VEGETATIVE PROPAGATION IN FORESTRY

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ABSTRACT.--Even though rooted cuttings have been used in Japan for more than a century to regenerate forests the use of clonal material for production propagules is not broadly accepted. Plantation experience with clonal stock for some of the major forest crops is still being developed. There are three major advantages of clonal propagules over seedlings from a tree improvement program for the establishment of forest plantations, potential cost reduction of the propagule, decreased time to get tree improvement gains into field plantations and an increased wood production gain each generation. Small numbers of plantlets have been produced by tissue culture technology for all major forest crops. The advantages of rooted cuttings will apply to the production use of plantlets but will be even more effective. We have not yet established a single production scale plantation of any species with plantlets. As with cuttings a long experience period will be necessary for general acceptance. The production use of tissue culture plantlets, although they have tremendous potential, is still very much in the future.

INTRODUCTION

A significant part of the domestication process of any plant is an adequate method of propagation. Propagation must be easy to control by man and it must adequately and consistently reproduce the genetic improvement developed in each strain. With most annual plants this is not a problem. Seed is easy to produce and using modern crop improvement technology seed produces the uniformity and genetic improvement necessary in modern agriculture. In some cases such as the potato, selected strains are propagated vegetatively as the method of choice. But for these few exceptions domesticated annual plants are propagated by seeds with vegetative propagation playing no significant role.

With woody perennial plants however, quite another approach is found. Most domesticated woody plants are propagated vegetatively. Because the plants are long lived and produce for an extended period, the extra effort required for vegetative propagation is of no consequence. And because woody plants usually have rather long life cycles it is difficult to breed enough successive generations to develop uniformity as well as superiority. The rubber tree (Hevea brasiliensis) is perhaps the best example of the refined use of vegetative propagation. New strains are developed by combination and selection in the usual breeding process. Production trees are developed from these selections in a unique way by double grafting.

Special clones are selected to give a good stable root system. On these are grafted clones with desirable stem characteristics primarily with ample latex ducts for tapping. On top of these interstocks are grafted clones with good crown characteristics such as vigor, latex production and resistance to wind damage. Thus, the production tree is built with great care (Dijkman 1951).

With the wild stands of forest trees no longer able to supply the future needs of man for forest products, the forest industry has embarked upon the initial stages of domestication. This process will result in domesticated strains of various forest trees to increase wood production in commercial forests. Vegetative propagation for plantation propagules will probably be a significant part of the domestication venture.

This paper will review the status of vegetative propagation of forest trees by discussing the potential advantages and disadvantages and to display how it might be accomplished.

THE ADVANTAGES OF VEGETATIVE PROPAGATION IN FORESTRY

Seed has been the traditional method of propagation in forestry from the very beginning of a regeneration effort. It was a natural transition from the earlier efforts to control natural seed fall. When this proved inadequate methods of direct seedling itself were developed and eventually the production of seedlings in a nursery became the standard practice. But with the advent of accelerated tree improvement efforts it was realized that seed had significant limitations compared with vegetative propagules for production plantations. Most important has been the potential for increased gains from any one generation of a tree improvement effort. Because of the ability to select for both additive and nonadditive gene effects, a significantly higher gain is anticipated from the vegetative propagation of planting stock. Shelbourne and Thulin (1974) and Libby et al. (1972) have examined this subject. Kleinschmit (1974) has indicated that at least a 10% increase in gain can be expected from planting selected clonal propagules rather than selected families. Our own work with western hemlock (Tsuga heterophylla (Raf.) Sarg.) substantiates this. Furthermore, this 10% increase in gain should be possible, each generation with selected clonal propagules.

It is still necessary for the breeding activities to be conducted in a recurrent selection program to develop new genotypes. It appears feasible with both Douglas-fir and loblolly pine to conduct the breeding activities for each generation in a potted breeding orchard. The families produced can then be tested in a clonal field test where not only would the family be represented by several individuals but each individual would be replicated as well. The selected individuals from this test could then be placed in a hedged orchard for the production of operational cuttings. Current technology suggests that the cuttings for the hedging orchard should be taken at the same time as the genetic test cuttings and maintained by hedging until selections have been made.

The second significant opportunity available with clonal propagation of operational planting stock is the saving of time. The principal leverage point in an industrial tree improvement program is time. It now takes at least 16 years after selection for either a Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) or loblolly pine *(Pinus taeda* L.) orchard to attain full production. It is only when this orchard has attained full production that the gains of a tree improvement effort are fully realized as benefits to the corporation in the form of improved growing stock in the field.

Ross 1975a found in studies with 1-year-old seedlings of Douglas-fir that 45 cuttings could be obtained per seedling by special hedging techniques. It is conceivable using this technique to produce as many as 1/2 million cuttings from a single seedling clone in a 5-

year interval (Ross 1975b). Even with only a few hundred selected clones from each geographic area it is possible to produce large quantities of operational planting stock in a short time. It is anticipated that the current 16-year period for development of seed orchards might be shortened to 4-years with rooted cuttings to produce full planting stock requirements after selection from genetic tests. And this savings in time could result in propagules with at least a 10% additional increment in gain over seedlings.

The third advantage of clonal propagules over seedlings as the end product of a tree improvement program is a potential overall reduction in cost. Now with current technology cuttings do cost more to produce in the propagation phase. Kleinschmit (1974) has estimated that cutting costs are at least 30% above seedlings. Our preliminary estimates indicate it may be as great as twice standard 2-0 seedling costs with the potential of reducing this with mechanization.

In fully exploiting the process however, there is the potential for a substantial off-setting reduction in costs. Libby et al. (1972) found that radiata pine (Pinus radiata D. Don) hedges when fully established will yield about 100 cuttings/m^2 each year. Our own experience is that more nearly 400 cuttings/m^2 are obtainable annually from both Douglas-fir and loblolly pine. In a hypothetical hedging orchard half of which was used for production and half for access rows, about 2 million cuttings per hectare could be produced annually.

With a seed orchard using loblolly pine as an example, about 0.5 kg of seed is produced annually per tree or 8,000 plantable seedlings. A fully stocked orchard should have no more than 100 trees per hectare. Thus, a seed orchard will produce 800 thousand seedlings annually in contrast to 2 million cuttings from the same land area. For the same planting stock requirement the orchard area need only be 1/2 the size with cuttings, assuming 80% rooting, with a consequent saving in capital and operating costs.

The potential for further reductions in cost are possible with the new technology of tissue culture to be discussed later.

THE PROBLEMS OF VEGETATIVE PROPAGATION

With some species of forest trees the use of cuttings for the operational production of planting stock is a new and untried process. But a few species have been cultured long enough as clones to give some optimism that the problems can be resolved for other forest trees of interest. The Japanese have been successfully propagating *Cryptomeria japonica* for centuries by vegetative means (Toda 1974). In Germany, Kleinschmit (1974) has set out one million Norway spruce *(Picea abies* L. (Karst.)) cuttings in 1973 alone. These trees have been growing under plantation conditions sufficiently long to demonstrate the success of clonal stock.

Other species such as Douglas-fir and loblolly pine have no such background, but field studies have been established to evaluate growth, root development and wind firmness for vegetative propagules of these species. It is anticipated that unresolvable problems will not develop for Douglas-fir and loblolly pine but an experience base must be developed before a production program is initiated.

Plagiotropic growth habit (the retention of a branch-like form of growth) is of concern to foresters. It does not appear to be significant in Norway spruce (Kleinschmit 1974) or radiata pine although other differences in form characteristics are noted (Sweet and Wells 1974). Little experience is available with loblolly pine. However, plagiotropic growth habit is not a characteristic of grafted stock in seed orchards even when fully mature scions are used so it is not anticipated that rooted cuttings of loblolly pine will be subject to this problem. Slower growth of mature cuttings may be a problem, however, and maintenance of juvenility may be necessary.

Douglas-fir, however, does show plagiotropic growth. It is common in seed orchards with grafted stock of mature scions and persists for several years. Cuttings commonly exhibit plagiotropic growth (Copes 1976). The length of time it persists and the proportion of cuttings with abnormal growth are dependent on the age of the ortet from which the cuttings are taken. Cuttings from younger ortets exhibit abnormal growth less frequently, and those that do recover more rapidly (Ross 1975a). Results of our work indicate a significant clonal relationship as well, with some clones exhibiting no abnormal growth.

In summarizing the existing knowledge on Douglas-fir, it seems that if ortets less than 4-years old serve as the source of cuttings, plagiotropic growth will not persist for more than a year or two. The real concern is whether this level of juvenility can be maintained for at least another several years by hedging. Controlled studies are now in place to evaluate this potential. If juvenility can be maintained by hedging, then testing and selection can be completed and the hedge will be productive for a number of years. While final understanding of this issue must await the outcome of these studies, preliminary responses from 36-year-old ornamental hedges indicate maintenance of juvenility may be possible for even this length of time.

In addition to the question concerning cutting performance in plantations and the maintenance of juvenility during the propagation period, there are basic concerns as to whether clonal plantations are even a desirable means of operational forest regeneration. These concerns derive primarily from the assumption that large land areas will be planted to one or a few clones. The subsequent discovery that these clones are susceptible to an environmental or biotic factor causing mortality would naturally jeopardize the survival of all similar plantations. Forest landowners have a great stake in the correct use of clonal planting stock. The financial success of their plantations is dependent upon it.

There are three factors to be considered in the use of clonal stock. First, of course, not all forests will be regenerated with clonal planting stock, but rather only those intensively managed commercial forests used for wood production. Thus, there will be large areas of forest managed at a low level or not at all which will be regenerated naturally or by the planting of seedlings.

Secondly, not all intensively managed forests will be planted with clonal stock. One of the older programs by the Lower Saxony Forest Service (Kleinschmit 1974) anticipates planting only 40% cuttings by 1990. The remaining plantations would be initiated with seedling stock of seed orchard origin.

Thirdly, very large numbers of clones will be used as a basis for the establishment of plantations on any one site. The aim of the above program is to provide at least 100 clones for each of the most productive sites. With this number a sufficiently broad genetic base can be maintained to respond to adverse biotic or environmental factors.

This is not to suggest that single clones may not be grown on small management units. There may be real advantages from the management, harvesting and utilization point of view to have uniformity by management unit by planting a single clone. Harvesting, perhaps, would be simplified and the specific wood properties of a clone could be used for a higher quality product without sorting single stems. But the broad genetic base would be maintained in that all the clones would be represented in the ecotype for that site condition.

The general consensus, based on those clonal programs already under way and those under consideration, is that the knowledgeable use of clonal material will provide a genetic base sufficiently broad for forestry operations. But larger numbers of clones than commonly used in agriculture for small geographic ecotypes are necessary. With annual agricultural crops, a few clones or inbred lines will often supply most of the production of that crop on a worldwide basis (NAS 1972). This relationship would be unacceptable with intensively managed forests.

METHODS OF VEGETATIVE PROPAGATION

Perhaps the oldest method used commercially for clonal propagation is grafting. It has been used as the preferred method of propagating select fruit trees and the rubber industry has developed grafting as the central means of implementing the breeding gains in production plantations (1). But it has little potential in forestry for the production of operational planting stock. It is a costly process and the graft union is an exceptionally weak point on the stem, commonly subject to incompatibility in many species (Copes 1967).

The current method of producing propagules in forestry is by rooted cuttings. At least two species, *Cryptomeria japonica* (Toda 1974) and *Picea abies* (Kleinschmit 1974) have been propagated in sufficient numbers to support a production program. At least three other important commercial forest crops, radiata pine, loblolly pine and Douglas-fir, are in various stages of developing technology to support a production program. While there are some problems as previously discussed, the use of rooted cuttings as production planting stock for forest plantations will very likely continue to be expanded.

The methods of producing large quantities of rooted cuttings varies significantly. Kleinschmit (1974) uses the rooting bed technique with plastic greenhouses to maintain humidity. *Cryptomeria* has been rooted directly in the plantation under favorable conditions but more commonly in nursery beds (Toda 1974). Radiata pine likewise has been rooted in nursery beds without a cover (Fielding 1954) but it more commonly requires some means to maintain higher levels of humidity. In our own facilities Douglas-fir and western hemlock cuttings have been rooted in small containers in a greenhouse as well as in nursery beds with a plastic coverhouse. Much more can be learned that will reduce costs but functional systems are now available.

There is another method, only in its earliest stages of development, that offers great promise for the production of clonal planting stock and that is tissue culture. With the first production of carrot plantlets from tissue culture (Steward et al. 1958), few in forestry could envision a significant impact in their field. It was not until the production of the first aspen plantlets by a series of workers beginning with Mathes (1969) in 1964, Wolter(1968) and Winton (1968) that the potential for this new technology in forestry became apparent.

The first conifer plantlets were produced in Brown's laboratory (Sommer et al. 1975) in 1973 from cultures of longleaf *(Pinus palustris* M.) and loblolly pines. With this work came the hope that all of the advantages of clonally propagated planting stock could eventually be realized in forestry through tissue culture.

Since that time other commercial conifers have been cultured to produce plantlets. Douglas-fir and western hemlock plantlets have been produced by Cheng (1976, 1977) and the production of Douglas-fir plantlets is now the subject of an intensive investigation. Cultures of radiata pine have likewise produced plantlets (Reilly and Washer 1977). All of these major forest trees have yielded plantlets in relatively small numbers. In most cases, shoot production is limited or the low rate of root initiation on the shoots combines to keep plantlet production small.

The commercial application of tissue culture and particularly its successful use in the horticulture business gives encouragement that the problems can be overcome in forestry as discussed in recent reports by Wochok (1978)and Wochok and Abo El-Nil (1978). There are many problems for which solutions must be found. But progress seems satisfactory for such a new venture in commercial forestry. There are now at least 3 corporations with active research programs in forest tree tissue culture and numerous universities have projects as well. This increasing interest speaks well for the importance of this technology in our business.

But we must remember that at this date there are no forest plantations established from tissue culture sources. At best there are only a few small test plots recently planted with plantlets. We have no experience with conifer plantlets in a field environment. There have been many plantations of rooted cuttings established and some are now nearing harvestable age. Much of the information developed On the field performance and plantation management of rooted cuttings may also apply to plantlets. But many field plantations of plantlets will be necessary to develop a base of experience before the forest industry will feel comfortable with plantlets as a useful production tool.

Even though the Japanese have been regenerating forests with rooted cuttings for more than a century and other programs are well established, the use of rooted cuttings as an operational propagule is not generally accepted in the forest industry, but once clonal propagation becomes a standard forest regeneration tool the advantages of tissue culture will become apparent. Cost per propagule of tissue culture plantlets should be significantly lower than that for rooted cuttings, tissue culture technology may be able to accomplish the same objective in one year.

The important breakthrough in mass propagation will come when plantlets or embryos can be cultured in liquid suspension culture. As yet no conifer has been produced by this means. But the fact that American elm *(Ulmus americana* L.) has yielded to a similar method (Durzan and Lopushanski 1975) gives encouragement. The production of large numbers of clonal planting stock necessary for commercial forestry operations should then be more realistically attainable.

Tissue culture has the promise of contributing substantially to productive commercial forests of the future. Mass propagation is the tissue culture objective with the greatest immediate impact. But there are at least several other potential developments in tissue culture even further out in time. Some are concepts with such great potential for change it is difficult to clearly view their ultimate effect. But even with modest success it is evident that the impact on production forest will be great.

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