality containerized seedlings require proper soil preparation, careful planting work followed by active young stand management in the first years after planting.

The guidebook was prepared by a group of experts in reforestation from Finnish Forest Research Institute, Forestry Development Centre Tapio, on the one side, and St. Petersburg Forest Technical University, St. Petersburg Forestry Research Institute, Northern Research Institute of Forestry, Forestry Institute of the RAN Karelian Research Center, on the other side.

The recommendations given in the guidebook sum up the experience of establishing forest plantations with container tree seedlings of different companies in Finland and in the North-West of Russia (the Republic of Karelia, Arkhangelsk and Leningrad regions).

Whereas the whole text of the guidebook was written jointly by the Russian and Finnish authors, some parts of it given in frames were prepared by the Finnish authors in order to introduce the practice used in Finland today.

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Establishment of forest plantations
with container tree seedlings

Contents

1. Preparation of planting stock for delivery and transportation to a forest site

Containerized seedlings grown in forest nurseries should be sorted before they are sent to the consumer, planting sites, or for storage. Small and defective seedlings are rejected. Only the seedlings of standard size are packed in laminated cardboards or plastic pallets. The planting material of forest tree species should meet the requirements specified in Appendix 1 to the Reforestation rules adopted in 2007 (Table 1).

Table 1

Requirements for planting material of forest tree species

Tree species	**Requirements for planting material**		
	Age No less than, years	**Root collar diameter** No less than, mm	**Height** No less than, cm
Middle taiga region of European Russia			
European white birch	2	2.0	20
Norway spruce	3–4	2.0	12
Scotch pine	2–3	2.0	12

According to Amendments to the Reforestation rules adopted in 2013, it is also allowed to use container tree seedlings younger than of the age specified in Table 1 if they have reached normative dimensions in height and root collar diameter.

Storage of planting material in an open area (photos T. Saksa).

Containerized seedlings, which were stored in an open area in winter, are put into laminated cardboards or transport containers after the peat in the cells has melted. Packaging is done manually or on special equipment. Typically, a cardboard box contains 200 seedlings grown in Plantek-81 containers.

Containerized seedlings, which were stored in cold storages, can be transported to the reforestation area in the packaging, usually laminated cardboards in which the seedlings had been placed for storage. If plastic boxes or container trays (cultivation trays) are used for transportation, the customer returns them to the nursery after the seedlings have been planted out.

If the seedlings are placed into laminated cardboards for winter storage in cold storage, they should undergo preventive treatment against the pine weevil *(Hylobius abietis)* in autumn before packaging. The preventive treatment of the containerized seedlings that were stored in the open air is carried out in spring before packaging.

Currently, there are two ways to protect seedlings from the pine weevil: spraying of seedlings with insecticides (synthetic pyrethrin) or application of various kinds of protective coatings (e.g., Flexcoat ®, Conniflex®) on seedling stems. In the first case, the seedlings are sprayed with suspension of the insecticide through a mobile irrigation installation, irrigation tunnel or knapsack sprayers until the seedlings get completely wet. In the second case, the stems are covered with a protective layer of wax or sand mixed with aqueous adhesive, which ensures fixing of sand on the stems. The treatment is carried out with special equipment. The last operation is drying in an oven in which the adhesive hardens.

Containerized seedlings are transported to the reforestation area not earlier than three days after they were treated with insecticides.

The transportation equipment used for delivery of planting material to the reforestation area is chosen so that it should be most suitable for each specific nursery, depending on the purpose of the planting stock, forest site conditions of the planting site and the distance from the nursery to the planting site. In every case, seedlings must be protected from wind and sun during the transportation.

For long distances (150 km or more), planting material should be transported by special container trucks, equipped with transport pallets which allow boxes with seedlings to be arranged in a few (3 to 5) tiers covered with plastic. Container trucks often have devices for loading and unloading of transport pallets. To make more efficient use of vehicles, it makes sense to use container trucks.

If road conditions make it impossible to deliver containerized seedlings directly to the reforestation area by a container truck, it is necessary to provide a place where transport pallets are transferred onto a trailer drawn by a tractor which delivers the planting material to the destination. Planting material may be delivered directly by a tractor for a distance of 15–20 km.

Quality standards for containerized seedlings in Finland

In the autumn or spring during packaging the seedlings are sorted according to quality standards:

- **Healthy:** no diseases, defects
- **Bud:** no deformities
- **Needles/leaves:** sound green
- **Size:** height and diameter in right relation to growing density and container size
- **Stem and branches:**
  straight
  no forks or multiple-leadering
  healthy bark and phloem
- **Integrity of root plug:**
  roots bind the whole plug
- **Root system:**
  no frost or disease damages
  structure: no deformations or root-bound root plugs

After winter storage, most nurseries test routinely root growth capacity of seedlings (RGC-test). In addition, the annual evaluations of seedling stock are performed regularly by authorities according to the national seedling requirements, which are harmonized with the directive of forest reproductive material described by EU.

Size recommendations for containerized seedlings in Finland

Container seedlings should be vigorous and they should have proper relation between stem height and root volume. Suggestion for mean heights of pine and spruce seedling lots grown in different densities/in different sized cells:

Size class	Cell volume, cm^3	Growing density seedlings/ m^2	Age years	Target mean height of spruce seedling lot, cm	Target mean height of pine seedling lot, cm
Mini	15-40	1200-2000	0.5	(5-12)	5-8
Small	40-80	700-1200	1-1.5	12-22	6-14
Medium	80-125	500-700	1.5-2	15-26	10-16
Large	125-200	300-500	2	20-30	14-22
Max	> 200	< 300	2-3	25-45	-

Rikala 2012

Vigorous 1- and 2-year-old pine and spruce seedlings.

2. Storage of planting stock until planting

For temporary storage, it is desirable that containerized seedlings be placed on flat ground under the canopy of trees. If the planting material was transported in closed boxes, the boxes must be opened immediately if the seedlings are already growing. If the planting material was transported straight from cold storage, boxes must be opened after the seedlings have melted. In order to ensure ventilation, holes (e.g., hand-holes) should be opened on the sides of the boxes when delivered to a storage site. If it is impossible to put the planting stock under the canopy of trees, it should be protected from the sun and wind with covering materials used in agriculture. After winter storage, seedlings must thaw out. For this purpose, they should be kept in boxes on a forest site for about a week in spring time.

Also, provision should be made for watering the planting stock. The storage life of planting material without watering depends on weather conditions, the volume of the peat substrate in the cell and the covering materials used. In hot weather and a strong wind, planting material can be stored without watering for no longer than 1-2 days. If it is cool and cloudy and the seedlings are in a dormant stage, i.e., they have not started growing, the storage period may be extended for up to two weeks without deterioration of the planting stock quality. After winter storage of seedlings in containers in the open air, it is better for them to be transported to forest sites in the same containers.

Two examples of storages on the reforestation site (photo T. Saksa).

Recommendation for maximum time span between nursery and planting

Suitable time span between nursery and planting depends on the type of winter storage and package of seedlings, on the seedling development phase (dormant or growing), and on the temperature at the moment of delivery (spring, summer, autumn).

Maximum recommended storing times for container seedlings of Norway spruce in southern Finland (for Scots pine, storing time is about half of that for Norway spruce)

Condition of seedlings/ packing	May < 10°C[1]	June 15°C	July 18°C	August 15°C	September 10°C
Cold storage/ closed packing	14-21	7-14			
Outdoor storage/ closed packing	4-7	2-4	1	1-2	2-3
Outdoor storage/ closed packing	7-14	4-6	2-3	3-4	4-6

Blue numbers: dormant material
Green numbers: growing seedlings

[1] Average daily temperature

In the best case, dormant seedlings will be planted before they start to grow. Growing seedlings should be planted within few days after they have been delivered from the nursery. The roots of growing seedlings should not grow in a large extent out of root plug before planting.

3. Preparation of a planting site

Soil treatment for establishment of forest cultures can improve the thermal conditions, aeration of soil, provide density favorable for root growth, improve mineral nutrition, and decrease the competitive effect of ground cover on the growth of planted seedlings. The method of soil treatment depends primarily on planting site conditions. The planting site should be free from undercuts and felling debris to provide acceptable conditions for operation of forest machines.

In areas with dry sandy soil and clay sand (lichen and heather pine forests), containerized pine seedlings are usually planted out without soil treatment. If the ground litter is more than 3 cm thick, it is advisable to plant out seedlings in the places where the litter had been removed (scarification of soil); however, it is not recommended to mix litter with the mineral part of soil because of the deterioration of the hydrological regime of soil.

When pine plantations are established on poor sandy soils in white-moss pine forests, containerized seedlings should be planted into ditches at the bottom of plowed furrows. Such forest sites can be used for natural regeneration or sowing.

In areas with fresh sandy soil and clay sand (cowberry pine forests), containerized pine seedlings are planted out without soil treatment.

No soil treatment is needed for containerized pine and spruce seedlings on clear-cut area from pine and spruce forests with fresh loamy soils with normal moisture. In this case, it is desirable that seedlings should be of larger size. However, in these forest site conditions, planting of containerized seedlings on mounds made

with different soil tillage tools, provides a higher growth rate of the planted seedlings due to a thicker humus layer of the soil and better heating of soil in artificial mounds.

In loamy soils with temporary overwetting at the beginning and end of the vegetation period (fresh blueberry pine and spruce soils), 15–20 cm microelevations is a requirement for the successful establishment of forest plantations in such conditions.

In areas with moist loamy soils that remain overwet almost throughout the entire vegetation period (wet blueberry pine and spruce forest), mounds should be as high as 20–25 cm, and in some cases, it is necessary to provide for discharge of water, which is carried out by cleaning of temporary channels to allow for water escape in early spring.

On wet soils of heavy texture (polytric pine and spruce forests) that are overwet throughout the entire vegetation period, planting of containerized pine and spruce seedlings on microelevations without discharge of the excess water from the clear-cut area through a system of shallow plow furrows cannot ensure the success of the creation of forest plantations. In this case, the seedlings grow very slowly and there is a risk of losing them. 30–40 cm microelevations can be made in the form of continuous layers, ridges, and discrete mounds. Water drainage furrows should go down the surface slope. The soil is treated late in summer and autumn in the year preceding the establishment of forest plantations.

On waterlogged clearings (soils of heavy texture or with thick peat layer), the establishment of forest plantations is only possible when the seedlings are planted out on plowed layers which provide surface drainage.

The use of tillage tools that do not form drainage grooves does not require any special cleaning operations of the reforestation area. However, when a tillage tool runs into an obstacle (stumps, rocks), it jumps over it. As a result, mounds can be destroyed and their quantity per unit of area will be reduced. In the case of plowing, it is necessary that stumps should be uprooted and stones removed.

The tools that provide mixing of litter with the soil mineral horizons provide the best quality soil treatment for establishment of forest plantations. They are a TTS-Delta disc harrow, PSh-1 screw plow, and KLM-1 tool for making discrete mounds. These tools provide spots with the distribution of organic matter over the whole profile of mound (discrete or plow layer).

In the groups of forest conditions in areas with fertile soils that do not require changes of the water regime, in Russia it is possible to use chemical treatment of the soil. It is carried out by spraying during the vegetation period. The width of treatment is no less than 2–2.5 m. Containerized seedlings can be planted out in the area a month after the chemical treatment. This technique makes it possible to preserve the most fertile soil horizons, to eliminate competition of undesirable herbaceous vegetation for up to 2 years, and woody plants, for a period of 5 years. The chemical treatment of the soil reduces the need for weeding in plantations.

In the reforestation areas where weeding is done with the use of machinery, the rows of seedlings should be straight, without any curvatures. If weeding is done with the help of portable tools, the requirement for straight rows is not obligatory.

Left: Making 20–25 cm high layers and plowed furrows for removing excess water with a PSh-1 plow (photo A. Zhigunov).
Right: Making 15–20 cm high mounds on clearings with temporary overwetting with ORM-1.5 (photo A. Zhigunov).

Chemical soil treatment in areas with fertile soils that do not require any changes in the water regime (photos A. Yegorov, A. Zhigunov).

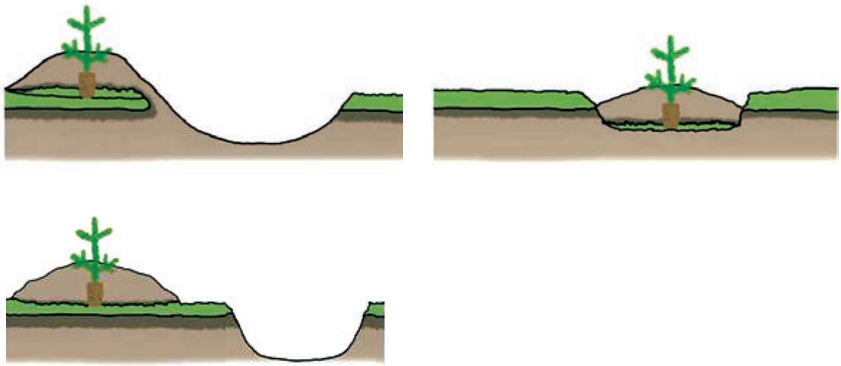
Choice of soil preparation method

Site fertility, soil texture and water table are the most important factors behind the selection of the soil preparation method. On poor sites, only the soil surface needs to be opened (humus layer partly removed), whereas on fertile sites, planting spots should be on elevated spots (mounds). Disc trenching or patch scarification are best suited for poorer sites. On fertile sites, various kinds of mounding methods are the most common soil preparation methods today. The type of mound depends on the water table and soil texture of the regeneration site.

Disc trenching and patch scarification tracks

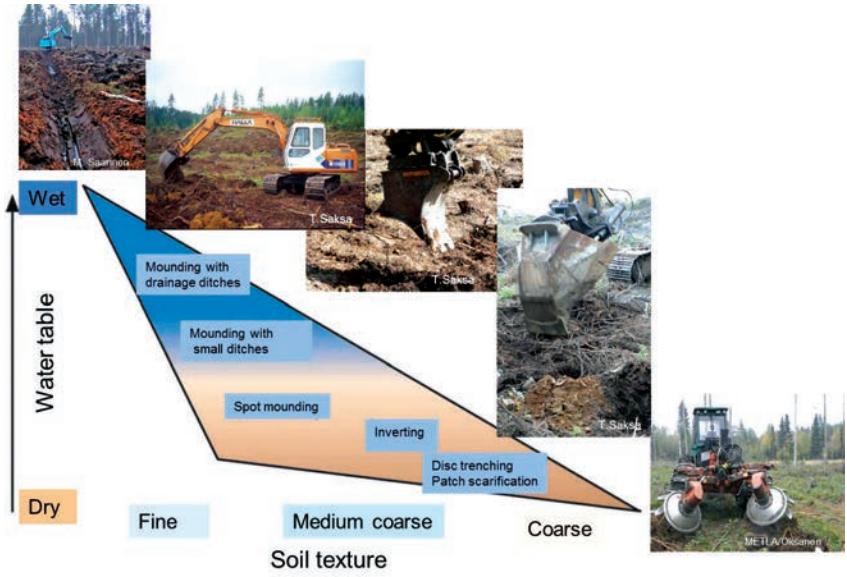
For planting, the surface of soil preparation track should be pure mineral soil in order to minimize pine weevil damages. Seedlings should be planted in 2 – 3 cm depth in the middle of the track.

Different mound types: spot mound, inverting and mound from ditches



Regardless of the mounding method, the seedling should be planted so that its roots will reach the humus layer inside or below the mound. Planting depth should be at least 5 cm because erosion makes the mound lower.

Choice of soil preparation method
according to water table and soil texture



Proper site preparation is the key element behind successful planting results with containerized seedlings.

4. Time of planting

Using containerized planting material for reforestation significantly extends the period of planting. For example, in areas with excessively wet soils the work on establishment of forest plantations with containerized seedlings (delivery of containers and soil treatment) can be carried out in summer because these areas are difficult to reach in early spring and late autumn.

Some forest sites may be inaccessible in the absence of regular roads. In this case, the containers with spruce seedlings can be delivered in winter. After delivery, the planting material must be covered with snow to provide its good storage.

In Russia, there is an experience of establishing forest plantations with containerized seedlings in winter. The root systems of spruce seedlings will not be damaged during this period even if temperatures drop to –27°C. The root systems of pine seedlings are damaged at –17°C, which is why it is not advisable to use containerized pine seedlings. Special tractors equipped with holemakers YaL-1 are used to make holes in frozen soil into which containerized seedlings are placed. Since it is impossible to fully embed the root plug, the seedlings are left in this condition until spring, when they are naturally covered with melting soil. It only remains to see that they are set straight.

The possibility for application of such equipment for winter planting depends on the depth of snow cover. The quality planting is provided in the conditions when the snow mantle does not exceed 20 cm. This equipment is also used for planting on reclaimed areas. This method is also suitable for forest sites with wastes of solid overburden that remain after the technical stage of recultivation.

In early spring, plantations are established with containerized seedlings that were kept in special storage facilities. After the peat substrate of the containerized seedlings that were stored in the open air has

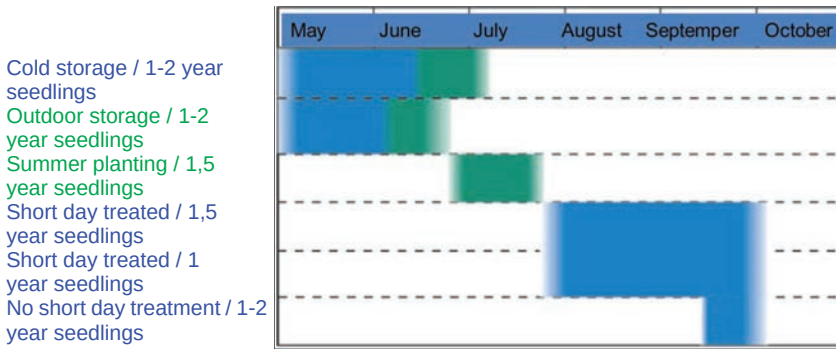
thawed out, the planting material is used for planting in late spring and early summer.

The planting material stored in the areas for completion of growth in late summer and autumn periods is planted out after the seedlings are subjected to short-day treatment.

Proper seedling material for the whole growing season

Containerized seedlings can be used throughout the whole growing season. In particular, the planting machines ought to have proper seedling material for the whole working season, from May to October in southern Finland. Seedlings produced for spring, midsummer, late-summer or autumn time must have different growing schedules in the nursery.

An example of guidelines for using containerized Norway spruce seedlings for the whole planting season



Luoranen et al 2012

Blue : dormant material Green : growing seedlings

5. Planting work

For manual planting from a temporary storage area, containerized seedlings are put into special baskets or trays convenient for workers to deliver seedlings to the planting site. For mechanized planting, seedlings are usually loaded into planting cassettes of a tree planting machine at a temporary storage area.

The Pottiputki® planting tool produced by different companies in Finland and Sweden is most widely used for manual planting of containerized seedlings. The planting tube produced in Russia has a similar design. It is most widely used for planting of containerized seedlings with a large volume of root plugs (over 200 cm^3) in the mixed forest zone (Nizhny Novgorod oblast).

Pottiputki® with the inner diameter of 36–73 mm can be used to plant out the seedlings grown in Plantek® containers from 256 (cell volume of 15 cm^3) up to 36F (cell volume of 275 cm^3). The tube diameter is chosen so that it should be 5–10 mm wider than that of the root ball of the seedling. The planting depth is adjusted to fit the height of the root ball to be planted.

Planting of seedlings with the planting tube is an efficient and economical method of planting. However, the planting tube is suitable for planting on prepared soil or light sandy soil without soil treatment.

On heavy-texture or stony soils, containerized seedlings are planted with the use of various hoes and shovels as in planting of bare-root seedlings. Cylindrical shovels are also used for these purposes in Russia. They are rather effective for high-clay loam soil and turf-covered soil.

All over the world, forest engineers have conducted much work on designing tree-planting machines for creation of forest plantations with

containerized seedlings. However, only M-Planter, Bracke and Risutec tree-planting machines are widely used in Finland. Finnish UPM, for example, uses planting machines in 30 % of all plantings carried out by this company. These machines make soil preparation (mounding) and do planting of containerized seedlings simultaneously.

In Russia, much effort was made to create an automated tree-planting machine based on the soil preparation machine ORM-1.5. The prototype models of a combine KLM-1 were capable of creating discrete mounds and planting containerized seedlings in the automatic mode. However, this machine did not go into production.

A two-row planting machine SL-2 designed for planting open-root seedlings and transplants was upgraded to plant containerized seedlings in plowed layers. Russia has a wide experience in using SL-2A, a modification of SL-2, for establishing forest plantations with containerized seedlings.

On virgin soil, the embedment depth should be 2 cm: the upper edge of the seedling peat substrate should be 2 cm below the soil level. On mounds, the embedment depth should be at least 4 cm so that the root system of plants (root plug) could be located in the humus layer, covered with mineral layers of soil on the top.

Particular care in planting should be taken of the seedlings with nonlignified apical shoots as they break easily.

The planting capacity of Pottiputki® is 1100–1300 seedlings per day. Productivity of mechanized planting depends on technical characteristics of the machines used.

Planting of containerized seedlings manually and with planting machines

Containerized seedlings are easy to plant manually with planting tubes or planting machines. In both cases, it is important that roots are well developed and they will keep the root plug compact. At the moment manual planting covers about 95 % of the whole planting area in Finland. The planting machines used in Finland do soil preparation (mounding) along with planting operation. The productivity of planting machines used today is about 150 – 200 seedlings per hour.

Left: Manual planting with Pottiputki® planting tube (photo Metla/Oksanen). Right: Planting with an AM-Planter tree-planting machine (photo Metla/Oksanen).

6. Planting density

The initial density of forest plantations created with the use of containerized seedlings must be at least 3000 seedlings per hectare in the taiga zone and mixed coniferous and deciduous forests on fresh, wet and waterlogged soils, and it must be a minimum of 4000 seedlings on dry soils. When forest plantations are created with transplants and containerized seedlings, the number of plants per hectare may be decreased to 2000 plants (1000 plants per ha for container oak transplants). These standards were established by Reforestation rules adopted in 2007 by the Forest Code of the Russian Federation and Amendments to Reforestation rules authorized by the Ministry for Natural Resources and Ecology of the Russian Federation adopted in November 5, 2013. The initial density of forest plantations is determined in Reforestation rules irrespective of tree species.

In Russian scientific literature, we can find different recommendations for the initial density of plantations and arrangement of spots for planting material with open roots depending on the forest site conditions, tree species, the method of soil treatment, and the purpose of growing plantations (Table 2). For containerized seedlings, planting densities could be lowered. Plantations of light-demanding species — pine, larch, and birch — should be grown in less dense spacing than those of shade-tolerant species, spruce, for example.

Table 2

The initial planting densities of pine and spruce on different forest site types

Group of forest types	**Planting density, seedlings/ha**	
	Pine	**Spruce**
Lichen	5000 – 6000	–
Cowberry	3500 – 4000	–
Shamrock	4000 – 4500	3500 – 4000
Bilberry	3500 – 4500	3000 – 4000
Sphagnum	3000 – 4000	3000 – 4000

If the planting stock for a plantation has been selected, improved by breeding or is of larger size, the planting density can be lowered. The arrangement of spots for the plants depends on the possibility of using machines for soil treatment and tending.

The distance between the rows of pine is 3–4 m (2–3 m on dry and poor soils). The distance between the rows of spruce is 3–5 m, and 4–5 m for larch. The distance between plants in a row is determined depending on the required planting density and average distance between rows.

Finnish recommendations for planting densities

Planting density depends on tree species and site fertility. The guidelines for target planting densities on different sites and different tree species in southern Finland are given below:

Tree species	Most fertile	Medium	Poor sites
Pine	-	2000 - 2500	2000 - 2500
Spruce	2000 - 2200	1800 - 2000	-
Birch	1600 - 1800	1600 - 1800	-

Planting density should be checked during the planting work.

7. Using fertilizers to stimulate growth of forest cultures

Fertilizers should be applied based on the economic considerations of accelerating the growth of forest cultures. However, their application is not mandatory. Application of mineral fertilizers during planting can only be recommended on cutover land with dry poor soils to accelerate the growth of cultures in the first 2–5 years of growth. On rich soils, mineral fertilizers are not applied during planting because of low economic efficiency.

Nutritional imbalance restrains the growth of forest plantations, making them susceptible to negative effects. Special recommendations are available on using complexes of micronutrient elements in forest plantations aimed at increasing their resistance to late spring frosts. Mineral fertilizers could also be applied after plants were badly damaged by hard frosts.

It is not uncommon that mineral soils that were previously used for agricultural purposes suffer the lack of boron. Drained peat soils rich in nitrogen may suffer both from the lack of boron, potassium and phosphorus. Application of complex fertilizers with microelements (1.5 – 2.5 kg/ha) normalizes plant growth within 1–3 years.

Strong boron deficiency in a five-year-old spruce seedling (photo R. Rikala).

8. Control of ground cover development

The grass cover (*Calamagrostis, Juncus, Deschampisa, Carex,* and *Epilobium, Rubus, Equisetum* on fertile forest sites) is a serious competitor to the planted containerized seedlings, especially in the first years after planting. The absence of proper tending may result in stunted growth and even loss of plants. Pine is much less competitive to grass cover on clear-cut area than spruce.

The methods and duration of control of grass cover depends on site conditions, the biological characteristics of the cultivated tree species, the method of soil preparation, the method of planting, and size of the planting material used.

The main factor determining the need for control of grass cover is how intensive herbaceous vegetation is, which depends on soil fertility and moisture as well as the composition of the stand that grew on this site before cutting. In general, grass control is necessary if soil is covered with herbaceous vegetation for more than 30-40 %. In rich growing conditions (shamrock), this occurs in a year after the seedlings were planted on prepared soil. If there was no soil preparation before planting, the measures aimed at controlling ground cover should be taken either before planting or within 12 months after planting. If soil is prepared properly, no control will be needed the following 3 years.

At the age from 2 till 5, plantations need the most intensive tending because during this period the danger of adverse mechanical effects of grass cover is particularly high: seedlings may fall over after the grass dies in autumn. The methods and timing of tending should provide for growth of target species in the unshaded conditions.

Elimination of ground cover in plantations may be carried out both by mechanical and chemical methods. Grass and other herbaceous vegetation should be either cut off (mowed down) with special gasoline (petrol) mowers (Husqvarna, Secor, et al.), or with cultivators if planting was carried out without mechanical site preparation and trees are planted in rows.

As regards chemical methods, in Russia the development of ground cover is controlled by application of glyphosate preparations, Anchor-85 (potassium salt of sulfometuron-methyl), and their mixes prepared immediately before use. Of all the variants, the most effective is the mix of glyphosate with Anchor-85. These measures provide the most complete and rapid death of all the major herbaceous species on clear-cut areas, regardless of their height and phase of development. Spraying is carried out in August-September. The recommended dose is 4–6 l/ha of glyphosate + 100–150 g/ha of Anchor-85. One treatment is usually enough to provide the protective effect for 1.5–2 seasons. One treatment of Anchor 85, an effective herbicide with a prolonged soil effect, applied alone or mixed with glyphosate, allows for a significant increase in the growth of pine and spruce as they are no longer suppressed by herbaceous vegetation.

From economic and forestry efficiency considerations as well as environmental safety, it makes no sense to treat the whole area with herbicides. The trees planted in rows should be treated along the rows covering a space of 1–1.5 m on both sides. When trees are planted in groups, you should treat only the area directly around them. The number of treatments depends on site conditions and weather conditions of the current year.

Left: Suppression of spruces with young deciduous growth.
Right: A spruce plantation after chemical treatment of young deciduous growth with glyphosate (photos A. Zhigunov).

Left: Removal of young deciduous growth in pine plantation rows. Right: Regulation of young mixed growth by glyphosate injections in trunks of deciduous species (photos A. Yegorov).

9. Removal of unwanted deciduous trees

Tending, in particular, removal of unwanted woody vegetation, in forest plantations before they are ranked as wooded land is regulated by Reforestation rules (2007). This treatment is mainly aimed at preventing unwanted fast-growing deciduous forest tree species from developing as they may retard the growth and cause fall out of the established plants. The methods, the number and duration of tending depend on climatic and natural conditions, biological features of the cultivated tree species, method of soil treatment, biometric parameters of the planting material used.

Various tools and machines are available to do tending in plantations with trees planted in rows. The most commonly used tool is a motorized brush cutters (Secor). The so-called 'corridor tending' method allows for using tractor rollers, brush cutters (for example, Bracke C12.a) or mounted tools for thinning (Risutec II).

Herbicide spraying works well for treatment of plantations in corridors and regular groups. If you need to remove the growth of hardwood in the case when the trees are uniformly distributed or grow in groups over a site, you may introduce herbicide into insections (injection) on tree trunks using special tools.

The application of herbicides prevents the emergence of root suckers, which greatly increases the efficiency of silvicultural tending and reduces its costs.

Before forest plantations are transferred to the category of forested land, it is recommended to completely or partially remove undesirable woody vegetation which shades the target species, so that they could subsequently form an upper storey. In Russia, the requirements for such plantations are determined by the federal document Reforestation rules (2007). The rules determine the age at which plantations should be transferred to forests, the number of main tree species, and the average height of the main tree species for each forest region (Table 3).

Table 3

The requirements for young plantations the areas of which must be transferred to the category of forested land

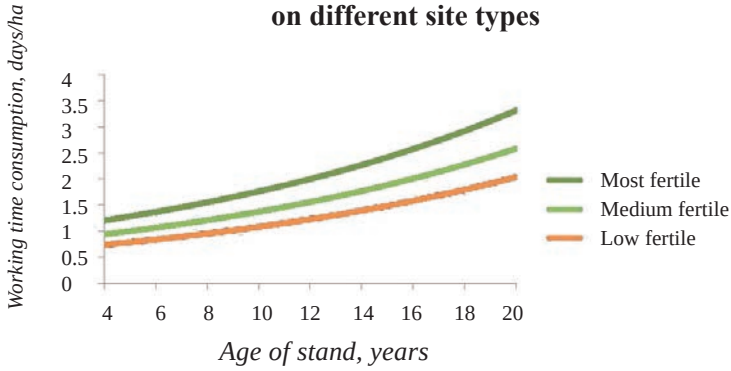
Tree species	**Types of forest and types of forest sites**	**Age** No less than, years	**Number of trees of main species** No less than, trees/ha	**Average height of trees of main species** No less than, m
Middle taiga region of European Russia				
European white birch	Shamrock, bilberry	5	1700	1.1
Norway spruce	Cowberry, shamrock	9	2000	0.7
	Bilberry	9	1700	0.7
	Polytric pine, grass pine	10	1500	0.7
Scotch pine	Lichen, heather	8	2200	0.8
	Cowberry, shamrock	8	2000	0.9
	Bilberry	8	2000	1.0
	Polytric pine, grass pine, sphagnum	9	2000	0.8

The restrictions for the height of natural regeneration of deciduous trees are common to all regions. They are given in section 3.6 of the Russian OST 56-99-93 standard called "Forest cultures. Quality estimation." The maximum height of unwanted species should not exceed half the value for the cultivated species within the radius of 1.2 m; it can be of the same value for Class 1 plantations within the radius of 1.2–3.5 m, and it is three times as much as the value for the average height of cultures in Class 2 plantations.

Early cleaning

Almost all conifer stands need early cleaning 4 to 6 years after planting. Direct seeded or naturally regenerated pine stands may be cleaned a little later. The purpose of early cleaning is to remove the competitive vegetation from the vicinity of conifer saplings. Broad-leaved trees and shrubs are cut with a brushcutter.
Delaying early cleaning for one year increases working time about 10 %.

Working time consumption in early cleaning on different site types



Most of the cleaning work is done manually with brush cutters. In the recent years mechanized young stand management methods have been developed. One very promising innovation is an uprooting machine (Naarva uprooter). After uprooting there is hardly any new sprouting from stumps or roots and so there will not be a need for any other young stand operations.

An uprooting machine in the work (photo T. Saksa) and a new model of Naarva uprooter (photo Pentinpaja).

10. Disease and pest control

To prevent damage of coniferous species from pine weevil, the seedlings should be treated before planting in forest nurseries before they are transported to the planting area, which in most cases provides sufficient protection for one or two years (see Section 1).

To prevent damage of coniferous species from pine fungi, the initial density of planting should be reduced by increasing the distance between plants to 1.5–2.0 m. Also, measures should be taken to provide for a larger share of deciduous species in the plantation. The advance of the disease can be retarded by planting more deciduous species in the plantation in the places where the disease is widely spread.

In young plantations infected with *Phacidium infestans* Karst. sick and dead plants should be dug into the soil or burnt.

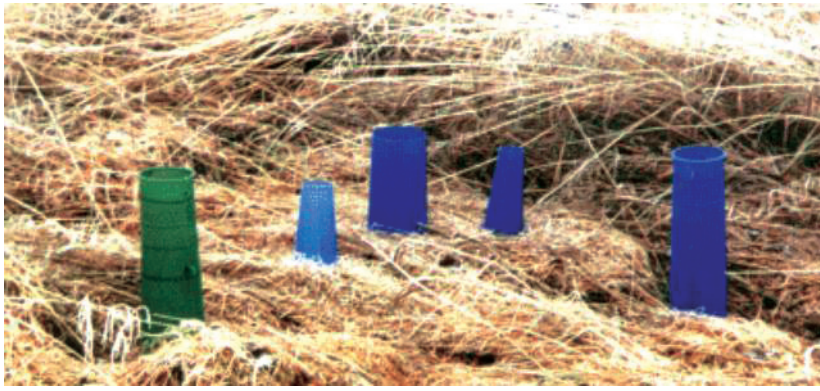
To prevent the spread of *Melampsora pinitorqua* in young pine plantations, it is recommended to completely remove aspen from the cultures.

Spread of *Aradus cinnamomeus* Panz. can be retarded by keeping rather high density and mixed composition of trees in plantations.

In case there is a risk of crop damage of conifers by elks, their number should be controlled, besides, foraging areas with salt licks will help solve the problem. In some cases, particularly valuable plantations are enclosed with a 3.0–3.5 m high hedge. Sometimes repellents work well to keep animals away from young trees.

Protection of seedlings against rodents

Protection of seedlings against rodents is common only on reforestation areas on former agricultural lands. These areas have usually very firm growth of ground vegetation. Plastic shelters are also used when cultivating high value ornamental trees, etc.



Different kinds of shelters against voles and other rodents (photo Agrame Oy).

11. Pre-commercial thinning

Elimination of unwanted young growth of deciduous species in young stands (cleaning and thinning) is performed at crown closure of woody vegetation. It is aimed at improving the species composition and quality of the main species and creating optimal conditions for the growth of target species. This is achieved by removal or suppression of unwanted woody vegetation, and, if necessary, control of the main (target) species density. Failure to provide proper cleaning and thinning in due time influences the growth of trees and productivity of the stand much stronger than failure to provide proper commercial thinning.

The density of young pine, spruce and birch plantations before cleaning and thinning is specified by the requirements for the quality of young plantations (Table 3). Depending on site conditions, a young plantation must include at least 2000–2200 Scotch pines, 1500–2500 Norway spruces, and 1700 European white birches per hectare.

In pine plantations, deciduous species are removed along the rows, and large trees, if any, should also be removed in the space between rows. Aspen should be totally removed because it is a carrier of a dangerous disease caused by *Melampsora pinitorqua.* The distance between the trees planted in rows should be more than 1 m. Pine plantations at pre-commercial thinning (approximately 15 years) should be thinned to the density of 2000 trees per hectare. During the second pre-commercial thinning the density of pine plantations should be decreased to 1500 trees per hectare.

During cleaning in spruce plantations, all deciduous species, with the exception of those growing in glades, should be removed completely. The height of deciduous species cannot exceed that of spruces. At the age of 12–14, spruce plantations are thinned to the density of 1100–1300 trees per hectare; the trees are selected by the stem diameter, in so doing, all stunted and defective trees should be removed.

Birch is a fast-growing light-demanding species, radial growth of which suffers from crown narrowing. When targeting at achieving pulpwood that meets modern requirements for size, young birch plantations should be grown at a density of about 2000 trees per hectare. In this case, if the maximum height of birch is about 15 meters, one thinning to the density of 800-1000 trees will suffice.

When carrying out cleaning and thinning in young stands it makes sense to leave only the trees that can achieve commercial dimensions. The time of thinning depends on the efficiency of cleaning, the state of young stands, and further planned activities.

The selection of trees should be done within biogroups by marking, first of all, the best trees, and then promising and unwanted trees and removing stunted trees.

The wood cut at cleaning and thinning is usually of no commercial value. It is left in the forest and decays with time. However, these operations, which regulate target tree density, are of vital importance for future mechanized commercial thinning.

The intensity and periodicity of tending depends on the density and composition of young stands, the state of the target species and type of site conditions. Intensive care, which implies taking proper measures in due time, increases profitability of the first commercial thinning. The intensity of tending depends on the frequency of occurrence of the best main species. In the case that their occurrence is 60 %, it makes sense to remove all unwanted species by mechanical or chemical methods.

The standards for forest thinning in Russia are determined for each forest region depending on the composition of forest stands by the Rules of Forest Tending, 2007, Appendix 2. The age at which tending should start, the minimum crown density before and after tending, cutting intensity (% from stock), its repeatability for each type of thinning (lighting, cleaning, thinning, intermediate cutting) as well as the target

Table 4

Standards of forest thinning in mixed coniferous and deciduous stands in the middle taiga region of European Russia

Composition of forest stands before thinning	Group of forest types (quality class)	The age when thinning starts, years	Cleaning		Thinning		Commercial thinning		Target composition by the age of cutting (ripeness)
			Min crown density before and after thinning	Thinning intensity, % by stock (years)	Min crown density before and after thinning	Thinning intensity, % by stock repeatability (years)	Min crown density before and after thinning	Thinning intensity, % by stock (years)	
Mixed coniferous and deciduous stands with predominance of pine	Lichen (IV)	15 - 20	0.8 / 0.6	25 - 30 / 15	0.8 / 0.6	25 - 30 / 15	0.8 / 0.7	25 - 30 / 20	(7-8)P(2-3)B
	Cowberry (IV)	10 - 15	0.7 / 0.5	30 - 40 / 15	0.7 / 0.5	30 - 40 / 15	0.7 / 0.5	30 - 40 / 20	(8-9)P(1-2)B
	Shamrock (III – II)	5 -10	0.6 / 0.4	40 - 50 / 15	0.6 / 0.4	30 - 40 / 15	0.7 / 0.4	30 - 40 / 15	(8-10)P(2-0)B
	Bilberry (IV – III)	10 - 15	0.7 / 0.5	30 - 50 / 15	0.7 / 0.5	30 - 40 / 15	0.7 / 0.5	30 - 40 / 20	(7-9)P(1-3)B
	Polytric pine forest (IV)	15 - 20	0.7 / 0.5	25 - 30 / 20	0.7 / 0.5	20 - 30 / 20	0.8 / 0.6	20 - 30 / 20	(6-8)P(2-4)B
Mixed spruce and deciduous stands with predominance of spruce	Shamrock (I)	8 - 10	0.7 / 0.4	30 - 50 / 6 - 8	0.7 / 0.5	30 - 50 / 8 - 10	0.7 / 0.6	30 - 40 / 10 - 15	(9-10)S(0-1)B
	Bilberry (II – III)	8 - 10	0.6 / 0.4	30 - 50 / 6 - 8	0.7 / 0.5	30 - 40 / 8 - 10	0.7 / 0.6	20 - 30 / 10 - 15	(8-9)S(1-2)B
	Polytric pine forest (IV)	10 - 15	0.7 / 0.4	30 - 50 / 8 - 10	0.7 / 0.5	30 - 40 / 8 - 12	0.7 / 0.6	20 - 30 / 10 - 15	(7-8)S(2-3)B
	Forests with running water and high grass (I-II)	8 - 10	0.6 / 0.4	30 - 50 / 6 - 8	0.7 / 0.5	30 - 40 / 8 - 10	0.7 / 0.6	20 - 35 / 10 - 15	(7-9)S(1-3)B
	Grass-marsh (IV-III)	10 - 15	0.7 / 0.4	30 - 50 / 8 - 10	0.7 / 0.5	30 - 40 / 8 - 12	0.9 / 0.7	20 - 30 / 10 - 15	(7-8)S(2-3)B

composition of stands by the age of final felling (maturity) are determined individually for each composition of stands (Table 4).

The age at which stands should be thinned as well as types of thinning (Table 5) are determined by the Rules for forest tending (2007) (Appendix 1).

Table 5

Age periods for performing different types of forest thinning for the European part of Russia

Types of forest thinning	**Age of forest plantations, years**				
	Conifers at the cutting age		**Deciduous tree species at the cutting age**		
	Over 100	Less than 100	Over 60	50–60	Less than 50
Cleaning	Before 10	Before 10	Before 10	Before 10	Before 10
Pre-commercial thinning	11-20	11-20	11-20	11-20	6–10
Commercial thinning	21–60	21–40	21–40	21–30	11-20

The time of tending affects its cost. For example, using brush cutters in a leafless period takes about 25 % less time than the same procedure in a leafy period. However, the trees cut during the growing season produce less sprouts than those cut in winter. In young coniferous stands cleaning can be carried out ‘in windows’, which means that unwanted deciduous undergrowth and all larger trees should be removed within a radius of about one meter around coniferous trees. If 40% of deciduous trees remain, their shade significantly suppresses the formation of stump sprouts. Excessive cleaning of deciduous species will make you do cleanings more frequently in the future.

Finnish principles for young stand management

Pre-commercial thinning takes place about five years after early cleaning (spruces are 3-4 meters, pines 5-7 meters in height). After this treatment there should be 1800-2200 stems in spruce stands and 2000-3000 in pine stands. In Silver birch stands the stem number should be about 1600 after pre-commercial thinning operation.

After pre-commercial thinning the canopy of the stand should close as soon as possible. When the trees are 14-16 meters in length (stand age is about 25-30 years), it is time for the first commercial thinning.

Ten-year-old, about 4 metres in height, planted Norway spruce stand just before and just after pre-commercial thinning operation. Stand was early cleaned at the age of five (photos Metla/ OKsanen).

12. Quality estimation of forest plantations

After the trees of the cultivated species reach target parameters, the process of growing forest cultures is considered complete; thereafter, in Russia, the area of forest plantations is transferred to the category of lands covered with forest vegetation. The requirements for the parameters of these plantations are established by the Reforestation rules (2007), Appendix 1, individually for different forest regions and species. The requirements specify the age of plantations (age, no less than), the average height of the trees of the main species (m, no less than), and the number of trees of the main species (thousand trees/ha, no less than). Forest plantations that meet these requirements are considered standard (see Table 3).

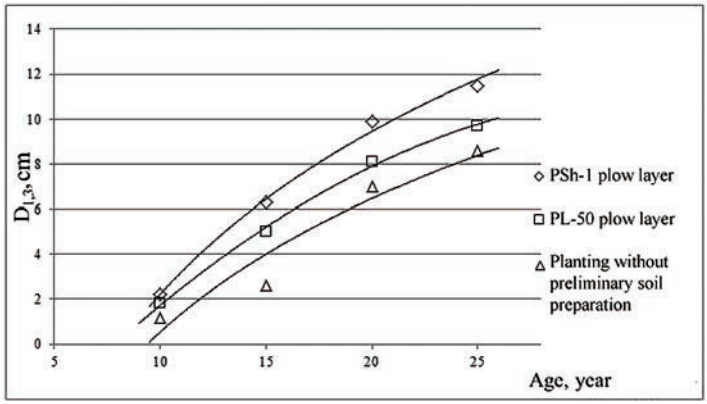
Generalization of the parameters of forest plantations in the southwest of the Leningrad region has shown that the use of different technological schemes and regimes of growing forest plantations can result in drastically different results for growth (Table 6).

Table 6

The height of Norway spruce in the eight-year-old plantations in mixed shamrock and blueberry forest sites

No.	Technological scheme of growing forest plantations	Average height, m
1	Experimental plantations with application of the latest technologies (biological potential): plantations established on plowed ridges with large transplants grown from selection seeds; preventive control of ground cover development and removal of deciduous trees	4.7
2	Experimental plantations: plantations established with standard transplants on plowed ridges and discrete mounds; early suppression of competition of herbaceous vegetation and deciduous trees	2.6 – 4.5
3	Commercial plantations: plantations established with application of the technology recommended for the region	1.2 – 3.5
4	Commercial plantations: plantations established in violation of the recommended technologies: small planting material, planting without soil preparation, delay in control of grass and deciduous sprouts	0.7 – 0.8

The requirements for biometrical parameters of plantations that are to be transferred to lands covered with forest vegetation specified by Reforestation rules (2007) are not stimulating for forestry enterprises to use advanced technologies in nurseries and plantations because these requirements provide minimum parameters: the average height of 0.7–0.9 m (see Table 3).



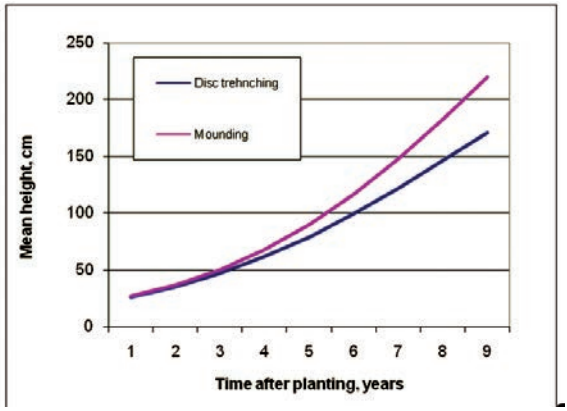
Dynamics of spruce plantation growth for different plowed ridges in wet blueberry spruce forest.

25-year-old Norway spruce and Scotch pine plantations. Time for first commercial thinning (photos A. Zhigunov).

Left: 20-year-old plantations of European white birch.
Right: 20-year-old plantations of lodgepole pine (photos A. Zhigunov).

Height development of spruce on different soil preparation tracks

Spruce seedlings planted on mounds have much better growing conditions than those growing on disc-trenching track. After nine growing seasons the mean height of a spruce stand planted on mounds was more than 20 % greater than the mean height of a spruce stand planted on disc-trenched area.



The mean height development of spruce plantation on disc-trenched or mounded regeneration area (Saksa et al. 2005).

13. Evaluation of reforestation cost-efficiency

The complete rotation time of a forest stand established with planting can be divided into the following stages:

1. Establishment of forest plantations (soil preparation, planting of seedlings or saplings, complementary planting, control of ground cover development and removal of unwanted deciduous trees).

This stage starts with soil preparation and lasts till the time when forest plantations are transferred to the category of forested land. In the Russian taiga zone, this stage lasts, depending on the region and cultivated species, from 4 (birch plantations in southern taiga) to 11 years (Norway spruce in the north-taiga region).

2. Young stand management

Cleaning and pre-commercial thinning are done up to the age of 20 in coniferous plantations, the age of 10 in short-rotation deciduous stands, and the age of 20 in deciduous stands with the rotation period of 60 years.

3. Commercial thinnings

First thinning and intermediate cuttings are done at the age of 21–60 for coniferous species with the cutting age of over 100; the age 21–40 for coniferous species with the cutting age of less than 100, and birch with the cutting age of 60.

4. Final felling.

The first two stages of forest growing are cost-ineffective and unprofitable and do not yield any commercial profit. The costs of creating forest plantations will be determined by the condition of the planting site and planned activities for growing forests (Table 7). Calculation of costs and incomes in Table 7 was done for the use of forests stipulated by the Forest Code of the Russian Federation “Establishment of forest

plantations and their management", Article 25. There are no restrictions on felling of trees in such forest stands (Article 42). The calculation of the costs and incomes from different forest operations over the whole stand rotation period are based on the data from different forest industry companies as well as expert assessments.

Table 7

The costs and incomes in a planted and properly tended spruce stand during the whole rotation period

Operations	Year	Cash flow; 0 % rate		Cash flow; 2 % rate		Merchantable wood, m^3/ha
		Costs, rubles/ha	Income, rubles/ha	Costs, rubles/ha	Income, rubles/ha	
Planting material, 2500 pcs.	1	12250	-	12250	-	-
Soil preparation and weeding	4	23500	-	21710	-	-
Cleaning up to the age of 10	10	10000	-	8203	-	-
Pre-commercial thinning	15	5000	-	3715	-	-
First commercial thinning	25	16000	37800	9752	23040	40
Second thinning	40	24000	121120	10869	54854	80
Third thinning	49	32000	157800	12127	5980	80
Final felling	55	23600	560000	86145	188442	320
Total	-	378750	876720	164773	326136	520
NPV	-	-	497970	-	161364	-

Net present value (NPV) has been calculated with 0 % and 2 % interest rates. In this example, net present value is positive up to 6 % interest rate.

Cleaning and thinning are only costs because it is usually impossible to produce merchantable wood before the age of 20 in coniferous stands. These activities are a necessary investment in order to gain more profit from stands already at the first commercial thinning. Cleaning and thinning done properly in proper time will make it possible to do the first commercial thinning earlier and to increase the yield of merchantable wood per unit of area.

The purpose of intermediate thinning is the maximum improvement of product structure and increase of the average diameter of the stand by the time of final felling. High-quality wood provides more expensive assortments (saw logs, veneer logs) and, consequently, higher profits per unit of forest site area.

The first commercial thinning is the first intermediate cutting during which a part of merchantable wood is removed. It is of vital importance from the standpoint of forestry even though its economic efficiency is quite low.

The first commercial thinning is aimed at increasing the growth of best quality trees. The return from it will show itself later as increased revenue from the following cuttings. The share of the first thinning in the total revenue during the whole stand rotation period comes up to ten percent at best.

The timing of thinning is determined by the composition and condition of the stand. It is recommended that thinning should be done before the share of the living crown of pine trees falls down to below 40 %, and that of spruces and birches to 50% of the total tree height. Failure to provide the first thinning in proper time results in loss of part of the stand growth and in increased natural mortality.

There are no universal indicators for density of pine plantations after the first thinning. Any density from 800 to 1500 trees per hectare can be justified. The most common density is somewhere in the middle of this range.

Growth of young spruce stand will be on high level, even if it is thinned by 30–40% of the basal area of the stand. The density of the remained stand after thinning should be from 900 to 1500 trees per hectare.

Regeneration chain - investment for a new forest stand

Regeneration chain, comprising soil preparation, planting, early cleaning, pre-commercial thinning, determines the investment for the new forest stand. These operations constitute a chain and the result of it depends on the weakest link in the chain.

Operation	Time, year	Cash flow; 0 % rate		Cash flow; 2 % rate		Merchantable wood, m^3/ha
		Costs, €/ha	Income, €/ha	Costs, €/ha	Income, €/ha	
Mounding	1	336		336		
Seedlings+planting	1	720		720		
Early cleaning	4	200		185		
Pre-commercial thinning	9	390		326		
First thinning	30		1280		707	56
Second thinning	39		1793		828	61
Third thinning	49		2762		1047	77
Final felling	55		15814		5321	321
Total		2126	21649	1567	7903	515
NPV			19523		6336	

The first incomes will be earned in the first commercial thinning when the planted conifer stand is 25-35 years old. The next thinnings will follow about ten years after each other later and at the age of 55-60, it is time for final felling. In southern Finland with the present costs and timber prices, we can get about 3-5 % interest rate for the investment made in spruce planting.

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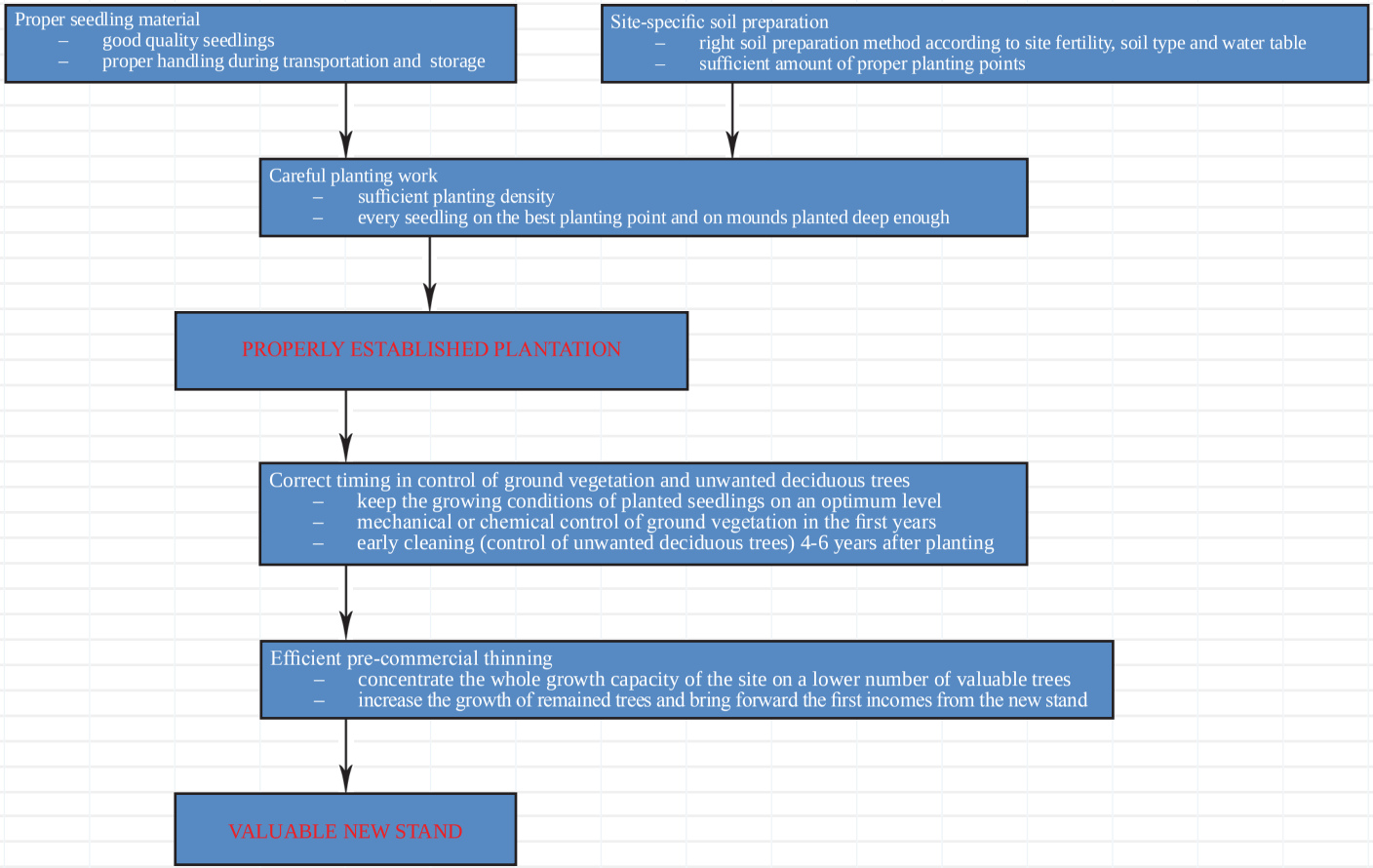
Contributory factors for growth of forest plantations established with container tree seedlings



Establishment of forest plantations with container tree seedlings
St. Petersburg, Suonenjoki:
St. Petersburg Forest Technical University,
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