RESEARCH NOTE

Field performance during 14 years' growth of *Picea abies* cuttings and seedlings propagated in containers of varying size

M. HANNERZ AND L. WILHELMSSON

The Forestry Research Institute of Sweden, Uppsala Science Park, S-751 83 Uppsala, Sweden

Introduction

Vegetative propagation of conifers through cuttings has an important role in reforestation programmes throughout the world. *Cryptomeria japonica* (L.f.) Don in Japan, *Pseudotsuga menziesii* (Mirb.) Franco and *Picea mariana* (Mill.) B.S.P. in North America and *Pinus radiata* (D.) Don in New Zealand and Australia are all examples of important species that are part of operational programmes for cutting propagation (Ritchie, 1991). In Europe, clonal forestry programmes are operating with *Picea abies* (L.) Karst. (Högberg *et al.*, 1995), *Picea sitchensis* (Bong.) Carr. (Deans *et al.*, 1992) and *Larix* × *eurolepis* Henry (Radosta *et al.*, 1994). In Sweden, clonal forestry with Norway spruce (*Picea abies*) dates back to mid 1970s. In practical clonal forestry, as performed in southern Sweden, the realized gain in volume ranges from 15 to 20 per cent, when compared with seedlings of recommended provenance (Högberg *et al.*, 1995). This gain is not merely genetic, cuttings may also offer physiological advantages, e.g. faster initial growth than seedlings, thus shortening the establishment phase. Gemmel *et al.* (1991) found that 8-year-old cuttings gained 15 per cent in height compared with seedlings of the same genetic origin. However, the authors suggested that the increased growth during the first years may not be persistent, as the leader length of year 8 did not differ between the two stock types. Roulund *et al.* (1985) compared seedlings and cuttings from selected clones of Norway spruce. Three-year-old cuttings were 9 per cent shorter than seedlings when planted, but, at 13 years, cuttings were 18 per cent taller than seedlings. According to Roulund and Bergstedt (1982), 10-year-old cuttings of Sitka spruce were 25 per cent taller than seedlings.

Other features of Norway spruce cuttings compared with seedlings are lower susceptibility to pine weevil damage (Mattsson and Thorsén, 1992) and a reduced risk of winter damage

(Hannerz, 1994a). Cuttings may show a plagiotropic (slanting) growth during the first years after rooting (Dekker-Robertson and Kleinschmit, 1991). Kleinschmit and Schmidt (1977) found that cuttings of Norway spruce had a lower number of first order branches and a higher number of second order branches than seedlings, up to 40 cm height. Roulund *et al.* (1985) showed that cuttings of Norway spruce had more tapered stems (height:diameter ratio) than seedlings. When applying the absolute form-quotient (the ratio between the diameter halfway between breast height and top of the tree and the diameter at breast height), cuttings had a better form than seedlings. There was no difference in stem form between 10-year-old cuttings and seedlings of Sitka spruce (Roulund and Bergstedt, 1982). According to Kleinschmit and Schmidt (1977), cuttings of Norway spruce had a larger diameter than seedlings of similar height at 15 years of age. Other characteristics of Norway spruce cuttings resulting from ageing are, e.g. reduced symmetry (Bentzer, 1988), reduced rooting ability (Dormling *et al.*, 1976) and deteriorated stem form (Roulund, 1979) Cuttings of radiata pine (*Pinus radiata*) show considerable advantages when compared with seedlings, e.g. better stem form, straighter trunks and lower branchiness. Fielding (1970) and Anon. (1991) report thinner bark and more frequent and earlier flowering of cuttings than of seedlings.

The initial size and vigour of the plants may also have important influences on survival and growth in the field (Hultén, 1992). The biomass of the plants is highly dependent on growth time and spacing in the cultivation. Height and diameter growth during the first year in the field were significantly larger for Norway spruce seedlings cultivated with a low number of seedlings per area-unit (Hultén, 1992).

If cuttings are to be commonly used in practical forestry, there is a need for more information on the long-term performance of cuttings in relation to seedlings. Important factors to explain are the persistence of growth superiority and significant differences in form characters when compared with seedlings.

This paper presents a field comparison of injuries, form and growth of container-cultivated cuttings and seedlings. The influence of container size is also evaluated. The principal aim of the study was to compare field behaviour of cuttings and seedlings of equivalent genetic origin.

Material and methods

All seed sources originated from the Vitebsk region in Belorussia. Two close, but separate, sources were used for cuttings (Vitebsk vitebsk, 55°15′N, 30°43′E, 200 m a.s.l.) and seedlings (Vitebsk suraizsky, 55°24′, 30°10′E, 150 m a.s.l.). Cuttings were taken from 2-year-old seedlings raised at Eds nursery (60°16′N, 18°20′E, 10 m a.s.l.). The plants were rooted or sown in a greenhouse in Uppsala in central Sweden (59°48′N, 17°38′E, 15 m a.s.l.) in containers (Hiko and Paperpot) of varying size filled with chip-peat (Table 1). Cultivation started in the spring of 1980, and both cuttings and seedlings were kept in the greenhouse until July of the first year. Thereafter, the plants were transferred outdoors to an irrigated nursery area, where they were kept until planting in May 1982. Rooting success was between 75 and 80 per cent for each container. The experiment was established 20 km north of Uppsala (60°03′N, 17°48′E, 25 m a.s.l.), on a clearfelled mire with a peat layer of approximately 0.5 m. The site was drained, but still waterlogged in parts of the experiment, and expected to be exposed to late spring and early autumn frosts. Paper was not removed from the Paperpot plants. Site preparation, including scarification, was performed with a mattock.

The experiment included 10 blocks with each treatment (stock type × container) occurring

Table 1: Containers used for cuttings and seedlings, respectively

Container*	Volume (cm^3)	Density (plants m^{-2})
Hiko V50	50	767
Paperpot FH408	70	1066
Paperpot FH508	117	616
Paperpot FH608	173	428

* Hiko is a container system with hard-plastic cells from which the plants are lifted out at planting. Paperpot is a degradable system with paper in a honeycomb pattern of cells.

once within each block. Each replication was composed of 16 plants, in a 4 × 4 plant plot. The plant spacing was 1 × 1 m. Three of the blocks were later excluded from the experiment due to waterlogging.

Assessments

In 1982, 1984 and 1986, observations were made on damage and survival. Observed frost injuries were separated into spring frost and autumn frost damage in 1982, and in 1984 only spring frost damage was recorded. Frost injuries were scored in five classes where 0 = no damage, 1 = light damage, 2 = moderate damage, 3–4 = severe frost damage, based on the proportion of injured year-shoots. Beside frost damage, scattered observations were made of insect damage, water logging and browsing. In the early spring of 1989, seven growing seasons after planting, assessments were made of survival and total height.

The last assessments were made in the autumn of 1995, 14 growing seasons after planting. Height, survival, damage and length of current leader were measured in seven blocks. In the first two blocks, additional variables were assessed. These were length of one current lateral shoot (consequently the one pointing most to south), length of 1991 leader (10 growing periods after planting) and corresponding length of lateral shoot (southward pointing), number of branches in the whorls of 1995 and 1991 and diameter at breast height (1.3 m). Apical control was defined as the ratio between length of the leader and the lateral branch of the same growing period. This is the inverse of the quotient defined by Cannell (1974) for describing apical control. With the present definition, a high value corresponds to a high level of apical control.

Statistical analysis

Damage and survival scores were first linearized by transformation to normal score values according to Gianola and Norton (1981), where the damage score values are related to an underlying continuous normally distributed scale, according to the proportion of trees in different classes, expressed as standard deviation units. Normal scoring was done within blocks, eliminating block differences in injury levels. Normal score values were used for statistical analysis, however, results are presented as actual frequencies of surviving trees and trees with no or slight injuries. Mean height and increments were calculated for all living plants. Relationships between diameter and height were evaluated for plants taller than 1.3 m. Analyses were run with the SAS General Linear Models procedure. Means from 4 × 4 tree-plots were used as input data.

Presented values result from the mean over containers for cuttings and seedlings, respectively, and the mean over seedlings and cuttings for each container, respectively. The terms plant or tree refer in the following to both seedlings and cuttings.

Height growth, survival and frost damage (data from seven blocks), and branch characters, diameter and apical control (data from two blocks), were analysed with linear model 1. Differences between stock types or containers were evaluated with Tukey's test. Analyses which included the effect of interaction between stock type and container were first run, but since the effect was not significant for any of the tested variables, it was excluded. Block was excluded when analysing survival and damage, as the normal scoring procedure had eliminated the block effect.

Model 1

$$y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + e_{ijk}$$

where:

y_{ijk} = observed value of plot ijk
μ = overall mean
α_i = fixed effect of stock type (i = 1,2)
β_j = fixed effect of container (j = 1,4)
γ_k = fixed effect of block (k = 1,7 and 1,2)
e_{ijk} = random residual

Stem form (only assessed in two blocks) was regarded as the linear regression of tree height on diameter at breast height, and effects of stock type or container on diameter were evaluated with tree height as covariate (model 2). The interaction $\alpha_i \times x_{ijkl}$ denotes the effect on the slope of the regression line and α_i the effect on the intercept.

Model 2

$$y_{ijkl} = \mu + \alpha_i + x_{ijkl} + \alpha_i \times x_{ijkl} + \gamma_k + e_{ijk}$$

where:

y_{ijkl} = diameter of tree *ijkl*
α_i = fixed effect of stock type (i = 1,2) or container (i = 1,4)
x_{ijkl} = height of tree *ijkl*
$\alpha_i \times x_{ijkl}$ = interaction of stock type or container and height
γ_k = fixed effect of block (k = 1,2)
e_{ijkl} = random residual

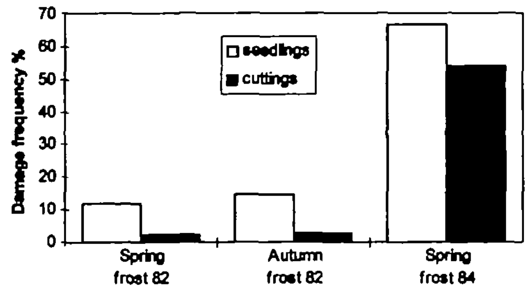

Figure 2. Frost damage on seedlings and cuttings in 1982 and 1984. Frequency of plants with moderate-severe frost injury.

Results

Survival and injuries

Mean survival after 14 years was 79 per cent. The mortality occurred almost exclusively during the first 4 years after planting (Figure 1). Container had a strong significant effect ($P <$ 0.001) on survival, with trees from small containers having the lowest survival. There was no significant effect of stock type (cuttings 80 per cent and seedlings 78 per cent) on survival.

On all occasions with frost, injuries were more frequent on seedlings than on cuttings (Figure 2). Container had no effect on the frost injuries after 1 year, but there was an effect after 3 years (Table 2).

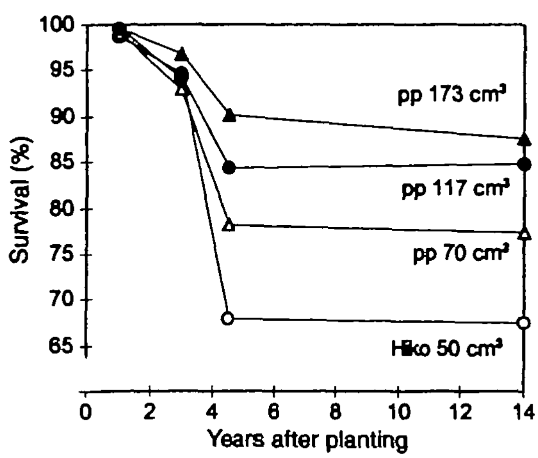

Figure 1. Survival of plants cultivated in containers of different size. pp, Paperpot container.

Height growth

Cuttings were, on average, 5.3 per cent and 5.7 per cent taller than seedlings after 7 and 14 years, respectively, but the difference was not statistically significant (Tables 2 and 3). Leader length was 9.2 per cent larger for cuttings after 14 years.

There was a strong effect of container on height growth after 7 years, but not after 14 years. After 7 years, plants cultivated in large containers (173 cm^3) were 21 per cent taller than plants cultivated in small containers (50 cm^3). After 14 years, the difference was 14 per cent. The pattern was broken by the medium-sized containers, where plants in the 70 cm^3 containers were taller than those from the 117 cm^3 container.

Form characters

The diameter at breast height was positively correlated with tree height ($r = 0.96$). There was no effect of stock type or container on either the slope or the intercept of the regression of height on diameter (P-values >0.6, Figure 3). Number of branches and apical control at the 10- and 14-year branch whorl tended to be higher in cuttings than in seedlings, but the difference was not significant according to model 1 (Tables 2 and 3). The container size did not have any effects on branch characters and apical control (Tables 2 and 3).

Discussion

Susceptibility to frost during the first years after planting differed clearly between seedlings and cuttings in this study. These findings support earlier results, showing that cuttings are more resistant to winter injuries (Hannerz, 1994a). The lower frequency of frost injuries can hardly be explained by differences in size of the plants. Plant heights were not assessed in the early years, but at planting they were regarded as close to even. The weak influence of container size on frost injuries also disagrees with the hypothesis that plant size should be a major explanation of the differences in frost hardiness. A more plausible explanation is the higher ontogenetic age of the cuttings, compared with that of the seedlings. Growth rhythm of Norway spruce changes with age, towards later bud burst and earlier growth cessation. According to Ununger *et al.* (1988) a 6-year-old seedling has

Table 2: *P*-values resulting from ANOVA according to model 1

	Stock type	Container	Block	d.f.
Survival, 14 years	0.53	**0.0007**	–	51
Spring frost, 1 year	**0.0002**	0.20	–	51
Autumn frost, 1 year	**0.0001**	0.99	–	51
Spring frost, 3 years	**0.003**	**0.007**	–	51
Height, 14 years	0.26	0.23	0.28	45
Height, 7 years	0.16	**0.004**	0.74	45
Leader length, 14 years	0.09	0.10	0.05	45
Diameter, 1.3 m	0.22	0.85	0.27	10
Lateral shoot, 14 years	0.08	0.67	0.09	10
Apical control, 14 years	0.14	0.98	**0.04**	10
No. branches, 14 years	0.15	0.92	0.39	10
Lateral shoot, 10 years	0.36	0.67	0.94	10
Apical control, 10 years	0.15	0.72	**0.025**	10
No. branches, 10 years	0.23	0.82	0.83	10

Survival and frost damage variables were run without block in the model. Significant effects ($P<0.05$) are printed in bold. Degrees of freedom for the error-term (d.f.) are noted.

Table 3: Mean values for stock types and containers

		Stock type		Container size (cm^3)			
Variable	Unit	Seedlings	Cuttings	50	70	117	173
Height, 14 years	cm	209	221	201	221	210	229
Height, 7 years	cm	73.8	77.7	69.0	75.8	74.8	83.3
				a	ab	ab	b
Leader length, 14 years	cm	23.9	26.1	23.5	25.9	23.6	27.0
Diameter, 1.3 m	mm	15.4	19.1	15.5	17.3	19.1	17.2
Lateral shoot, 14 years	cm	13.8	15.6	14.0	14.3	15.6	14.9
Apical control, 14 years	ratio	1.62	1.75	1.70	1.66	1.69	1.67
Branches, 14 years	number	4.20	4.57	4.47	4.29	4.32	4.47
Lateral shoot, 10 years	cm	10.5	11.5	10.4	11.0	12.1	10.5
Apical control, 10 years	ratio	1.80	1.95	1.86	1.81	1.96	1.87
Branches, 10 years	number	4.42	4.61	4.46	4.49	4.63	4.48

Significant differences between treatments according to Tukey's test ($P<0.05$) are indicated with different letters. If no letters are printed, the differences were not significant.

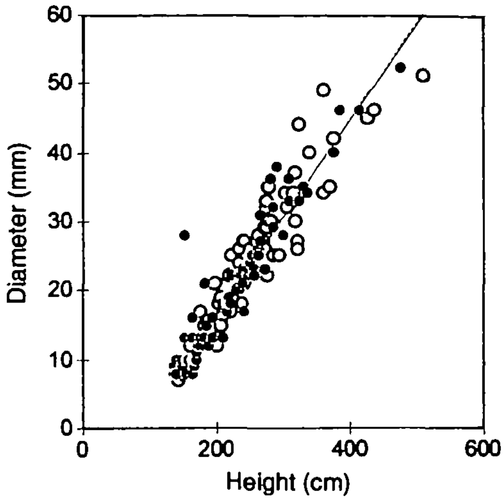

Figure 3. Diameter at breast height for cuttings (open symbols) and seedlings (filled symbols). The regression lines for cuttings and seedlings, respectively, cover each other.

only half the shoot elongation period of a 2-year-old seedling. A shorter elongation period increases the probability to avoid, or reduce the risk for frost injuries (Hannerz, 1994b). In this study, cuttings were taken from 2-year-old donor seedlings. In a clonal forestry programme, the donor plants will be even older, as clones have to be field tested before selection is made for mass propagation (Högberg *et al.*, 1995).

There was a strong effect of container size on survival, but a weaker effect on frost injuries. Early summer frost and autumn frost were the most important detected injuries on surviving plants. Mortality might, however, be caused by a number of different factors, e.g. weed competition, waterlogging and frost desiccation, where plant size has a strong effect.

The height difference between cuttings and seedlings was lower, and not significant, in this study than in the other referred studies (Kleinschmit and Schmidt, 1977; Roulund and Bergstedt, 1982; Roulund *et al.*, 1985; Gemmel *et al.*, 1991), but still in favour for the cuttings. There was no evidence that the difference should decline with age.

Container size had a large effect on the plant height, despite the relative advantage of the largest containers over the smallest seeming to decline with age. It is a weakness in this study that the initial sizes of the plants were not measured. It can be assumed that the plants produced at lower density (larger containers) were more robust and vital, even if no height differences were observed. Timmis and Tanaka (1976) showed that low-density Douglas fir seedlings had higher root-collar diameter and dry weight, and lower shoot:root ratio and height. The difference also resulted in higher fall frost hardiness for low-density seedlings. At the next spring, however, there was no effect of seedling density (Timmis and Tanaka, 1976). O'Reilly *et al.* (1994) studied western hemlock seedlings, and found that seedlings at low density flushed earlier than seedlings produced at high densities. Hultén (1992) studied how seedlings produced at different spacings performed in field. He found that plants cultivated in containers with larger spacing produced a more robust and vital shoot, which also results in improved survival and height growth after several years in the field. These results support the effects of container size on survival and height growth found in this study.

According to this study, stem form did not differ between cuttings and seedlings. There was a tendency that cuttings had better apical control and more first order branches than seedlings. The latter is contradictory to the results of Kleinschmit and Schmidt (1977). However, their study was restricted to very young (up to 40 cm height) cuttings and seedlings. Differences in stem taper between small cuttings and seedlings are logical when considering that a cutting has an initial diameter already before being rooted. When measured on older plants or trees, earlier studies have shown contradictory results, as described in the *Introduction.* The studies by Roulund and Bergstedt (1982) and Roulund *et al.* (1985) compared cuttings from selected clones with unselected seedlings, which is a constraint when interpreting the results.

Genetic differences between cuttings and seedlings might also have contributed to the results in this study. The large differences between cuttings and seedlings as regards frost injuries and also height, could, however, hardly be explained by this fact. There was no selection step in the nursery. The seed sources were both from within a limited area in Belorussia. With respect to growth rhythm and growth, it has been suggested that the Belorussian region should be divided into a northern and a southern group (Persson, 1987), but according to Persson's study, no significant differences were to be found within the Vitebsk region. This was also the result of a provenance study by Hannerz (1993).

Conclusions

Both stock type and the container used in nursery influenced the field performance. The main effect of stock type was on frost damage, where seedlings were much more vulnerable to frost. There was no difference in stem form or apical control between cuttings and seedlings. The results represent one single experiment on a frost prone site, and it is not certain that the conclusions can be generalized also to less frost-prone sites. Cuttings were rooted from young donor plants. With older donor plants, the ontogenetic ageing may also affect characters such as apical control, branchiness and stem form. This is an important matter for further research.

Spacing and container size in the nursery have a large impact on survival and growth in the field. This effect was even higher than that from stock type in this experiment. However, cultivating plants with large spacing also involves higher production costs, which must be balanced with the result in the field.

Acknowledgements

The establishment of the experiment was financially supported by the Swedish Council of Agricultural and Forestry Research. We are grateful to colleagues at The Forestry Research Institute of Sweden for valuable help with the study and the manuscript. Viggo Thofte and Nils Jerling contributed with technical assistance in the field.

References

Anon. 1991 Promising future for radiata pine cuttings. *What's New in Forest Research.* No 212. New Zealand Forest Research Institute, Rotorua, New Zealand, 4pp.

Bentzer, B. 1988 Rooting and early shoot characteristics of *Picea abies* (L.) Karst. cuttings originating from shoots with enforced vertical growth. *Scand. J. For. Res.* 3, 481–491.

Cannell, M.G.R. 1974 Production of branches and foliage by young trees of *Pinus contorta* and *Picea sitchensis*: Provenance differences and their simulation. *J. Appl. Ecol.* 11(3), 1091–1115.

Deans, J.D., Mason, W.L. and Harvey, F.J. 1992 Clonal differences in planting stock quality of Sitka spruce. *For. Ecol. Manage.* 49, 101–107.

Dekker-Robertson, D.I. and Kleinschmit, J. 1991 Serial propagation in Norway spruce (*Picea abies* (L.) Karst): Results from later propagation cycles. *Silvae Genet.* 40 (5/6), 202–214.

Dormling, I., Ehrenberg, C. and Lindgren, D. 1976 *Vegetative Propagation and Tissue Culture.* Research Notes No 22. Royal College of Forestry, Dept. of Forest Genetics, Stockholm, 18pp.

Fielding, J.M. 1970 Trees grown from cuttings compared with trees grown from seed (*Pinus radiata* D. Don). *Silvae Genet.* 19, 54–63.

Gemmel, P., Örlander, G. and Högberg, K.A. 1991 Norway spruce cuttings perform better than seedlings of the same genetic origin. *Silvae Genet.* 40, 198–202.

Gianola, D. and Norton, H.W. 1981 Scaling threshold characters *Genetics* 99, 357–364.

Hannerz, M. 1993 *Norway Spruce Provenances in Central Sweden—Height Growth and Damage in a Twelve-year Provenance Trial in Southern Gästrikland.* Redogörelse No 1. SkogForsk, Uppsala, 23pp. (In Swedish with English summary)

Hannerz, M. 1994a *Winter Injuries to Norway Spruce Observed in Plantations and in a Seed Orchard.* Report No 6. SkogForsk, Uppsala, 22pp.

Hannerz, M. 1994b Predicting the risk of frost occurrence after budburst of Norway spruce in Sweden. *Silva Fenn.* 28(4), 243–249.

Hultén, H. 1992 Olika plantor för olika ståndorter. *Skog&Forskning* 3/92, 28–33. (In Swedish)

Högberg, K-A., Eriksson, U. and Werner, M. 1995 *Vegetative Propagation and Clonal Forestry: Focus on Norway Spruce.* Redogörelse No 2. SkogForsk, Uppsala, 38 pp. (In Swedish with English summary)

Kleinschmit, J. and Schmidt, J. 1977 Experiences with *Picea abies* cuttings propagation in Germany and problems connected with large scale application. *Silvae Genet.* 26, 197–203.

Mattsson, S. and Thorsén, Å. 1992 Regeneration and its inherent problems. In *The Rationalisation Conference 1992.* G. Frumerie (ed.). Redogörelse No 1. The Forest Operations Institute of Sweden, Stockholm, pp. 35–48. (In Swedish with English summary)

O'Reilly, C., Owens, J.N., Arnott, J.T. and Dunsworth, B.G. 1994 Effect of nursery culture on morphological development of western hemlock seedlings during field establishment. I. Flushing, shoot elongation, and bud development. *Can. J For. Res.* 24, 53–60.

Persson, B. 1987 *Growth Rhythm and Growth Capacity of Belorussian Provenances of Norway Spruce* (Picea abies (*L.*) *Karst*). Slutrapport till Skogsstyrelsens Forskningsnämnd. Garpenberg, Feb 27 1987. (In Swedish with English abstract)

Radosta, P., Paques, L.E. and Vergers, M. 1994 Estimation of genetic and non-genetic parameters for rooting traits in hybrid larch. *Silvae Genet.* 43 (2–3), 108–114.

Ritchie, G.A. 1991 The commercial use of conifer rooted cuttings in forestry: a world overview. *New Forests* 5, 247–275.

Roulund, H. 1979 *Stem form of cuttings related to age and position of scions.* (Picea abies *L. Karst*). Forest Tree Improvement No 13. Arboretet Hørsholm. Akademisk Forlag, København, 24pp.

Roulund, H. and Bergstedt, A. 1982 Sammenligning mellem frøplanter og stiklingsformerede kloner af sitkagran (*Picea sitchensis* (Bong.) Carr.). 10 års resultater. *Dan. Skovforen. Tidskr.* 67, 218–235. (In Danish with English summary)

Roulund, H., Wellendorff, H. and Werner, M. 1985 *A clonal experiment in Norway spruce* (Picea abies (*L.*) *Karst*). *15 years results.* Forest Tree Improvement No 17. Arboretet Hørsholm. Akademisk Forlag, København, 33pp.

Timmis, R. and Tanaka, Y. 1976 Effects of container density and plant water stress on growth and cold hardiness of Douglas-fir seedlings. *For. Sci.* 22(2), 167–172.

Ununger, J., Ekberg, I. and Kang, H. 1988 Genetic control and age-related changes of juvenile growth characters in *Picea abies*. *Scand. J. For. Res.* 3, 55–66.

Received 4 April 1997