**Factors affecting success of cutting propagation in ornamental forms of Norway spruce (*Picea abies* Karst.) of Northern origin**

**Nikkanen Teijo, Heiska Susanne, and Aronen Tuija**

**Finnish Forest Research Institute, Punkaharju Research Unit**

**Finlandiantie 18, FI-58450 Finland**

**Abstract**

In the Northern Europe, hardy and decorative conifers are needed for landscaping activities to broaden the selection of available varieties. Ornamental forms of Norway spruce (*Picea abies*), either naturally born or bred, could provide suitable material for this purpose. The aim of the present study was to examine the propagation ability of Norway spruce forms having potential to be used in landscaping under harsh environment, using rooting of shoot cuttings as propagation method. In addition of different ornamental forms, other factors affecting rooting success, such as donor age, timing of propagation, type and length of cutting, and rooting medium were studied. On the basis of the results, careful selection of suitable genotypes is needed for commercial production. There was a large variation in rooting success among the genotypes and the forms belonging to different growth habit classes. Generally, the forms having normal height growth but coloured needles rooted more easily than the forms without apical dominance or showing reduced or pendulous growth. The shoots used as plain cuttings, without the heel, should preferably be over 5 cm in length. The timing of cutting collection is important, the shoots collected from dormant donors at winter rooted much better than the ones collected at late summer. It would also be advantageous to have the rejuvenilised donor trees grown under controlled conditions, the cuttings from the younger donors rooting better than the ones from the older donors. With optimisation of the rooting conditions, further improvement of rooting success can be expected.

**Key words:** ageing**,** genotypic variation,ornamental tree,*Picea abies*, propagation time, rooting medium

**Introduction**

In modern societies, landscaping is a growing business, both in private and public sectors. In the Northern Europe, the market now demands consistent and sustainable production of hardy, decorative ornamental conifers. These could replace the less hardy imports from Central Europe and would be suitable for use in landscaping under the harsh conditions, in which deciduous tree species appear without leaves for half a year (Nikkanen 2009). According to the review by Sæbo et al. (2005) on urban tree selection, an ideal conifer tree species should have, not only good overall adaptation to local climate, but also reasonable tolerance to urban environments and stresses. In addition, slow growth and reduced size combined with special appearance, for example a columnar form, would be favourable in many cases, because of less pruning required and labor resources saved in the maintenance work (Raisio 2009).

There are decorative conifers that are hardy and well adapted to harsh Northern conditions. These are found among the normal trees in Northern forests as rare whims of nature, presenting a variety of peculiar forms: weeping spruces and pyramid pines, dense dwarf spruces, witches’ broom pines, golden spruces and pines, for example. These natural mutants have been collected and registered e.g. in Finland (Oskarsson and Nikkanen 2001, Nikkanen 2009) and in Latvia (Zilins et al. 2009). Recently, also a small number of crossings between certain forms have been produced in order to find new, decorative tree forms for ornamental use. New forms raised this way are crossings between the red coloured spruce (*Picea abies* f. *cruenta*), the weeping spruce (*P. abies* f. *pendula*) and the compact globe spruce (*P. abies* f. *globosa*) (Lehtonen and Nikkanen 2008).

An effective propagation method is a prerequisite for utilisation of the natural mutants or bred ornamental varieties of conifers. Characters of a special tree form are based on the favourable combination of genes carried by an individual. In order to produce similar phenotypes, this genotype has to be kept unchanged. This can only be done by using vegetative propagation. In conifers, potential vegetative propagation methods include different grafting techniques, rooted cuttings and tissue culture. Grafting as a propagation method works generally well in coniferous species, but is labour intensive and has only moderate multiplication rate (Dirr and Heuser 2006). Higher multiplication rates can be achieved by rooting shoot cuttings, but the applicability of the method varies remarkably among coniferous species (Dirr and Heuser 2006). Compared with grafting and rooting shoot cuttings, tissue culture has the highest multiplication rate. However, in conifers tissue culture can only be initiated from young explants, normally from seed embryos. Development of tissue culture techniques is currently taking place; the first report of propagation of 10-year-old white spruces by somatic embryogenesis has recently been published (Klimazewska et al. 2011). The method is, however, not yet suitable for routine multiplication of conifers with well-known characteristics, like the trees selected for ornamental use.

Of the Nordic conifers, Norway spruce (*Picea abies*) is the species having the biggest number of recorded special forms (Oskarsson and Nikkanen 2001), thus also providing the best opportunities for selecting new ornamentals for harsh conditions. In Norway spruce, rooting of shoot cuttings is successful and could be used for propagation of the selected forms. Propagation of the cuttings in Norway spruce has been studied already for a long time (see e.g. Farrar 1939), in effort to apply it for tree breeding and reforestation purposes (Kleinschmit et al. 1973, Kleinschmit and Schmidt 1977, Sonesson and Hannerzt 2002, Mikola 2009). There is, however, only some information on propagation of ornamental forms published (Kelly 1972; Oliver and Nelson 1957; Iseli and Van Meter 1980). Generally, the recommended conditions for rooting shoot cuttings of spruce and the results of rooting following different treatments vary extensively, and thus it can be concluded that local conditions and genotypes should always be considered in order to achieve commercially satisfactory results (Dirr and Heuser 2006).

The aim of the present study was to examine the propagation ability of Norway spruce genotypes having potential to be used in landscaping under harsh environment, using rooting of shoot cuttings as propagation method. In addition of different genotypes representing varying growth habits, multiple factors potentially affecting success of rooting, such as donor age, timing of propagation, type and length of cutting, and rooting medium were examined in order to find the best options for production of new, hardy ornamentals for Northern conditions.

**Material and methods**

*Plant material*

In its genetic register, the Finnish Forest Research Institute (Metla) has records of 1850 individual trees that are genetic deviants of our native tree species. The number of deviant Norway spruce trees in the register is 950. Many of these deviant trees have also been conserved in clone archives and arboretums, some of which have offered material for this study.

The main criteria for the selection of special forms for the present study were their appearance and potential as an ornamental tree. In addition, the selected genotypes had to be available in arboretums or clone archives in such numbers that allow collection of numerous shoots. Genotypes representing different forms were selected following the specifications obtained from the landscaping professionals: low-growing forms with no apical dominance, erect forms with pendulous growth, globular forms with reduced growth and forms with special color of needles (Figure 1). Shoot material used as cuttings was collected mainly from rather old donor trees, but in some cases also younger material, i.e. donors rejuvenilised by grafting on seedling stock, was available (Table 1). The origin, age, growth habit, and needle colour, characteristics of all the material, are presented in Table 1.

*Preparation of cuttings*

Shoots for cutting propagation were collected from six different locations: old clone archives at Imatra and Punkaharju, a field experiment and a propagation garden located also at Punkaharju, a young stand in Tuusula, and from private arboretum in Mäntsälä (Table 1). Shoots used as cuttings were not taken directly from the donor trees, but bigger branches were first excised and stored. Later these branches were used as source of cuttings. In upright growing forms of more than five meters in height, branches were cut from the second quarter of the crown from the top, and from shorter and dwarf trees all the crown was used.

For the first experiment established in March the branches were collected from 8 to 12 weeks before establishment of the experiment. The collecting took place on 15th of December in Mäntsälä, on 17th of December in Tuusula, on 11th of January in Punkaharju and on 18th of January in Imatra. The branch material was stored in boxes with snow, at the temperature of -6°C in Ruotsinkylä and -5°C in Punkaharju. The experiment was established within four days, from 9th to 12th of March.

For the second experiment established in August the branch material was collected some days before the establishment of the rooting experiment, between 11th and 16th of August, and the cutting preparation and insertion into rooting media took place from 17th to 19th of August. After collection the material was stored under moist conditions in cold storage, at the temperature of +2-+4°C.

Only lateral shoot tips representing the youngest growth were used for cuttings, but two different types of cutting preparation were applied. In each ornamental form, half of the material was prepared by excising the shoot near to base (plain cuttings), while the other half was torn off so that a heel of previous year’s growth was left on the cutting (cuttings with the heel). Finally, the heel was carefully trimmed with a knife.

*Rooting experiments*

Two types of rooting media were used both in March and April experiments: the mixture of fertilised peat (White 420 W F6, Kekkilä, Finland) and vermiculite in proportion of 50:50, and the mixture of Spruce-Rhododendron Soil™ (Kekkilä), bark and vermiculite in proportion of 15:15:70.

The both experiments were conducted using a split-split-plot design with the rooting media as a main plot factor, the ornamental form as sub-plot factor and the cutting type as split sub-plot factor. To control the variation in rooting conditions within the greenhouse, the experiment was split into two blocks.

In the March experiment, both blocks were divided into two main plots, one containing seven growing boxes of peat-vermiculite rooting medium and the other containing seven boxes of Spruce- Rhododendron soil-bark-vermiculite medium, ie. altogether of 14 boxes within the block and 28 in the whole experiment. In the August experiment, the main plots consisted of eight boxes of each medium ie. altogether the total of 32 boxes in the whole experiment. In each box, there was room for 200 cuttings, which was, in the most cases, divided into two ornamental forms (sub-plot factor). In every form, half of the cuttings were plain and the other half with heel (split sub-plot factor). The number of the cuttings per ornamental form-cutting type-rooting medium –combination was 50, i.e. 400 cuttings were rooted per each form, except in a few cases, in which there was not material enough for that, and thus the number of the cuttings in some split sub-plots was 25 at the minimum. Location of the cutting types was randomized within the forms, and the location of forms was randomized within the boxes containig the same rooting media. Location of the rooting media was randomized within the blocks.

Rooting experiment was established at Punkaharju (N61°48’, E29°20’) in the greenhouse equipped with bottom heat and controllable growing conditions. The air temperature in the greenhouse was set to 15°C, and the temperature of rooting media to 22°C. The air humidity was regulated by an automatic mist system, and targeted to 80 - 90 %. Additional light was applied during rooting when necessary, and set to 12h/12h day/night photoperiod so that the minimum of 12 000 lux of light during the day period was achieved.

Fungicide treatment was applied in the both experiments. Spraying of the cuttings was carried out in two- week intervals using 0.07 % Topsin M® (Nippon Soda Ltd, Japan). In addition, when fungal growth was observed on the media, spraying with 0.3 % Tirama 50™® (Kemira Agro, Finland) was applied.

*Observations and measurements*

Observations and measurements of the March experiment started 12 weeks after shoot immersion, and continued for 4 weeks from 6th to 30th of June. In the August experiment observations started also 12 weeks after establishment of the experiment, ie. 14th on November and continued until 30th of November.

All the cuttings were observed and measured, 4558 cuttings in the March experiment and 6250 in the August experiment. The measured traits were vitality and size of cutting, rooting of cutting and number of roots. Vitality was classified in three categories: alive and new shoot growth, alive but no new shoot growth, and dead. Length of cutting was measured, and the number of roots was counted.

All the rooted cuttings were transplanted into fertilised peat (White 420 W F6, Kekkilä), and their cultivation was continued in normal green house conditions. The vitality of the cuttings in the March experiment was observed again after the first growing season.

*Statistical analyses*

Statistical analyses were computed only for the data collected from the March experiment, due to low rooting success in the August experiment. Rooting percent for each split sub-plot was calculated as the proportion of the cuttings with one or more roots of all cuttings inserted.

To evaluate the effect of the rooting media and cutting type on the rooting amongst the studied clones and families, a mixed model analysis of variance (ANOVA) was computed for the rooting percent using a model adjusted for a split split-plot design randomized on complete blocks. The statistical model used, consisted of block (two levels), rooting media (two levels), clone or family (12 levels), cutting type (two levels) and their interactions as fixed factors (see Table 2). The model was built by testing block\*media and block\*clone or family within media as random factors. The block\*media factor was omitted from the model as redundant, and thus, only block\*clone or family within media was used as a random factor in the final model.

Also a model for probability of rooting was developed using logistic regression analysis. Rooting medium, clone or family, needle colour, growth habit, age of donor tree, cutting type and block were tested as covariants for binary response variant (rooted or not). The best fit of the model was evaluated by stepwise addition of the covariants into the model, and by comparing the coefficient of determination (Nagelkerke’s R2) and goodness of fit test variables (Hosmer and Lemeshow χ2) computed for the different models. The best fitting model included rooting medium, needle colour, growth habit, and age of donor tree as factors (see Table 3).

The relationship between the length of cuttings and rooting percent was tested with Pearson Correlation analysis. For the analysis, the mean cutting length per each split sub-blot was used.

Prior to the parametric analyses, the distribution of the data was evaluated from residual plots. All the statistical analyses were performed using PASW (version 17.0).

**Results and discussion**

In the present study, altogether 10808 shoot cuttings of Norway spruce were tested for their rooting. The cuttings represented 17 different taxa that were classified according to their growth habit and needle colour. The rooting success varied remarkably among and within these classes. Timing of propagation had the biggest influence on the rooting percentage of the cuttings. Also the age of the donor tree and rooting medium used were found to affect the rooting success.

***Timing of cutting propagation***

In the present study, there was a striking difference in the rooting success between the March and August experiments. In March, the overall rooting percentage was 16.7 %, and in the best ornamental forms almost 50 % of the cuttings rooted (Fig. 2a). After the first growing season, 98.3 % of the rooted cuttings were alive. New shoots were observed in 33 % of them, i.e. majority of the cuttings had roots developed but no shoot elongation taking place in the first growing season. Of the 6250 cuttings collected in August, however, only 44 (0.7%) rooted. Because of this very low rooting success, the effects of the other factors were examined using only the data from the March experiment.

The tested propagation times in the present study were chosen based on the conclusions made in the earlier studies that recommend either use of winter cuttings collected from dormant donors (Farrar 1939, Oliver and Nelson 1957, Girouard 1975) or summer cuttings collected at the end of active growing period but before cold acclimatisation of the donors takes place (Kelly 1972, Iseli and Van Meter 1980).

In Farrar’s (1939) study in Connecticut, US, the timing of winter cutting collection was critical for rooting success: during the period from October to January, the best rooting was achieved in the cuttings taken in December. The same collection time produced the best rooting also for the ornamental forms *P. abies* f. *ohlendorffii, P. a.* f. *pygmaea,* and *P.a.* f. *remontii*  studied in Ottawa, Canada (Oliver and Nelson 1957). Kelly (1972) studied dwarf forms of Norway spruce in Ireland and considered the rooting of summer cuttings better than that of winter cuttings taken in March. In his timing experiment with summer cuttings, he collected shoots at two week intervals from late July to the beginning of September, and and he observed the best rooting generally for the cuttings collected at mid-August. The optimum collection time for each of thse twelve genotypes tested, however, varied from late June to mid-August.

Girouard (1975) made an extensive study on timing of cutting propagation in Norway spruce in Quebec, Canada. He collected shoots from 7-year-old donors with the interval of 2-3 weeks throughout two consecutive years, and found the rooting percentages being the highest in cuttings taken in April and May just before or during bud burst. The second most favourable collection period was during October and November when the donor plants had been subjected to cool temperatures. Iseli and Van Meter (1980) made experiments with cutting collection time as well, using dwarf forms of Norway spruce in Oregon, US. They found summer cuttings collected from the beginning of August to mid-September rooting better than the ones taken in winter, from January to mid-March.

In the present study, only the winter cuttings rooted reasonably. This might be related to the Northern origin (N60º24’ – N63º48’) of the present taxa and their adaptation to the short growing season at high latitudes. Growth cessation in Norway spruce, induced by short days, and the critical night length, as well as temperature sum needed, is dependent on the latitude of origin (Partanen 2004, Gyllenstrand et al. 2007). Thus, mid-August as collection time of cuttings was not optimal for the present genotypes, although recommended by several earlier studies performed with more Southern origins of Norway spruce. Probably the physiological status of the Northern trees at mid-August is already turned towards dormancy which inhibits rooting. The optimal time for collecting summer cuttings of the very Northern origins of Norway spruce still needs to be found. Considering the overall shortness of the growing season, this time window presumably is rather narrow, and might thus not be convenient, considered from the perspective of practical propagation.

As an alternative to immedeate rooting in the greenhouse with bottom heat and additional lights, the cuttings taken at late summer or early autumn could be stored and rooted later on. According to Oliver and Nelson (1957), the cuttings can be inserted into rooting medium and kept there covered/ in plastic greenhouse, over the winter. Rooting will then take place in spring with increasing temperature and light.

***Rooting success of the different ornamental forms***

There was remarkable variation in the rooting percentage of the cuttings among the tested ornamental forms, as shown in Figure 2 and Table 2. Significant differences in rooting success were also found among the groups of different taxa, classified according to their growth habit and needle colour (Table 3).

Genotypic variation in the rooting success of the cuttings is well known. Kelly (1972) studied rooting of summer cuttings from twelve ornamental dwarf forms of Norway spruce and found remarkable differences in the rooting percentage among the genotypes. In *P. a.* f.  *nidiformis,* *P.a.* f. *microsperma,* and *P.a.* f. *prostata* the rooting percentages around 80 could be achieved, while in other genotypes the best results varied from 10 to 68 %, depending on timing of cutting collection. Also Roulund and Pellett (1974), Kleinschmit et al. (1973), and Hannerz et al. (1999) reported wide differences in rooting success among Norway spruce clones.

In the present study the rooting success varied among the forms representing variable growth habits. The forms showing normal height growth were among the best-rooting ones independently of their age or spring time needle colour (Fig. 2, Table 2). The lower rooting success of the other forms, i.e. the ones without apical dominance, the ones with reduced growth, and the pendulous ones, may be related to their internal phytohormone balance. Formation of adventitious roots is enhanced by auxins, and cutting propagation utilises a natural phenomenon of polar transport of endogenous auxin. Auxin is synthesized in plant part with rapid cell division, especially in apical shoot meristems and young leaves, and is then transported to roots (Taiz and Zeiger 1991), as shown also in conifers (Sundberg and Uggla 1998). The polar transport accumulates auxin just above to any wound site, such as the cutting base, where it then promotes the initiation of root primordia (Taiz and Zeiger 1991). Branches of conifers growing upward are characterised by a higher auxin transport capacity than horizontal ones (Veierskov et al. 2007). The absence of upward shoots or small amount of young needle tissue with active auxin biosynthesis could thus contribute to lower rooting success in the ornamental forms growing slowly and /or without the apical dominance.

***Cutting size***

In the present study, there was a connection between the length of the cuttings and the rooting success: the ornamental forms having the longest cuttings were also the ones with the highest rooting percentages (Fig. 3).

The bigger cuttings have more photosynthetic capacity and storage carbohydrates available for formation of adventitious roots. The superiority of the bigger cuttings have been reported by several studies. Farrar (1939) found longer (> 10 cm) cuttings to root better than shorter ones. Roulund and Pellett (1974) preferred cuttings 9-12 cm in length. Hannerz et al. (1999) studied cuttings of 3,5-7,5 cm in length and observed positive correlation between rooting percentage and shoot length. In dwarf ornamentals, however, annual shoots are often very short. Iseli and Van Meter (1980) reported that bigger cuttings of dwarf forms having a leader and two tiers of side branches root as well as smaller cuttings consisting of a single shoot. This observation can be utilised in commercial propagation in order to get saleable plants faster. According to Kelly (1972), production of a saleable dwarf spruce (12-24 cm in diameter, 8-12 branches) from the rooted cutting takes normally three growing seasons.

***Cutting type***

The cutting type – plain cuttings versus the ones with the heel – had no significant effect on the rooting percentage in the present material, although there were single genotypes that preferrred one cutting type over another. (Fig. 2b, Table 2). In all, plain cuttings are faster to produce compared with those with heel and thus, from a practical point of view, use of plain cuttings can be recommended. Furthermore, removal of basal needles from cuttings is not needed in Norway spruce, because it has been found to reduce rooting and to increase the cost of propagation (Roulund and Pellett 1974).

Plain cuttings have been recommended in the earlier studies. Farrar (1939) found that the cuttings without the heel rooted better than the ones with the heel. He suggested the more abundant resin flow from the plain cuttings being favourable for their rooting, by resins protecting the cuttings from bacteria and fungi during the rooting process. Also in Roulund and Pellett’s study (1974), plain cuttings were superior to cuttings with the heel. In Girouard’s (1973) study, presence or absence of the heel had no effect on the rooting of the cuttings, but the presence of the tissue from the previous year growth seemed to hinder shoot formation and elongation.

***Position of cutting in the donor tree***

Only lateral shoot tips were used as cuttings in the present study. Oliver and Nelson (1957) found lateral tip cuttings rooting better than terminal tip cuttings. Also Ferguson (1968) in his review on cutting propagation of Norway spruce, reported lateral shoots rooting more readily than terminal ones, but noted plagiotropic growth habit being more probable in lateral than in apical cuttings. On the other had, Girouard (1975) considered both lateral and terminal shoots to be suitable as propagation material.

Cuttings collected for the present study, originated either at upper part of the tree crown, or in the case of dwarfish forms, they were collected all over the crown. Use of upper crown shoots might have decreased rooting percentage to some extent, because Hannerz et al. (1999) showed that in the cuttings taken from lower crown positions of the 10-year-old Norway spruce trees, the rooting was 4-5 times higher (45 %) than at the upper positions (9.8 %). The same phenomenon was also observed by Roulund (1975) who reported an average increase of rooting of 2.5 % per a whorl from the top to the lower parts in a study with 6-21 –year-old Norway spruces. When considering growth habit of rooted cuttings, the use of upper crown shoots can, however, be reasoned. Due to topophysis, the cuttings often maintain the growth habit that they had as shoots on the donor tree (Olesen 1978), and therefore the risk of plagiotropic growth is smaller when cuttings are taken from the apical, upward growing parts of the crown.

***Donor tree age***

The age of the donor tree had a significant effect on rooting success of the cuttings in the March experiment in the present study (Table 3). The average rooting percentage of the cuttings originating in the 20-year-old trees was 26.4, while of the cuttings from the older trees (45-55 years of age) only 13.8 % rooted. The age factor also explains the observed differences in rooting within the globular and pendulous growth habit groups, the coloured donor trees of those being younger than the other genotypes having the same growth habit. In the August experiment, the overall rooting was very poor, and of the rooted 44 cuttings, 35 originated in the younger donors, representing mostly the pendulous forms from Ruotsinkylä and Mäntsälä. Among the rooted ones were also seven cuttings of the clone E11387 collected from 5-year-old graft in the propagation garden, while none of the E11387 cuttings taken from the 55-year-old donor tree rooted.

Roulund and Pellett (1974) reported that the rooting success of Norway spruce cuttings decreases with the increasing age of the donor tree. In their study, the decrease in rooting was approximately 4% per year from age of 6-9 years, then 6% per year for donors of 9-13 years of age, and 1% per year for 13-21 year –old donors. Good rooting percentages have, however, been reported even for older trees: In Farrar’s (1939) study with the 40-year-old trees with normal growth habit, the optimum treatment of winter cuttings resulted in 89% of them producing roots. Also in the study with the ornamental varieties *P. abies* f. *ohlendorffii, P. a.* f. *remontii* and *P.a.* f. *nidiformis,* Oliver and Nelson (1957) found that lateral shoot cuttings taken from the 20-30 year-old trees in late June rooted up to 90% in optimum conditions. The rooting percentages were, however, reduced to 63, 0, and 30, respectively, in a rainy and cold year.

With the increasing donor tree age, the risk of plagiotropic growth of the rooted cuttings also increases. Kleinschmit et al. (1973) and Roulund (1975) reported that the transition of cutting growth habit from branch-like to orthotropic growth will take longer time when cuttings originate in older trees, and proportion of the cuttings showing plagiotropic growth habit is bigger. According to Pulkkinen (1992), this change of growth habit is even slower in the cuttings of the pendulous forms than in the ones with normal crown type. In the present study, reliable observations on the growth habit of the cuttings of different ornamental forms could not be done because of the young age of the rooted cuttings.

Harmful effects of donor tree ageing can be counteracted to facilitate commercial propagation. If rooting of cuttings has been successfully accomplished, even in small numbers, serial propagation can provide a way to slow down or arrest maturation processes in Norway spruce (St. Clair et al. 1985). In this technique new cuttings are taken from the rooted cuttings with a few years intervals, and thus more juvenile donor plants will continuously be available for propagation. Also repeated re-grafting onto juvenile rootstock can be used for the same purpose. The results from the clone E11387 in the August experiment suggest that this approach would work also for ornamental forms of Norway spruce. In order to facilitate the propagation of the selected Norway spruce clones, the Finnish Forest Research Institute has started to establish collections of young grafts of these, i.e. so called propagation gardens.

***Rooting medium***

Of the two rooting media tested in the present study, the peat-vermiculite mixture (50:50) was shown to be significantly better for rooting in the March experiment than the 15:15:70 mixture of Spruce-Rhododendron Soil™ -bark-vermiculite (Fig 2a, Tables 2-3). Also in the August experiment, 42 of the 44 rooted cuttings were propagated on the peat medium. Water-retention ability of the vermiculite is, however, high, and it can be speculated that with more airy medium mixtures (e.g. with perlite having no water-retention ability) the rooting percentages could have been better.

Many different types of rooting media have successfully been used for rooting of Norway spruce cuttings, often peat mixed with another material to provide more air space in the medium. Avoidance of over-watering is important to prevent decay of cutting bases, and the several media has been devloped for this. In his review on cutting propagation in Norway spruce, Ferguson (1968) described the mixture of sand and peat (1:1) being the best choice for rooting medium. Also Girouard (1973) used the same mixture. Hannerz et al. (1999) mixed peat and Leca grains in 1:1. Kelly (1972) used 2:1 mixture of peat moss and sand, while Roulund and Pellett (1974) preferred 1:1 mixture of fresh spaghnum moss and sand. They, however, reported also rockwool, sand and gravel all giving acceptable rooting results. Also pure perlite (Girouard 1975, Iseli and Van Meter 1980), vermiculite (Oliver and Nelson 1957), and coarse sand (Farrar 1939) have all been successfully used.

***Greenhouse conditions***

The greenhouse conditions of the present study were adjusted as recommended by the earlier studies, i.e. an automatic mist system to control air humidity of 80-90 %, additional illumination, and bottom heat were applied with the air temperature set for 15ºC and the medium temperature set to 22ºC. In the March experiment, the targeted conditions were fullfilled well, except that on some sunny days at the end of the rooting period, the temperature of air fluctuated, raising temporarily up to 20ºC. In the August experiment, the greenhouse conditions were kept within settings.

According to Iseli and Van Meter (1980), needles should never be allowed to dry completely during rooting period, and mist system is required to prevent this. At the same time, the rooting medium should not be over-watered. Farrar (1939) recommended high humidity, up to 90 %. Roulund and Pellett (1974) preferred greenhouse as light as possible, although recommended that during summer rooting direct sun should be avoided. Girouard (1975) provided additional illumination, regardless of the time of the year when cuttings were rooted. Bottom heat is not required for rooting, but it fastens the rooting process with 4-6 weeks (Iseli and Van Meter 1980). For example, Hannerzt et al. (1999) maintained temperature in rooting substrate at 20-22ºC, and the air temperature at less than 10ºC during the rooting phase.

No fertilisation during rooting period was applied in the present study, as recommended by Roulund & Pellett (1974) to reduce development of fungi and algae. Several fungicide treatments were, however, needed to prevent fungal growth, potentially because of the pre-fertilised rooting media used.

***Other factors contributing rooting success***

Besides the factors studied in the present work, nutrient status of the donor plant and hormonal treatments are also considered important for rooting of Norway spruce shoot cuttings (Ferguson 1968, Dirr and Heuser 2006). Nutrient status of the donor trees was not examined in the present study because most of the cuttings were collected from big trees growing in the distant clone archives. To optimise the rooted cutting production, however, the donor plants should be grown in containers and maintained at optimum nutrition level, with good control of weeds, pests and diseases (Iseli and van Meter 1980). Alternatively, the rejuvenilized donor plants can be planted in soil at special propagation garden, as was done with a few ornamental forms studied in the August experiment of the present study.

The published reports on the effect of phytohormone treatments on the rooting of the Norway spruce cuttings are contradictory. As reviewed by Ferguson (1968) and Dirr and Heuser (2006), auxin treatments have resulted in various outcomes, from rooting inhibition with increased mortality, and no effect at all, to increased rooting. In the preliminary experiments performed partly with the same genotypes of Norway spruce as in the present study, IBA treatment of the winter cuttings collected in February-March was found to have either inhibitory or no effect at all on the rooting success (Teivonen 2010). Based on this result, no auxin treatment was applied in the present study. This is in agreement with the observations of Farrar (1939) who achieved the better rooting percentage in winter cuttings without auxin treatment than using IBA. Similar result with summer cuttings was reported by Girouard (1973), who also noticed the auxin treatment to have negative effect on the growth of the new shoots in rooted cuttings.

Besides the auxins, there is only a little information about the effect of the other phytohormones on rooting. Rönsch et al. (1993) tested (22S, 23S)-homobrassinolide, a synthetic phytohormone belonging to the group of brassinosteroids, for treating winter cuttings of Norway spruce, and found the treatment improving rooting percentage from 50 to 92.

**Conclusions**

The present results show that ornamental forms of Norway spruce of Northern origin can be propagated as rooted shoot cuttings, but for commercial production careful selection of suitable genotypes is needed. Rooting success varied tremendously among the genotypes and the forms belonging to different growth habit classes. Generally, the forms having normal height growth but coloured needles rooted more easily than the forms without apical dominance or showing reduced or pendulous growth. Commercial nursery specialized in ornamental tree production would like to have rooting of more than 50 % (pers. comm. Jari Mäntynen, Taimityllilä Co). Thus only a few of the ornamental forms tested in the present study can be recommended for propagation. These include *P.a.* f. *aurea* and *P.a.* f. *cruenta,* but also globular and pendulous forms with red needle color.

Rooting success of the ornamental Norway spruce cuttings can be increased by optimizing both the biological and technical factors. The timing of cutting collection is highly important. The shoots collected from dormant donors at winter rooted much better than the ones collected at late summer and subjected immediately to rooting conditions. It would be advantageous to have the rejuvenilised donor trees grown under controlled conditions, either containerized or in soil at propagation garden to optimise their nutritional status and weed, disease and pest control. Rooting conditions, especially the medium, still need further optimisation. Automatic mist system keeping air humidity constantly high, and the bottom heat have been found to be advantageous. The tested rooting media were suspected to have been too moist, and the use of more airy media could improve rooting results. Finally, the shoots used as plain cuttings, without the heel, should preferably be more than 5 cm in length

**Acknowledgements**

We would like to thank the personnel of Punkaharju Research Unit, especially Tiina Tynkkynen, Jouko Lehto, Heikki Paajanen, and Sebastien Cloarec for their technical assistance. Private arboretum owner Jukka Lehtonen and a forestry company Tornator are acknowledged for the spruce material given for the study. This study was funded by Ministry of Agriculture and Forestry in Finland, the project ”Promotion of competitiveness on nursery production by exploiting national gene resources”, and European Regional Developmental Fund, the project “Vegetative propagation – knowhow and technology for enhancing bioeconomy”.

**References**

Dirr, M. & Heuser, C. (2006). The Reference Manual of Woody Plant Propagation - From Seed to Tissue Culture. Varsity Press Inc. Cary North Carolina, USA. 410 pp.

Farrar, J.L. (1939). Rooting of Norway spruce cuttings. The Forestry Chronicle, 152-163.

Ferguson, D.C. (1968). Propagation of *Picea abies* by cuttings. The Plant Propagator, 14(2):5-9.

Girouard, R.M. (1973). Rooting, survivel, shoot formation and elongation of Norway spruce stem cuttings as affected by cutting types and auxin treatments. The Plant Propagator, 19(6):16-17.

Girouard, R.M. (1975). Seasonal rooting response of Norway spruce stem cuttings. The Plant Propagator, 21(3):9.

Gyllenstrand, N., Clapham D., Källman, T., Lagercrantz, U. (2007). A Norway spruce FLOWERING LOCUS T homolog is implicated in control of growth rhythm in conifers. Plant Physiology, 144:248-257.

Hannerz, M., Almqvist, C., Ekberg, I. (1999). Rooting success of cuttings from young *Picea abies* in transition to flowering competent phase. Scandinavian Journal of Forest Research, 14:498-504.

Iseli, J., Van Meter, M. (1980). Propagation of *Picea abies* cultivars by cuttings. The Plant Propagator, 26(3):9-11.

Kelly, J.C. (1972). Propagation of dwarf *Piceas* at Kinsealy. Proceedings of the International Plant Propagator’s Society, 22:238-240.

Kleinschmidt, J., Műller W., Schmidt, J., Racz, J. (1973). Entwicklung der Stecklingsvermehrung von Fichte (*Picea abies* Kart.) zur praxisreife. Silvae Genetica, 22:4-15.

Kleinschmidt, J. W., Schmidt, J. (1977). Experiences with *Picea abies* cuttings propagation in Germany

and problems connected with large scale application. Silvae Genetica, 26: 197-203.

Klimaszewska, K., Overton, C., Stewart, D., Rutledge, R.G. (2011). Initiation of somatic embryos and regeneration of plants from primordial shoots of 10-year-old somatic white spruce and expression profiles of 11 genes followed during the tissue culture process. Planta, 233:635–647

Lehtonen, J., Nikkanen, T. (2008). Metsäpuiden erikoismuotojen jalostus Suomessa. (Breeding of special forms of forest trees in Finland, in Finnish with English summary). Sorbifolia, 39(2):3-10.

Mikola, J. (2009). Successes and failures in forest tree cutting production in Finland. Working Papers of the Finnish Forest Research Institute, 114:27-30

Nikkanen, T. (2009). Hardy options for landscaping – domesticated exotics and special forms of Nordic

conifers. Working Papers of the Finnish Forest Research Institute, 114:27-30

Oliver, R.W., Nelson, S.H. (1957). Propagation of spruce from cuttings. Proceedings of the International Plant Propagators Society, 7:41-48.

Olesen, P.O. (1978). On cyclophysis and topophysis. Silvae Genetica, 27:173-178.

Oskarsson, O., Nikkanen, T. (2001). Metsäpuiden erikoismuotoja kultakuusesta luutakoivuun. Metsäntutkimuslaitoksen tiedonantoja 670. 54p.

Partanen, J. (2004). Dependence of photoperiodic response of growth cessation on the stage of development in *Picea abies* and *Betula pendula* seedlings. Forest Ecology and Management, 188:137-148.

Pulkkinen, P. (1992). The effect of crown form and plagiotrophy on the growth of *Picea abies* f. *pendula* cuttings. Scand. J. For. Res., 7:71-81.

Raisio, J. (2009). Conifers in landscaping – Potentials and problems. Working Papers of the Finnish Forest Research Institute, 114: 23-26

Roulund, H. (1975). The effect of the cyclophysis and the topophysis on the tooring and behavior of Norway spruce cuttings. Acta Horticulturae, 54:39-50.

Roulund, H., Pellett N.E. (1974). Propagation of Norway spruce (*Pice abies* L. Karst) by stem cuttings. The Plant Propagator, 20(1):20-26.

Rönsch, H., Adam, G., Matschke J., Schachler, G. (1993). Influence of (22S,23S)-homobrassinolide on rooting capacity and survival of adult Norway spruce cuttings. Tree Physiology, 12:71-80.

Sæbo, A, Borzan, Z., Ducatillion, C., Hatzistathis, A., Lagerström, T., Supuka, J., Garcia-Valdecanthos,

J.L., Rego, F., Slycken Van J. (2005). The selection of plant materials for street trees, park trees and

urban woodland. *In*: Konijnendijk, C.C., Nilsson, C., Randrup, T., & Schipperijn, J. (eds.) Urban

Forests and Trees. Springer. pp 257-280.

Sonesson, J., Hannerz, M. (2002). “Mellansvenska klonskogsbruksprojektet -slutrapport”. Skogforsk Arbetsrapport 505, 21 p.

St. Clair, B., Kleinschmit, J., Svolba, J. (1985). Juvenility and serial propagation of Norway spruce clones (*Picea abies* Karst.). Silvae Genetica, 34:42-48.

Sundberg, B., Uggla, C. (1998). Origin and dynamics of indoleacetic acid under polar transport in *Pinus sylvestris*. Physiologia Plantarum, 104:22-29.

Taiz, L., Zeiger, E. (1991). Plant Physiology. The Benjamin /Cummings Publ. Company, Inc.Redwood City, California, US. 565 p.

Teivonen, S. (2010). Havupuiden erikoismuotojen lisäysmenetelmät. Propagation of conifer selections (in Finnish with English summary), M.Sc. Thesis, Faculty of Agriculture and Forestry, University of Helsinki, 46 p.

Veierskov, B., Rasmussen, H., Eriksen, B., Hansen-Mǿller, J. (2007). Plagiotropism and auxin in *Abies nordmanniana*. Tree Physiology, 27:149-153.

Zilins, J., Lapse, J., Svilans, A. (2009). Investigation of conifers mutation forms in Latvia and the possibilities in selecting new sorts. Working Papers of the Finnish Forest Research Institute, 114:31-33

**Figure legends**

**Figure 1.**

Ornamental forms of Norway spruce tested for rooting winter cuttings in the March experiment.

**Figure 2.**

The average rooting percent (±SE) of the shoot cuttings originating in the different Norway spruce clones and families. (a) Rooting on different media. (b) Rooting of different cutting types.

**Figure 3.**

Relationship between the length of the cuttings and the rooting percent. In the plot, each dot represent the mean value of the clones and families. Pearson correlation test indicated that the relationship is significant (r=0.30, p=0.005). The correlation test was computed for the uncombined data (n=88).