VEGETATIVE PROPAGATION IN FOREST MANAGEMENT OPERATIONS

Bruce Zobel

Abstract.--A "revolution" involving vegetative propagation is on the new horizon in operational forest regeneration. Although vegetative propagules have been used for operational regeneration programs for many years in a few genera such as *Populus* in hardwoods or *Cryptomeria* in conifers, for most forest trees it has generally been considered something for the future. The future is now here and a great deal of progress has been made in the use of vegetative propagation in both hardwoods and conifers.

The appeal of vegetative propagation is in the gains possible through the transferal and utilization of all the genetic variance rather than only the additive portion used in standard sexual propagation programs. This is of special importance for certain growth and adaptability characteristics, and gains will be greatly improved over those that have been achieved using conventional methods.

Dangers are involved when vegetative propagules are used for operational planting, but with proper planning these can be controlled or reduced. The use of large-scale vegetative propagation requires weighing gains against risks and developing a system that results in a balance most beneficial for both short- and long-term objectives.

INTRODUCTION

During the past several years a great interest has developed about possible use of various methods of vegetative propagation in forest regeneration. This method of regeneration has been employed for a long time; there are records in the literature of using rooted cuttings of *Cryptomeria japonica* for planting during the past century, reported by Ono (1882) and Kanoo (1919). Methods of rooting were developed much earlier and commercial planting of cuttings has been standard for many years. Vegetative propagation has been used successfully for centuries by horticulturists. More recently in forestry its use for research and for seed production in clonal seed orchards has become standard. But aside from a few genera like *Populus, Salix* and *Cryptomeria,* vegetative propagation has not been used extensively in operational forest planting programs.

There are many types of vegetative propagation; this paper is not the place to discuss them. Several publications summarize such work; a couple of these are "Vegetative Propagation of Forest Trees--Physiology and Practice" (1977) and "Micropropagation d'Arbres Forestiers" (Anon, 1979b). Work on methodology necessary for use of vegetative propagation is developing well. Primary emphasis in this paper will be on the use of rooted cuttings for operational planting. Grafting is primarily used to preserve trees in clone banks or for seed orchards whose objective is large-scale seed production. The newest aspect of vegetative propagation that has received a great deal of publicity and attention is tissue culture. Although considerable development is still

---

[1] Professor Emeritus, School of Forest Resources, N. C. State University, Raleigh, North Carolina 27650

necessary to make it operational (Zobel, 1977; Durzan and Campbell, 1974), tissue culture has considerable potential. I will not discuss tissue culture specially in this paper; others in this meeting have that task.

This presentation will emphasize the status, value and use of vegetative propagation in operational forest regeneration programs, not the methodology as such. Great strides are being made with southern pines (van Buijtenen, et al., 1975; Anon, 1979a), with spruce (Birot and Nepven, 1979; Rouland, 1978, Rauter, 1977 and 1979), with radiata pine (Thulin and Faulds, 1968), with Eucalyptus (Campinhos and Ikemori, 1980), and other species. Much of this development has occurred during the past five years so there are many questions related to use of vegetative propagules in applied programs that are still debated. A whole series of papers dealing with aspects of vegetative propagation was published in 1977 by the Institute for Forest Improvement in Uppsala, Sweden.

WHY USE VEGETATIVE PROPAGATION?

What is the special value of vegetative propagation that makes it so appealing to the forest manager? Except for a few genera, it is usually easier to use standard seed regeneration than vegetative propagules, yet the effort toward vegetative propagation is being strongly sponsored (Libby, 1977 and 1979; Thulin, 1969; Fielding, 1963; Campinhos and Ikemori, 1980). Tests are generally inadequate as to the relative performance of vegetative propagules and seedlings (Sweet and Wells, 1974; Sweet, 1972; Rouland, 1978). Fielding (1970) lists a number of interesting similarities and differences.

A complete and technical answer and explanation could be long, detailed and complex. Simply stated, however, the advantage of vegetative propagation is the potential for greater genetic gain and greater uniformity. Genetic variation can be partitioned broadly into additive and nonadditive variance components. When seed regeneration is used, only the additive portion of the genetic variation can be manipulated by the tree improver, unless special efforts such as control-pollination or two-clone orchards are employed; this is not easy to do with potential problems (Libby, 1977). For some characteristics, gains using seed regeneration will be large, but for others that contain significant amounts of nonadditive variance, such as certain growth characteristics, gains through seed production will only be a portion of the potential that would be possible when vegetative propagation is used (Fielding, 1970). In general terms, <u>it is possible to capture and transfer to the new tree</u> all genetic potential through use of vegetative propagation while only part of the additive portion can be captured through seed production. For characteristics such as volume growth that have only low narrow-sense heritabilities, it appears possible to more than double short-term genetic gain by using vegetative propagules rather than seed regeneration.

Another advantage of vegetative propagation is the rapidity with which selected trees can be established from outstanding parents. It is not necessary to wait for seed production before producing vegetative propagules for operational use. Just as soon as a tree has been proven to be a good genotype, it can be used directly for the easy-to-root genera like <u>Populus.</u> In sprouting species such as the eucalypts, where stump sprouts are physiologically juvenile, it takes considerable time to develop a "sprout orchard" which will produce the desired number of cuttings for operational planting. Under the best of conditions it will take several years to develop enough rootstock from which cuttings can be taken. For more difficult rooters, action must be taken to produce partial or total juvenility or to maintain trees to be rooted in a juvenile stage through methods such as hedging (Libby, 1972; Anon, 1979a, 1979b).

There have been several schemes developed to maintain juvenility while testing the genetic worth of the trees (Pousujja, 1980; Libby, et al., 1972). Methods are being worked on that will cause tissue from mature trees to return to a juvenile stage (Chaperon, 1979) in pine by continued regrafting onto young stock. This methodology has not yet been widely tried but the implications are great; if generally successful it will enable vegetative propagation of trees that are old enough to have proven their genetic worth. A great danger, being ignored by too many persons who are interested in vegetative propagation, is assessment of the worth of a tree at too young an age, especially for growth characteristics. The time frame of such testing should be little different from that of progeny tests. It can be shortened, perhaps, if the clones are selected from families that are already progeny tested. Although there are occasional reports of good juvenile-mature correlations for volume growth, the bulk of the literature for most species indicates that a reliable estimate cannot be obtained until one-half rotation age (Franklin, 1979; Wakeley, 1971). This paper is not the place to argue this most important concept, but those of us who have had widespread experience with a number of species over a long period of time are very worried about bad decisions being made regarding genetic superiority for use in vegetative propagation from too early assessments. There is such an advantage in using physiologically young material that the assumption is too often made that if the tree is superior when young it will still be superior at rotation age.

CONSIDERATIONS WHEN USING VEGETATIVE PROPAGATION OPERATIONALLY

All sorts of problems and advantages could be listed relative to the operational use of vegetative propagation after the actual propagation methods have been developed well enough to use on a mass scale. If one brings all considerations to a common denominator, it adds up to GAIN VS. RISK, i. e., how much gain can be achieved while retaining an acceptable level of risk. The basic questions are widely argued but rarely decided because of differing emphases on the relative risks. It is not important to come to a consensus; what is important is to be aware of the gains and risks and to make a conscious decision as to their relative importance.

The first concept always raised, and of prime importance, is that of the danger of planting large acreages with the same or similar genotypes. This very real problem is a tough one but often is blown out of perspective when it is being argued. On the one hand, some persons cite agriculture and its widespread use of very narrow genetic bases with outstanding success to Society and to the grower. On the other side are those persons who decry planting large acreages of trees of the same species; to them this represents a dangerous monoculture, no matter how variable are the genotypes within the species. The correct position is, of course, somewhere between these extremes. Great care needs to be taken in invoking the horrors of monoculture, but monoculture can be a horror if ignored.

Many agricultural crops can tolerate greater genetic uniformity than forest trees because:

1. The farmer has greater ability to control pests, nutrients, competition and sometimes moisture, while in forest trees such rigid control is less possible or not practical.

2. Short-lived plants are grown only during a part of the year, when conditions are most suitable for growth, so they are relatively uniform.

3. If something goes wrong with an annual-crop variety it can be massively replaced the following year.

Forest trees must survive, grow and reproduce for many years, which will include many differing environments. Weather extremes and pests are numerous, and some are sure to show up during the rotation period of the tree crop; and in order for a tree or group of trees to survive and grow they <u>must</u> be able to tolerate a broad spectrum of conditions.

A common mistake made by laymen and by some foresters is to assume that members of the clone will have little or no adaptability. This is not true; the genotype of a clone can possess a considerable ability for adaptation to differing pests or adverse environments, and we should be able to select clones with greater adaptability than possessed by the average seedling. A forest tree needs this merely to survive and reproduce. The danger arises when the adaptability from the genotype is exceeded by adverse conditions; the result will then be that all trees of a given clone will be subject to attack. But in my opinion it generally takes a much greater change in the destructive agent to destroy a forest tree clone than a true breeding, homozygous agricultural crop. From what I have observed, pathological agents seem to be the ones that can most easily destroy forest trees whose genotypes have produced otherwise good, growing trees in a given environment. Forest trees seem to be less well buffered to attacks by pests than to weather extremes, especially for exotic pests that have come from an area outside the natural range of the tree species.

So the question is--how many clones are necessary for reasonable safety and maximum gain? As usual the standard answer is "It all depends on rotation age, on intensity of forest management, on genetic variability of the species and clones involved and the likely risks and the acceptable loss levels" (Libby, 1981). It is certain that hundreds of clones are not required, as the more cautious advise. I am recommending that 15 clones be used in any one environment for one species with which I work, which is known to be quite variable and which has wide adaptability; this species is grown on short rotations. This is within the range of 7-30 recommended by Libby (1981). Since there are six different environm ents, two of which are quite distinct, we feel that it is necessary to use about 50 clones in the total operation. However, the number needed cannot be determined until testing has been completed. When the nearly 400 clones that have been chosen and have been tested are ranked, it is evident that double the gain can be obtained if the best 15 clones give double the gain over the best 100 clones. For the species, its variability and short rotations, I have no fear of unusual danger by using the best 15 clones that give large gains.

As a broad generality, I feel that for most species 20 to 25 clones are about the correct number. There are special conditions, such as severe insect or disease attacks, or very severe environments, when very few clones will be justified because only a few are available. This is a short-term and rather risky strategy. Here it becomes a case of using those few that will survive known pests or severe environments such as freezing weather. Generally, however, the more severe the stress a given species or provenance is under (i. e., they are poorly adapted to environment), the greater the number of clones that should be used.

Closely related to the number of clones is their deployment; that is, if 15 clones are used, should they be planted scattered randomly, or should they be planted in small blocks of pure clones? This was argued as early as 1918 by Hirasiro, who felt mixtures of clones were the best. If trees are planted in clonal blocks, then the question arises as to the size of the blocks that are safe. Forest management and logging efficiency and product uniformity all favor large blocks, but the larger the blocks the greater the danger from monoculture, with its attendant risks from pests or adverse environments. It is essential, however, that the blocks meet some minimal operational size if they are to be efficient.

The immediate reaction of most persons is that clones should be planted in mixture. I do not agree with that for the following reasons; furtheLmore, the analysis of Libby (1981) indicates that mosaics of monoclonal plantings are often the best strategy:

1. Each clone tends to have a different growth curve and developmental pattern. At worst this means that some clones will never be able to develop properly in mixture and might even be severely suppressed by competition from other clones. At the least there will be differences in size and quality, reducing one of the greatest advantages of vegetative propagation, i. e., greater uniformity.

2. Planting and "nursery" operations are much simplified when planting by blocks.

3. Wood uniformity among trees is maximum within a block of trees from the same clone. I foresee the time when trees of different blocks may be used for special products, such as plywood or sawtimber.

4. It is suggested that mixing clones will slow down the spread of pests. This is certainly true for root diseases and for some insects but is less efficient for diseases spread by air-borne spores. I have observed many times that things such as leaf diseases or canker diseases seem to spread about equally rapidly in pure or mixed species stands.

5. If a really serious problem develops within a given clone, a whole block can be harvested and replaced to keep the forest in maximum productivity. Even if it were possible to salvage an individual clone (for example, one of 15), it cannot be replaced when clones are mixed and low stocking results. Generally salvage from mixtures is not economically feasible and often the salvage operation causes more damage to the residuals than the net return from the salvage.

How large should each clonal block be? Again there are all kinds of qualifications based upon species, rotation age and genetic uniformity. For species with reasonable variability and short-rotation ages, I have been recommending pure-clone blocks of 10 to 20 hectares. Many persons feel these are too large but I do not; anything much smaller than 10 hectares becomes inefficient to operate as a unit, and I don't feel the added danger from the larger blocks is that important. With more experience this recommendation may well change, but with what is now known we are going with 10- to 20-hectare blocks.

Another general concept that must be considered is cost of vegetative propagules vs. seedlings. Usually, vegetative propagules are much more expensive to produce and to establish than are seedlings. As methods are developed and experience is gained, costs of vegetative propagules can be reduced greatly (Kleinschmit and Schmidt, 1977) or even be no greater than seedlings (Campinhos and Ikemori, 1980). Direct cost comparisons are really not useful because one must weigh the added gains against the costs. Often a considerable additional cost per planted tree becomes insignificant when assessed on a cost-per-acre basis. For example, just a couple of percentage points of improvement in return from using the better cuttings can often more than justify a doubling or tripling of cost of plant establishment in the field. In my opinion, the cost differential between seedlings and vegetative propagules will continue to diminish as methods are seriously developed for operational scale programs.

Rooting ability varies greatly by clone (Sorenson and Campbell, 1980: Hyun, 1967). In some species, so few parent trees respond well enough to rooting that the broad genetic potential is reduced to an alarming degree. If one selects or develops 100 outstanding trees but only 10 of these root well enough to use operationally, the effectiveness of the program will be greatly limited. Differential rooting appears to be general and has been a serious problem in developing tissue culture methodology in the southern pines. Improved techniques will help some, but losses of large numbers of otherwise excellent genotypes because they have a poor rooting ability may prove to be a serious strain in some species.

OPERATIONAL USE OF VEGETATIVE PROPAGATION-- POTENTIALS FOR THE SOUTH

Little comment is needed on the use of vegetative propagation for species in the genera Populus, Salix, Sequoia, Picea or others. Methods for the first two are known and operational. The major criticism in poplars is not in methodology of regeneration but in lack of hard-hitting, ongoing breeding programs to produce better trees for the regeneration program. Although some organizations have intensive genetic improvement programs combined with their vegetative regeneration, most do not; these latter merely select within natural stands or plantations or produce F_1 hybrids to choose from. Hybrids are often no better than the parents used, and a genetics program to improve the parents before new hybrids are made is essential for long-term gain. Too many persons feel there is something magic about hybrids but they need improvement as do the pure species. Initial gains are large but future gains will be limited without intensive breeding programs.

The vegetative propagation programs in the conifers are just getting started, with the exception of Cryptomeria in Japan. Good gains will be possible by determining outstanding genotypes from current stands but this is not enough and new and improved trees need to be developed. I feel so strongly about this that I do not recommend that my clients spend a lot of time and money on developing sophisticated vegetative propagation techniques unless there is a parallel intensive genetic improvement program.

Although it is evident to biologists working in this area that a good phenotype may or may not produce a good plant when vegetative propagation is used, many persons assume that a good-looking tree will produce good cuttings. A shockingly large number of organizations do not even test the vegetative propagules and assume that propagules from a good tree will produce good forest trees. Others make the error of assessing the value of cuttings at too young an age. Too early assessment probably is the most serious error being made when vegetative propagation is used operationally; the error is not easily observed, no matter what the rotation age, although it is more evident under long rotation conditions. Libby (1977) addresses the differences in testing philosophy.

Outside of a few species, vegetative propagation is in the developmental stage in the South. Currently, for both rooted cuttings and tissue culture, technique development is of primary importance. Great progress is being made (van Buijtenen, et al., 1975; Pousujja, 1980; Mott, et al., 1976) and I feel it is only a matter of time till both the southern pines and some of the hardwoods will be operationally planted, using vegetative propagules. Methods of developing juvenility (Franclet, 1979) or maintaining juvenility by hedging (Libby, et al., 1972; Thulin and Faulds, 1968; Brix and van Driessche, 1977) are essential to further developments for operational planting of vegetative propagules in the South. Studies of growth and form comparing vegetative propagules to seedlings have been started in the southern pines; I am hopeful we can obtain information such as that by Rouland (1973, 1978) and Birot and Nepven (1979). The tremendous developments in just the past few years in the eucalypts (Campinhos and Ikemori, 1980; Laplace and Quillet, 1980; Franclet, 1963; Chaperon, 1979; Destremau, et al., 1980) show what can be done in a short time. Many questions of proper clone numbers and their allocation are still unanswered but excellent progress is being made. I feel that the progress with the eucalypts may well indicate what might happen in the South.

In my opinion the use of vegetative propagules is special in a forestry operation and they should be used for specific products or needs on the most suitable sites. For example, if a certain kind of wood is desired it can often be supplied by rooted cuttings, even though the genetic base may need to be restricted to fill this special need. For example, many eucalypts have interlocked grain or wood that is under internal stresses that cause splitting when the trees are felled. Occasional trees are straight-grained without internal stress and make fine high-quality plywood or furniture. The few clones with suitable wood can be used to supply the special need for quality. Often, disease-free trees have produced generally disease-free rooted cuttings; a prime example is Diaporthe cubensis on Eucalyptus in Brazil. I can foresee the same special usage of vegetative propagules in the South, i. e., to produce trees with special, uniform or otherwise desirable qualities. I do not foresee the use of vegetative propagules on a wholesale scale in the southern pines in the near future, although a very heavy usage could well occur for some quality hardwoods. Although not generally operational, studies on rooting cuttings have been done on sweetgum (Liquidambar styraciflua) by Brown and McAlpine (1964); on black walnut (Juglans nigra) by Carpenter (1975);

on black cherry (*Prunus serotina*) by Farmer and Besemann (1975); on sugar maple (*Acer saccharum*) by Gabriel, et al. (1961); on water oak (*Quercus nigra*) by hare (1977); on yellow-poplar (*Liriodendron tulipifera*) by McAlpine and Kormanik (1972), and on other hardwoods. Several of the authors mentioned feel that vegetative propagation in hardwoods can be developed operationally, and there is no doubt of its value for the species with high-quality woods.

We in the South have a major advantage in that we have ongoing programs for the development of genetically superior stock on which vegetative propagation can be used when the methodology has become more refined. If the South is to stay competitive in the long-term future, we need to take advantage of every possible improvement. Vegetative propagation is the best method to obtain quicker and larger yields of more uniform and desirable wood from genetically improved trees.

LITERATURE CITED

Anon. 1977. Vegetative propagation of forest trees--physiology and practice. Lecture from a Symposium in Uppsala, Sweden. February. The Institute for Forest Tmprovement and the Department of Forest Genetics, College of Forestry, The Swedish University of Agricultural Sciences. 159 pp.

Anon. 1979a. Twenty-Seventh Progress Report of the Cooperative Forest Tree Improvement Program. For. Gen. Lab., Texas Forest Service. pp. 4-5.

Anon. 1979b. Micropropagation d'Arbres Forestiers. AFOCEL. No. 12, Assoc. Fork-Cellulose (France). 76 pp. (A collection of papers)

Birot, Y. and G. Nepven. 1979. Clonal variability and ortet-ramet correlations in a population of spruce. Sil. Gen. 28(2-3):37-47.

Brix, H. and R. van Driessche. 1977. Use of rooted cuttings in reforestation. Brit. Col. For. Ser. and Can. For. Ser. Joint Rept. #16. 16 pp.

Brown, C. L. and R. G. McAlpine. 1964. Propagation of sweetgum from root cuttings. Ga. For. Res. Pap. 24, Ga. For. Res. Coun. 5 pp.

Campinhos, E. and Y. K. Ikemori. 1980. Mass production of Eucalyptus spp. by rooting cuttings. IUFRO Symp. on Genetic Improvement and Productivity of Fast-Growing Trees. Sao Pedro, São Paulo, Brazil. August. 16 pp.

Carpenter, S. C. 1975. Rooting black walnut cuttings with Ethephon. Tree Planters' Notes (Summer). p. 3.

Chaperon, H. 1979. Maturation and reproduction of cuttings of forest trees. Micropropagation d'Arbres Forestiers. AFOCEL. pp. 19-31.

Destremau, D. X., J. N. Marien and M. Boulay. 1980. Selection et multiplication vegetative d'hybrids d'eucalyptus resistant au froid. Symp. on Genetic Improvement and Productivity of Fast-Growing Trees. Sao Pedro, Sao Paulo, Brazil. August. 13 pp.

Durzan, D. J. and R. A. Campbell. 1974. Prospects for the mass production of improved stock of forest trees by cell and tissue culture. Can. Jour. For. Res. 4(2):151-174.

Farmer, R. E. and K. D. Besemann. 1975. Rooting cuttings from physiologically mature black cherry. Sil. Gen. 23(4):104-105.

Fielding, J. M. 1963. The possibility for the establishment of commercial plantations of Monterey pine. First World Consultation on Forest Genetics and Tree Improvement. Stockholm, Sweden. 5/10. 8 pp.

Fielding, J. M. 1970. Trees grown from cuttings compared with trees grown from seed (P. radiata). Sil. Gen. 19(2-3):54-63.

Franclet, A. 1963. Improvement of Eucalyptus reforestation areas by vegetative multiplication. First World Consul. on For. Gen. and Tree Impr., Stockholm, Sweden. 5/5. 8 pp.

Franclet, A. 1979. Micropropagation of forest trees--rejuvenation of mature trees in vegetative propagation. AFOCEL. No. 12. pp. 3-18.

Franklin, E. C. 1979. Model relating level of genetic variance to stand development of four North American conifers. Sil. Gen. 28(5-6):207-212.

Gabriel, W. J., J. W. Marvin and F. H. Taylor. 1961. Rooting greenwood cuttings of sugar maple--effect of clone and medium. Sta. Pap. No. 144, NE For. Expt. Sta., USFS, Upper Darby, Pa. 14 pp.

Hare, R. C. 1977. Rooting of cuttings from mature water oak. South. Jour. Applied For. 1(2):24-25.

Hirasiro, M. 1918. A proposal to grow seedlings and cuttings of Cryptomeria in thorough mixture. From Abstracts of Japanese Literature in Forest Genetics and Related Fields (edited by R. Toda). Vol. I, Part A, p. 163.

Hyun, S. K. 1967. Physiological differences among trees with respect to rooting. IUFRO Congress (München) III(22):168-190.

Kanoo, K. 1919. An outline of forestation by Cryptomeria cuttings in Obi, Miyazaki prefecture. From Abstracts of Japanese Literature in Forest Genetics and Related Fields (edited by R. Toda), Vol. I, Part A, p. 113.

Kleinschmit, J. and J. Schmidt. 1977. Experiences with Picea abies cuttings in Germany and problems connected with large-scale application. Symp., Vegetative propagation of forest trees--physiology and practice. Uppsala, Sweden. pp. 65-86.

Laplace, Y. and G. Quillet. 1980. Sylviculture intensive pour materiel vegetal ameliore. Symp. on Genetic Improvement and Productivity of Fast-Growing Trees, Sao Pedro, Sao Paulo, Brazil. August. pp. 1-8.

Libby, W. J., A. G. Brown and J. M. Fielding. 1972. Effects of hedging radiata pine on production, rooting and early growth of cuttings. New Zealand Jour. For. Sci. 2(2):263-283.

Libby, W. J. 1977. Rooted cuttings in production forests. 14th South. For. Tree Impr. Conf., Gainesville, Fla. pp. 13-27.

Libby, W. J. 1979. Clonal selection of forest trees. Calif. Agriculture 33(5):8-10.

Libby, W. J. 1981. What is a safe number of clones per plantation? Proc., IUFRO Meet. on Genetics of host-pest interaction. Wageningen. (In press)

McAlpine, R. G. and P. P. Kormanik. 1972. Rooting yellow-poplar cuttings from girdled trees. USDA, For. Ser. Res. Note SE-180. 4 pp.

Mott, R. L., R. H. Smeltzer, A. Mehra-Palta and B. J. Zobel. 1976. Production of forest trees by tissue culture. Tappi 60(6):62-64.

Ono, M. 1882. Which grow faster, seedlings or cuttings in the case of <u>Cryptomeria</u> or hinoki cypress? From Abstracts of Japanese Literature in Forest Genetics and Related Fields (edited by R. Toda). Vol. I, Part a, p. 22.

Pousujja, R. 1981. Potentials and gains of a breeding program, using vegetative propagation compared to conventional systems. Ph. D. Thesis, N. C. State Univ., Raleigh, N. C.

Rauter, M. 1977. Collection of spruce cuttings for vegetative propagation. For. Res. Note #11, Ministry of Natural Resources, Ontario, Canada. 4 pp.

Rauter, M. 1979. Spruce cutting propagation in Canada. Breeding Norway Spruce, Norway Spruce Provenances. IUFRO, Div. 2, Bucharest, Romania. 10 pp.

Rouland, H. 1973. The effect of cyclophosis and topophysis on the rooting ability of Norway spruce cuttings. Forest Tree Improvement #5, Arboretet, Hørsholm. Akademisk Forlag.

Rouland, H. 1978. Stem fotw of cuttings related to age and position of scions <u>(Picea abies).</u> Forest Tree Improvement #13, Arboretet Hørsholm. Akademisk Forlag. 24 pp.

Rouland, H. 1978. A comparison of seedlings and clonal cuttings of Sitka spruce <u>(Picea sitchensis).</u> Sil. Gen. 27(3-4):104-108.

Sorenson, F. C. and R. K. Campbell. 1980. Genetic variation in rootability of cuttings from one-year-old western hemlock seedlings. PNW-352 (Research Note), Portland. 8 pp.

Sweet, G. B. 1972. Effect of maturation on the growth and form of vegetative propagules. Second N. Amer. Biol. Workshop, Corvallis, Ore. Society of Am. For. pp. 46-47.

Sweet, G. B. and L. G. Wells. 1974. Comparison of the growth of vegetative propagules and seedlings of <u>Pinus radiata.</u> New Zealand Jour. For. **Sci.** 4(2):399-409.

Thulin, I. J. and T. Faulds. 1968. The use of cuttings in breeding and afforestation of <u>Pinus radiata.</u> New Zealand Jour. For. 13(1):66-77.

Thulin, I. J. 1969. Breeding of Pinus radiata through seed improvement and clonal afforestation. Second World Consul. on For. Tree Breeding, Washington, D. C. FO-FTB-69. 9/5. 6 pp.

van Buijtenen, J. P., J. Toliver, R. Bower and M. Wendel. 1975. **Mass** production of loblolly and slash pine cuttings. Tree Planters' Notes. 4 pp.

Wakelev, P. C. 1971. Relation of thirtieth year to earlier dimensions of southern pines. For. Sci. 17(2):200-209.

Zobel, B. J. 1977. Tissue culture (as seen by a plant breeder). Tappi 61(1): 13-15.