PART 5

USE OF VEGETATIVE PROPAGATION FOR PLANTATION ESTABLISHMENT AND GENETIC IMPROVEMENT

A PROGRAMME FOR LARGE-SCALE CUTTING PROPAGATION OF NORWAY SPRUCE

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ABSTRACT

The successful development of cutting propagation of Norway spruce (**Picea abies** L. (Karst.)) now makes breeding programmes involving large scale vegetative propagation of younger stock plants economically feasible.

In Lower Saxony, propagation is carried out in plastic green-houses, and the costs per cutting are roughly 30% above the costs of seedling plants. Selection of elite clones is undertaken from a very large number of seedlings, and about 21,000 clones with 400,000 plants are being tested at the present time. Clones which have already been through two selection stages are immediately handed over for use in practical forestry.

Experiments show an estimated genetic gain in growth rate of 40%, from synthetic multiclonal varieties, compared with the population mixtures normally used for afforestation. In comparison with selected provenances, the gain would be approximately 20%.

Especial value is attached to the maintenance of genetic variation in the synthetic varieties in order to withstand dangers which may arise, partly from the early age of selection (up to 20 years).

1. INTRODUCTION

The technique of propagation by cuttings, when incorporated into a breeding programme, is potentially an important tool for the transference of genetic improvement into practical forestry, *see,* e.g., Schreiner (1938, 1970).

The literature of the history and development of propagation methods with Norway spruce has been described previously (Kleinschmit *et al.,* 1973). Historically, the first Norway spruce cuttings mentioned in the literature were rooted by Oberförster Pfifferling in Hessen in 1830.

The following points summarise the results of all research on this subject for Norway spruce up to the present day:

1. The influence of propagation medium and treatment on rooting response in the species is great.

2. Considerable clonal differences exist in rooting ability.
3. Young plants can be rooted with an average success of 90% for all clones, but the rooting ability in some cases decreases rapidly with advancing age.
4. The influence of the position on the mother tree of a cutting on its later growth form (topophysis) becomes more pronounced with increasing age.
5. Irreversible fixations of growth form, as are known for *Araucaria* species, do not occur in spruce.
6. Irreversible fixations of age-induced growth rate have not been established.
7. The influence of hormone treatment on rooting depends upon the seasonal stage of development, the age of the cutting and its position on the stock plant.
8. The rooting response can be increased markedly by systematic fertilizing.
9. Ease of rooting is essentially not influenced by repeated propagation.

Knowledge of these facts has led to a reconsideration of the possibilities of using cutting propagation in forest tree breeding. There is little sense in propagating old selected trees vegetatively if they will be slow-growing, at least in the first critical years, or are going to grow plagiotropically along the ground as branches. However, while the genetic constitution of old trees is being established by means of progeny tests, younger offspring from the tested plus-trees will always be available for propagation purposes.

Even when the period of observation of progenies in tests extends beyond the age of optimal rooting capability and regenerative ability, new progenies can usually be produced from the original selected trees in the breeding programme. These will be similar to those in the first test and will be available at a young age for further selection and for propagation as cuttings.

The following questions will be considered in some detail in this paper:

1. What part is cutting propagation to play in the Norway spruce breeding programme of Lower Saxony?
2. What technical conditions must be created for large scale propagation?
3. What system of propagation would best meet economic requirements?
4. By what means should adequately tested elite clones be made available and how can risks be avoided?
5. How great a genetic gain is to be expected from such a programme?

2. CUTTING PROPAGATION IN THE NORWAY SPRUCE BREEDING PROGRAMME

In putting breeding results from Norway spruce into practical use it is customary to work either with seed stands from tested provenances or with seed orchards. Provenance selection is a necessity for beginning any breeding with forest trees and the results of provenance experiments can be applied very quickly—at least with a species which is fairly undisturbed in its natural range. With artificial stands it may happen that the stands have disappeared and/or knowledge of their source has been lost by the time results are available, as has often happened in Germany. The main disadvantage of Norway spruce seed orchards lies in the length of time between their establishment and their first seed production. Apart from this, however, flowering is irregular and the seed yield is limited, just as in stands.

Cutting propagation has none of these disadvantages, but the cost of rooted cuttings is high compared with seedlings. On the other hand, the possible genetic gain is greater than from all other propagation methods. There are also considerable advantages in the possibility of unlimited plant production, the quick adaptation even to very specialised breeding aims, for which the foundation of a seed orchard would be uneconomic, and the possibility of using clone-stands for seed stands (*see* also Thulin and Faulds, 1968; Cameron, 1968).

The economic side of the question must be settled, however, before a wider use of cuttings can be made in forestry. The results of economic calculations of alternative breeding methods with Norway spruce are presented in Fig. 1. This figure shows the net profit from 50 years breeding by four methods, calculated with the help of two computer programmes. Details of the cost and profit calculation methods will be published elsewhere.

FIG. 1. NET-PROFIT AFTER 50 YEARS BREEDING BY 4 DIFFERENT STRATEGIES

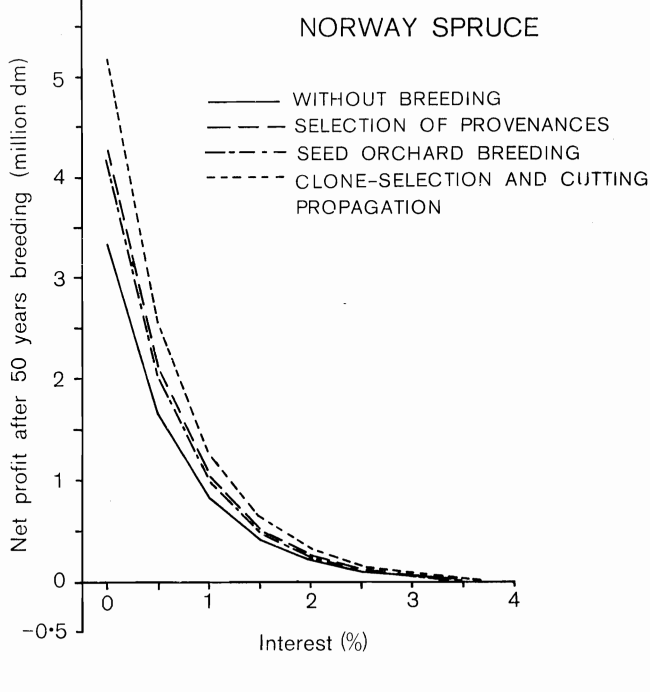
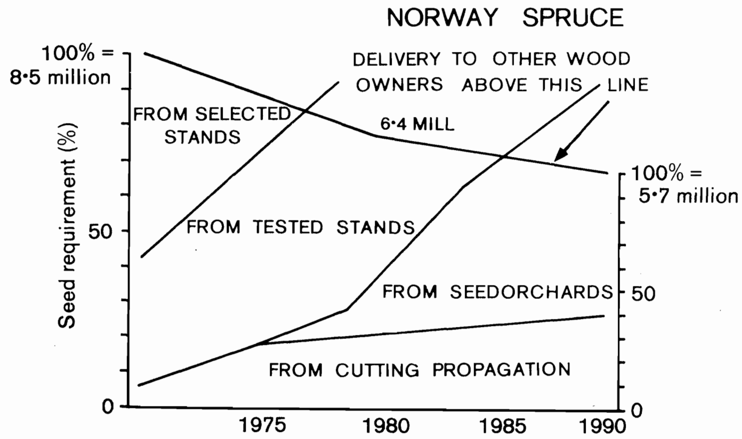


Fig. 1 shows that net profits are possible only at low interest rates. At these rates a breeding programme of cutting propagation is far superior to all other alternatives despite higher plant-costs. On the other hand the net profit from breeding Norway spruce in seed orchards is (despite the greater genetic gain) still below the net profit from provenance selection combined with seed collection in seed stands. This is explained by the relatively long period, of about 20 years in the case of Norway spruce, between grafting and the commencement of economic amounts of seed production.

On the basis of these results we shall in future confine seed orchard establishment of Norway spruce to preservation seed orchards, and produce grafts only for provenance and species hybridisation. Selection from good provenances remains a necessity as a basis for future breeding, as well as for cutting propagation, and will be continued intensively together with the testing of half-sib families.

Seen as a whole the supply of plants in the Forestry Service of Lower Saxony should develop according to Fig. 2.

FIG. 2. SEED PROCUREMENT OF THE LOWER SAXONY FOREST SERVICE



3. TECHNICAL CONDITIONS FOR LARGE SCALE CUTTINGS PROPAGATION

In 1968 work began on developing methods of cutting propagation of spruce for practical application.

Only physiologically young material is used. Propagation is carried out in Finnish plastic green-houses (Kleinschmit *et al.,* 1973). The green-houses are equipped with an automatic mist-system to keep the relative air humidity between 90-100%. The cuttings are taken in the months of March and April and set immediately. The rooting medium is gravel, 3-8 mm in size. Ventilation is carried out when the temperature rises above 30°C. The fungus *Botrytis cinerea,* which is the main danger to the cuttings, is controlled by the regular use of fungicides. Rooting takes place in May and June. From the end of June onwards the cuttings are prepared for open air conditions by regular ventilation and the nutrition is improved by repeated liquid fertilization. From the middle of July onwards the cuttings are transplanted by machine to the nursery where they start growing in the same season. After two further growing seasons the plants are ready to be planttd out. When 4-year-old parent ortets are used the rooting percentage is normally over 90%, but this can be improved by careful fertilization of the stock plants prior to taking of the cuttings (Kleinschmit, 1972). In Germany in 1973 approximately one million Norway spruce cuttings were set by this method at different places. The methods are technically ready for practical application.

4. CALCULATION OF PROFITABILITY AND COSTS

An exact calculation of costs has been presented by Kleinschmit *et al.* (1973). In brief it can be stated here that the costs per cutting plant were reduced, from approximately 800% above seedling costs at the experimental stage, to 30% above seedling costs four years later.

In the calculation of profitability, allowance was made for differences between cuttings and seedlings in the cost of planting stock and in yield. Differences in harvesting costs were also allowed for, as were different interest percentages.

The results of this calculation which are given by Kleinschmit *et al.* (1973, Fig. 6) show that cutting propagation of Norway spruce is always economically sound so long as there is a guarantee of a growth superiority of 10% and more. It will be shown in Section 5 that this should always be the case in breeding programmes. By widening the spacing, which is appropriate with genetically improved material, the establishment costs per ha can even be brought below those of seedling plantations (Kleinschmit *et al.*, 1973, Fig. 7).

5. SELECTION OF ELITE CLONES

The practical application of these methods presupposes the availability of a sufficient number of tested elite clones. The selection of such clones is made from progeny tests in the current breeding programme as well as from tested provenances. Apart from this, research is being intensified in the field of provenance and species hybridisation of spruce to provide material for future selection.

In our selection programme (which runs in parallel with our large-scale propagation programme) we limited ourselves first of all to selection from the species *Picea abies*. When testing the clones the number of plants per selected clone must be increased at each selection level in order to make sufficient tested material available at all times for practical forestry and to enable improvements to be put into practice immediately. Since clonal tests and propagation cycles run independently of each other, any new breeding material can be made available immediately for practical use. After the second selection step the clones are passed on to the field forester for propagation; at later selections the multiclonal synthetic varieties will be replaced by better ones.

In this process we follow the time-table shown in Table 1. In order to ensure variability, the selected elite clones should be used as clone mixtures with about 50-100 clones in a synthetic variety, by which means the ability for self-regulation is preserved. It is considered especially important that a certain level of genetic variation should be maintained in the synthetic varieties, especially with economically insignificant traits. This will reduce possible dangers, such as those that have arisen with poplar plantations.

It is clear from the increase in the number of plants per clone and the total number of plants that in a very short time (approximately 6 years after the beginning of selection) it would be possible to fulfil the annual planting requirements of the Forestry Service of Lower Saxony (about 3 million trees) from cutting plants, should this be desired. The limiting factor is to be found not in biology, but solely in the capacity of the propagation equipment.

Initially, selection was based on height only, with a selection intensity of $3.59\,\sigma p$ corresponding to a selection of one plant in 1,000 (Lerner, 1964). At the following selection steps, which involve selection on clone test results, the selection intensity is

TABLE 1 - Selection programme for Norway spruce clones

Year	Initial plant numbers	1. No. of clones selected	2. Selection 3 yrs after rooting	3. Selection 6 yrs after rooting	4. Selection 12 yrs after rooting	5. Selection 18 yrs after rooting	6. Selection 24 yrs after rooting
1968	600,000	200					
1969	10,000,000	3000					
1970	16,000,000	5000					
1	16,000,000	5000	70				
2	13,000,000	4000	1000				
3	13,000,000	4000	1700				
4			1700	50			
5			1300	700			
6			1300	1200			
7				1200			
8				900			
9				900			
1980					40		
1					500		
2					900		
3					900		
4					700		
5					700		
6						30	
7						350	
8						700	
9						700	
1990						500	
1						500	
2							20
3							300
4							500
5							500
1996							400
1997							400
Totals	68,600,000	21,200 (0.03%)	7070 (33%)	4950 (70%)	3740 (75%)	2780 (75%)	2120 (75%)
Plants per clone (planned)		10-20	100-200	1000-2000	up to 10,000	up to 10,000	up to 10,000
Plants per clone (possible)		20	200	2000	20,000	200,000	2,000,000

considerably lower (between 0.25 σp and 0.95 σp at each step). Since, however, other characteristics such as flushing, disease and cold resistance, etc., also come into consideration in these tests the actual selection intensities for single characteritics are lower than those stated.

The aim of providing multiclonal synthetic varieties with at least 100 clones for each of the most productive Norway spruce sites in Lower Saxony (about 40% of the total sites) could be achieved at any time. It depends only upon the investment made in propagation equipment, as sufficient clones have already been selected. At present, however, it is intended to enlarge the propagation facilities step by step in order to gain further experience of multiclonal synthetic varieties of spruce.

6. GENETIC GAIN

The results of Norway spruce provenance experiments, half-sib tests and clone tests carried out at our Research Institute are reproduced in Table 2. This shows that by selecting the best provenances a genetic gain of roughly 20% can be expected at the provenance level; a further gain of 10% can be expected at the level of half-sib families (bringing the total gain to 30%), and at the individual clone level at least another 10% can be gained at family level. The original breeding material used in these tests and the composition of the test-sites undoubtedly both affect these results. The situation is, however, always a realistic one, with the genetic variances and the possible genetic gain being cautiously estimated. The possible genetic gain is determined both by genetic variances and by the residual variance remaining in the breeding material.

TABLE 2 - Genetic gain under different selection intensities

Name of experiment	Character	Mean	Standard deviation	Genetic variance	Number	Genetic gain under different selection intensities absolute 15%	10%	5%	1%	0.1%	% of mean 15%	10%	5%	1%	0.1%
Provenance level															
Hasbruch	Height	123.7	51.1	0.13	167	6.90	8.84	11.32	16.08	20.71	5.6	7.1	9.2	13.0	16.7
Langlet	"	25.5	14.5	0.20	332	2.90	3.71	4.76	6.76	8.70	11.4	14.6	18.7	26.5	34.1
Half sib level															
Bremervorde	"	90.9	31.0	0.22	120	6.82	8.73	11.18	15.89	20.46	7.5	9.6	12.3	17.5	22.5
Katlenburg	"	97.8	29.2	0.22	120	6.42	8.22	10.54	14.97	19.27	6.6	8.4	10.8	15.3	19.7
Rotenburg	"	78.2	28.4	0.18	15	5.11	6.54	8.38	11.91	15.34	6.5	8.4	10.7	15.2	19.6
Katlenburg	"	120.5	28.9	0.31	8	8.96	11.47	14.69	20.87	26.88	7.4	9.5	12.2	17.3	22.3
"	"	99.2	26.2	0.11	15	2.88	3.69	4.73	6.72	8.65	2.9	3.7	4.8	6.8	8.7
Westerhof	"	373.8	92.4	0.07	48	6.47	8.28	10.61	15.07	19.40	1.7	2.2	2.8	4.0	5.2
"	"	386.0	79.4	0.09	35	7.15	9.15	11.72	16.65	21.44	1.9	2.4	3.0	4.3	5.6
"	"	375.1	19.4	0.05	24	0.97	1.24	1.59	2.26	2.91	0.3	0.3	0.4	0.6	0.8
"	"	386.9	82.2	0.03	24	2.47	3.16	4.04	5.75	7.40	0.6	0.8	1.0	1.5	1.9
Clone level															
Cuttings[1]	" 1971	165.8	34.5	0.10	5	3.45	4.42	5.67	8.05	10.37	2	3	3	5	6
Cuttings[2]	" 1971	184.2	45.5	0.35	5	15.93	20.38	26.12	37.11	47.78	9	11	14	20	26
Nursery expt[3] rooted 1968	" 1970	41.9	10.8	0.39	189	4.19	5.37	6.88	9.78	12.59	10	13	16	23	30
" 1970	" 1972	38.7	11.1	0.70	1912	7.76	9.94	12.73	18.09	23.29	20	26	33	47	60
" 1970	Flushing 1972	21.5 days	9.7 days	0.98	90	9.51	12.18	15.61	22.17	28.5	44	57	73	103	133
" 1970	Bud set 1972	44.0 days	28.7 days	0.95	90										

[1] Cutting experiment, planted at 5 different sites, including extreme conditions for Norway spruce

[2] Results of cutting experiment in line above when tree climatic zones are separated

[3] At age of 3 years

By means of thorough selection of elite clones a point is soon reached at which the genetic variance is almost nil and there remains only a residual variance which is determined by environment. At this point further improvement can be expected only by hybridisation, especially at the species level. This is planned.

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