Clonal approaches to hardwood forestry in the tropics

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Abstract

Although a few timber trees have been cultivated clonally for hundreds of years, it is only in the last 30 years that this approach has been more widely practised, especially in tropical species. Following research to understand the factors affecting rooting ability in tropical hardwoods, vegetative propagations techniques are now available that are applicable to almost all species. Different approaches to the selection of superior trees for cloning are examined. This paper reviews the key factors determining when and how to utilize clonal approaches to tree improvement, the choice of appropriate strategies to use, the issues of concern and some best practices. It reviews the techniques and practice of clonal forestry in a range of tropical hardwoods, as case studies, and examines some of the areas of research needed to move the approach forwards.

Key Words: Tree improvement, silviculture, vegetative propagation, plus-tree selection, *Eucalyptus* hybrids, *Triplochiton scleroxylon*.

Introduction

Trees, unlike agricultural crops, have been difficult to improve genetically, because of their long generation times, irregularity of flowering and fruiting, the prevalence of out-breeding and low heritability of desirable traits and the frequent absence of substantial germplasm collections. Although some genetic gains have been achieved by tree-breeding including hybridization, foresters have traditionally improved yield and form by provenance transfer. Clonal approaches to forestry are not new, and have been practised for hundreds / thousands of years in Europe with willows (*Salix* spp.) and poplars (*Populus* spp.), and with *Cryptomeria japonica* D.Don in Japan and China (Ohba, 1993). In the last 25 years, however, there has been growing interest in clonal forestry with conifers, *Eucalyptus* and a wide range of other commercially important species (Ahuja and Libby,1993 a/b; Evans and Turnbull, 2004). This has arisen from recognition (Leakey *et al*, 1982b; Leakey, 1987) of:-

(i) the potential to exploit the considerable amount of genotypic variation present within tree populations,
(ii) the increasing number of tree species that have been found amenable to vegetative propagation,
(iii) the opportunity to harness and exploit genotypic variation directly through the combination of vegetative propagation and clonal selection
(iv) the attractive investment opportunities in clonal forestry arising from:
  - increasing yields and quality,
  - shortening rotations,
  - the alleviation of biological problems (*e.g.* seed storage and poor viability) hindering reforestation with hardwood species.

With regard to the opportunities and strategies available to foresters, Libby (1985) has listed 16 potential advantages of clonal forestry. These include:-

(i) the ability to rapidly capture a greater proportion of the additive and non-additive genetic variation than can be achieved by breeding;
(ii) the elimination of inbred individuals from production plantations;
(iii) the mass production of valuable but expensive genotypes by hybridization or biotechnology;
(iv) the mass production of those rare individuals which have two or more favourable characteristics which are usually negatively correlated;
(v) the ability to select and utilize greater genetic diversity than is normally found in a single progeny;
(vi) the ability to use clones that are well adapted to a particular site ;
(vii) the greater simplicity and flexibility of managing sets of stockplants than in seed orchards;
(viii) the shorter period, compared to seed orchards, between selection and production ;
(ix) the increasing superiority of clones passing through multiple-trait selection programmes; and
(x) the ability to use mature tissues.

When to use vegetative propagation and clonal approaches to production

The decision to use vegetative propagation will be appropriate when a number of the following situations are evident (Leakey and Simons, 2000):

(i) a few individual trees are present in a wild population, which have a rare combination of desirable traits;
(ii) a tree improvement programme has identified opportunities for combining multiple traits for simultaneous selection and improvement. For example, in *Eucalyptus* hybrids, the combination of: stem volume, natural resistance to canker, stem form, natural pruning, thin branches, dense, well-formed crowns to shade out weeds, smooth bark, good coppicing ability, good rooting ability (over 70%), high wood density, and high yields of unbleached pulp (Campinhos and Ikemori, 1983);
(iii) high product uniformity is needed to ensure profitability and to meet market specifications,
(iv) the products of the tree species to be grown have a high-value that can justify the extra expense clonal propagation. This is particularly important if the market for the products is sufficiently large to minimize the risk of market saturation;
(v) the tree species to be propagated is a shy seeder, either not flowering and fruiting every year, or when producing only a very small seed crop - such as the product of a specific controlled pollination programme, hybridisation or a biotechnological manipulation;
(vi) the trees to be propagated are sterile, as in some hybrid progenies;
(vii) the timescale in which results are required is insufficient to allow progress through the slower process of breeding. This is particularly relevant in trees with a long juvenile period prior to the attainment of identifiable superiority and sexual maturity;
(viii) the seed produced through sexual propagation has a short period of viability (*i.e.* recalcitrant) and hence cannot be stored for later use. The same is true for seeds with a very low viability;
(ix) the knowledge on which selections are to be based is obtained either through the indigenous knowledge of farmers or a long-term experiment.

Conversely, sexual propagation *via* seed production is preferable when the requirements are for: large quantities of genetically diverse, low-value plants, and non-limited seed supplies.

A strategy for clonal forestry

The development of a strategy for clonal forestry should be based on the answers to the following questions (Leakey and Simons, 2000; Leakey and Akinnifesi, in press):

(i) What is the most appropriate level of technology to use?
(ii) Which is most appropriate, juvenile or mature tissue?
(iii) When using juvenile material, which is the best source?
(iv) When using mature material, what are the best methods for propagation?
(v) How can one ensure that sustained, cost-effective and easy rooting will be possible?
(vi) How can the best individual trees for cloning be selected from broad and diverse wild populations using?
(vii) What are opportunities for introducing new variation?
(viii) What is the role of vegetative propagation in research?
(x) How is it possible to ensure a wide genetic base?
(xi) How can clones be used wisely?

Answers to many of these questions will depend on the circumstances of the particular situation, but the last two questions are more fundamental. The wise use of clones will ensure genetic diversity is maintained in the ‘production population’. This requires a strategy for clonal selection that tests many clones of different origins for their yield and quality, but there are trade-offs between accuracy of genetic value estimation and intensity of selection (*i.e.* greater accuracy is at the expense of numbers of families, individuals per family, or clones).

Typically, there are four levels of testing (see Foster and Bertolucci, 1994):

- initial screening with large numbers (*e.g.* thousands or tens of thousands) of seedlings or, if seedlings have already been cloned, a few ramets per clone;
- candidacy testing with large numbers of cloned genotypes (fewer than with initial screening – *i.e.* hundreds or low thousands) and low numbers (two to six) of ramets per clone;
- clonal performance trials with moderate numbers of clones (*e.g.* less than 200) and large numbers (*e.g.* 0.1 ha plots) of ramets per clone;
- compatibility trials with small numbers of clones (*e.g.* 20 to 50) with very large plot sizes.

For cost effective clonal tree improvement programmes with limited or fixed resources, it has been found that the best strategy is to plant as many clones as possible with only relatively few individuals (ramets) per clone. Then there is the question: What is the best number of selected clones to grow? This question has been considered by Libby (1982), who concluded:-

(i) a mosaic of several unrelated clones in small monoclonal plantations is frequently the best strategy, particularly when many of the hazards are known;
(ii) mixtures of about 25-30 unrelated clones is probably the optimal strategy;
(iii) a mixture of large numbers of clones is as safe as a plantation of seedlings, but the genetic gains will not be as high as could be achieved by fewer clones;
(iv) the safest situation is likely to be a mixture of a relatively small number of unrelated clones of different species; this option, however, necessitates the selection of well-matched clones of compatible species;
(v) a mixture of 2-3 clones is probably the worst strategy, because of the risk that the loss of one clone will have a big impact; because of this, it is important that short-term commercial pressures do not result in the use of very few "super" clones.

Fears about clonal forestry

Some people have misgivings that clonal forestry will give rise to large, biologically-uniform stands that will be at risk from pests, diseases or other hazards. This view forms part of a general recognition that, particularly in perennial crops, successful replacement ecosystems must take into account the key role of genetic diversity. The important question, therefore, is whether clonal approaches to forestry overlook this important principle. Fortunately, so far, the clonal forestry projects described are all working with large numbers of clones and are thus not taking undue risks, although some are planting fairly large monoclonal blocks. Nevertheless, it is important to remember that tree improvement should be an on-going process and that selection procedures which are reducing the numbers of clones grown commercially at one end, should at the other be continually introducing new genotypes for testing (Leakey, 1991). Additionally, there is a need to further develop techniques of clonal silviculture to make full use of the already listed advantages of clonal forestry, some of which could minimize the risks. For example, the genetic diversity can, in fact, be more effectively maintained in clonal forestry than in more traditional approaches, by deliberately selecting highly productive but unrelated clones, rather than the continuum of related seedlings from a seed stand/seed orchard (Heybroek, 1978; Libby, 1985). The further development of clonal silviculture needs both more thought and experimental testing if the most appropriate system for growing a wide range of clones is to be achieved, both to maximize productivity and to minimize risk. In this connection, Libby (1982) has looked at the economics of silvicultural management in a statistical analysis of the risks of physical and biotic factors. He indicated that:-

(a) a mosaic of several unrelated clones in small monoclonal plantations is frequently the best strategy, particularly when, through experience, many of the hazards are known;
(b) mixtures of 7-25 unrelated clones is probably the optimal strategy;
(c) a mixture of large numbers of clones is as safe as a plantation of seedlings, but the genetic gains will now be as high as could be achieved by fewer clones;
(d) the safest situation is likely to be a mixture of a relatively small number of unrelated clones of different species; this option, however, necessitates the selection of well-matched clones of compatible species;
(e) a mixture of 2-3 clones is probably the worst strategy, because of the increased risk that a larger proportion of the plantations will suffer damage that will leave unacceptably few survivors; because of this, it is vitally important that short-term commercial pressures do not result in the use of very few "super" clones.

Another commonly raised fear of clonal forestry is that rooted cuttings may in some way have root systems that are inferior to those of seedlings, and consequently that clonal plantings are more susceptible to wind throw. Although seedling trees produce a taproot, most tree species subsequently produce a plate of large horizontal roots radiating away from the trunk and many of those forming on bare-root transplants are in fact adventitious. The extent to which the taproot and vertical sinkers then develop on a root plate is very variable between species (Jeník, 1978). It is therefore wrong to assume that all mature trees grown from seed have a taproot. Rooted cuttings may tend to form a root plate earlier than seedlings, but there is little if any evidence that well rooted cuttings which form a plate of adventitious roots lack the ability to form sinkers. So, while accepting that poor wind stability may occur if poorly rooted cuttings are planted, there seems to be no fundamental reason why clonal plants should be inferior in respect of their root system development. The problem can almost certainly be avoided by ensuring that only easily-rooted plant material is chosen for propagation and that the conditions and techniques used are those which ensure the rapid formation of a radially-arranged, vigorous root system. To a considerable extent, these requirements will be met by good stockplant management; the use of the most appropriate auxin concentration and cutting leaf area, and the avoidance of physiological stresses during the rooting period (Leakey, 2004).

Finally, the problems of non-erect or plagiotropic plants can occur with regard to vegetatively propagated trees, especially if the nursery staff has a poor understanding of the sources of this phenomenon. These undesirable plants are the result of using inappropriate shoots as a source of cuttings, and most commonly occur when cuttings are collected from the crowns of large trees. They also appear, even when cuttings originate from young plants, in species where polymorphism exists between lateral and main stem shoots. This problem can be avoided by efficient stockplant management and by the use of only mainstem-type shoots as the source of cuttings; such shoots are usually distinguished from branches by their phyllotaxy and orientation.

Techniques for vegetative propagation of tropical hardwoods

In the early 1970s, few timber trees were propagated vegetatively as most species were considered impossible to root as cuttings, and additionally, there was the feeling that timber trees would not grow properly from stem cuttings. By the mid-1970s, a number of species were being propagated as cuttings (eg. Martin and Quillet, 1974; Howland, 1975) and clonal forestry was on the increase. Since then there has been great progress in developing an understanding of the factors affecting rooting capacity (Leakey, 1985: 2004) and much is now known about the rooting process in stem cuttings of tropical trees.

Good rooting requires a propagation environment that minimizes physiological stresses. There are many systems that meet this requirement, from sophisticated fogging and automated misting units, to simple air-tight, polythene covered frame over a reservoir of water covered by layers of gravel and rooting medium (Leakey *et al*., 1990). This inexpensive and simple system is highly appropriate for areas without reliable sources of piped water or electricity. Generally, rooting is enhanced by an auxin application of about 40 • g of indole-3-butyric acid (IBA) and a leaf area of about 50 cm^2. The latter optimises the balance between photosynthesis and transpiration (Leakey *et al*., 1982a; Leakey 1985). Further work has identified the causes of within and between-shoot variation in rooting ability (Leakey, 1983; Leakey and Mohammed, 1985), the most important of which are: (a) stem length in single-node cuttings of more than 30mm, (b) the retention of relatively few shoots per plant, and (c) the interactions between nutrients and the light environment (Leakey, 2004). These results have been used to develop a sound, cost-effective system of stockplant management, based on physiological understanding of the factors affecting rooting-ability. Without this management it is likely that rooting success, as reflected by the speed of rooting, the number of roots per cutting and the percentage of cuttings rooted, will decline with time and with each successive crop of cuttings. There is also the risk, which must be avoided, that rooted cuttings originating from non-vigorous stockplants will develop into persistently plagiotropic and commercially unacceptable plants. The importance of good stockplant management must, therefore, not be overlooked.

The propagation of selected clones can be achieved by *in vitro* micropropagation and a growing number of tropical tree species have been found to be amenable to these techniques. However, to date, few species have reached the stage where they are produced commercially *in vitro*. This partly reflects the capital investment that is required, and partly the unit production cost of tissue-cultured planting stock, which is also dependent on skilled labour. In addition, mass propagation depends on robust and well-understood techniques. So far, few species are successfully mass propagated *in vitro*, as the techniques have lacked reliability.

Developments in clonal forestry

Tropical trees are generally amenable to clonal forestry being easy to propagate vegetatively (Leakey *et al*., 1990; Longman, 1993), and their rapid growth shortens the selection process. The following examples illustrate the success achieved.

(a) Fast-growing exotic hardwoods

(i) *Eucalyptus* hybrids

Large-scale reforestation programmes with clonal *Eucalyptus* spp. are in progress in the People's Republic of Congo and in Brazil.

Congo

Work by the Centre Technique Forestier Tropical (CTFT) started in 1953 with the introduction of 63 species, of which *E. tereticornis, E. urophylla, E. cloeziana, E. torelliana* and *E. alba* appeared to perform best in the savannahs around Pointe-Noire. Extensive provenance trials *(eg.* one with 102 provenances of *E. urophylla)* were then established, in which phenotypic variation between individual trees was found to be very considerable (Delwaulle, 1983). Progenies from these trees included some inter-specific hybrids, (*E. tereticornis* x *E. saligna* and *E. alba* x *E. urophylla*). Plus-trees were then selected within plantations, felled and multiplied using cuttings from coppice shoots, so that clonal trials could be established. The selection programme in Congo had, by 1980, identified 174 superior genotypes of *E. alba* x *E. urophylla* and 256 of *E. tereticornis* x *E. saligna,* using tree height, form, yield ha^{-1}, rooting ability and pulping quality as the criteria for selection (Delwaulle, 1983).

The commercial stage of this programme started in 1978, with the creation of the Industrial Afforestation Unit of the Congo (UAIC) and by 2003 the total area of clonal *Eucalyptus* was about 42,000 ha. Thereafter the annual planting required the production of about 600,000 cuttings per year, from each of two UAIC propagation units. Each of these units is supplied by about 20 ha of managed stockplants established at a density of 400 per hectare. Cuttings are collected from 95 stockplants per day, with a second harvest 6 weeks later, to give an annual production of about 150-200 cuttings per plant in the season. About 12,000 cuttings are set under continuous mist in each nursery each day.

In the early days clones were planted at 5 x 5 m spacing, in 50 ha monoclonal plots, but in 2003, some 15-20 clones, mainly *E. urophylla* x *E. grandis* were being planted in monoclonal blocks of 20-50 ha at a density of 800 stems/ ha. These plantings are prepared and maintained according to a defined work schedule, which ensures both the rapid and successful establishment of the cuttings and at minimal cost. The uniformity of the clonal material permits both planting at final spacing (so saving the costs of thinning operations) and the use of mechanical weeding. In these plantations, mean annual increments from selected clones after 6 years have averaged $35m^3\ ha^{-1}\ a^{-1}$, compared with $20\text{-}25m^3\ ha^{-1}\ a^{-1}$ from selected provenances, and about $12m^3\ ha^{-1}\ a^{-1}$ from unselected seedlots.

More recently, there has been a programme of controlled pollination is creating a wider range of hybrids some of which seem to be superior to those used previously.

Brazil

The rooting of *Eucalyptus* cuttings in Brazil by "Aracruz Florestal" started in 1975, reaching an industrial scale in a few years, with the objective of producing bleached wood pulp clonally. In 1999, the production target was 1,025,000 t yr^{-1} of bleached pulp (Campinhos, 1999), with pulp productivity raised through improved technology from 5.9 air-dried t $ha^{-1}\ yr^{-1}$ to 10.9 t $ha^{-1}\ yr^{-1}$. The total area of *Eucalyptus* plantations owned by this company was 132,147ha in 1999.

Canker, caused by *Diaporthe cubensis,* was minimized by selection for resistant clones, and improvements of yield, form and coppicing-ability were added by further clonal testing (Campinhos and Ikemori, 1983). Initially, plus-tree selection was carried out in *E. grandis, E. saligna* and *E. urophylla* plantations established between 1967 and 1972. More recently, individual trees arising from the hydridization of *E. grandis* and *E. urophylla* have been cloned, and some 5000 were then tested using the following selection criteria: (a) stem volume, based on diameter at breast height and tree height, (b) natural resistance to canker, (c) stem form, (d) natural pruning, (e) thin branches, (f) dense, well-formed crowns to shade out weeds, (g) smooth bark, (h) good coppicing ability, (i) good rooting ability- over 70% success, (j) wood density at breast height -preference for about 600 kg m^{-3}, (k) high yields of unbleached pulp, from 15 g samples collected at breast height.

In 1980, the second year of the large-scale planting programme, some 5 million cuttings were planted with expected mean and annual increments between 45-75m^3 ha^{-1} yr^{-1} can be expected from the hybrid clones planted at 3 x 3. This should be compared with yields from natural seedlings, which here have on average yielded 36m^3 ha^{-1} yr^{-1}, after 7 years. Refinements of the technique, including some mechanization, with expectations of lowering the costs, which already were already similar to those of producing seedlings. Maximum mean annual increments recorded are about 90m^3 ha^{-1} yr^{-1} (Campinhos, 1999).

Other major clonal forestry projects with *Eucalyptus* spp have also been implemented successfully in China, India, South Africa and in Chile.

(ii) *Gmelina arborea* Roxb.
A clonal approach to the improvement of *Gmelina arborea* was started in 1981 at Sabah Softwoods near Tawau in Sabah, with the objective of improving stem straightness and branching habit. From a total of 1200ha, a 30ha block of seed originating from the Philippines, was selected as the best stand. The best 100 trees per hectare were chosen (a 10% selection intensity) on the basis of tree height, bole length, diameter at breast height, stem straightness, height of first forking, bole circularity and the persistence, size and angle of the branches (Sim and Jones, 1985). These trees were coppiced and, after propagation, 20ha of stockplants were established at 1 x 2 m spacing. Cuttings are harvested at a rate of 20,000 cuttings per day and, when set under mist, have initiated roots in as little as 5 days. In 1981, half a million cuttings were planted from the 3000 selected clones.

The results from these clonal plantings, and also from seedlings originating from an open-pollinated block of plus-trees were a 100% increase in the number of 2 year-old-trees classified as 'straight' and a major reduction in those badly forked. The incidence of less severely forked trees was halved. Growth rates (diameter increment at breast height/month) were also improved, particularly in the clonal plantings, which have also provided the benefits of allowing planting at wider spacing. A further and more intensive clonal selection programme is planned and greater improvements in form and yield are envisaged.

(b) Medium growth-rate indigenous hardwoods

Examples of clonal forestry using indigenous hardwoods centre on West and Central Africa, where techniques have been developed for *Triplochiton scleroxylon* (K.Schum) in Nigeria and the Ivory Coast, and for *Terminalia superba* Engl. & Diels in Congo.

Triplochiton scleroxylon.

Nigeria

To overcome the problems of seed availability in this species, experiments to develop vegetative propagation techniques started in 1971 at the Forestry Research Institute of Nigeria (FRIN) and in 1973 at the Institute of Terrestrial Ecology (ITE) in Britain. The production of clonal material by vegetative propagation of *T. scleroxylon* seedlings of different origins within the natural range allowed: (a) the establishment of clonal trials, (b) the assessment of within-clone and within-seedlot variation, and (c) the determination of selection criteria (Howland *et al*, 1978).

Statistically significant clonal variation in a wide range of parameters was apparent within 18 months, and after 5 years, both basal log volume and stem form varied by 8-fold in a random sample of 100 clones. In this instance, selection of the 33 clones with above average stem volume and stem form would give genetic gains in excess of 30%. This rises to 80% if only the best 10 clones and to over 100% if only 4 clones are selected (Figure 1). The equivalent variation between these same clones attributable to seedlot origin was only 2-fold.

When looking for selection criteria between clones planted at 4.8m spacing, there were negative relationships after 18 months between branching frequency and both plant height and DBH. These relationships imply that the allocation of dry matter between the tree's main stem and its branches is an important component of yield, probably controlled by the physiological process of apical dominance. Before testing this hypothesis, a series of experiments in clonal *T. scleroxylon* investigated the effects of various physiological and environmental factors on apical dominance, as revealed by the patterns of lateral bud activity following decapitation (Leakey and Longman, 1986). As described later (see section on Identification of Superior Genotypes), this was used to develop a ‘Predictive Test’ to aid phenotypic selection. A World Bank forestry project in Cameroon adopted this technique on a practical scale, but unfortunately the funding was withdrawn, and the projected terminated, before the selected material could be assessed.

Ivory Coast
At the Centre Technique Forestier Tropical (CTFT) in Abidjan, studies were also aimed at the development of techniques for commercial-scale vegetative multiplication of *Triplochiton.* In particular, these studies include:
(i) the identification of superior phenotypes in young plantations by an analysis of their growth relative to that of their neighbours,
(ii) the management of coppiced stumps cut to different heights, with different frequencies of cutting collection, and
(iii) the establishment of clonal trials (Boutin, 1983).
It was intended that this research would be implemented under the afforestation project Société pour le Dévéloppement des Plantations Forestiers (SODEFOR) funded by the Commonwealth Development Corporation and World Bank. However, like the Cameroon afforestation project full-scale commercial application of these techniques again were terminated for political, rather than technical reasons.

Identification of Superior Genotypes

The identification of superior genotypes, as the ‘mother plants’ for cloning, is the start of the development of clones. In the projects described above, different approaches have been used to select material for propagation. Alternatives range from: (a) Phenotypic selection: choosing relatively few, large, mature trees of superior phenotype ('plus' trees) in either natural forest or plantations and then facing the problem of how to obtain easily propagated or "juvenile" tissues, to (b) Clonal selection: developing clones from large numbers of easily propagated seedlings, which are of virtually unknown genetic potential. These clones then have to be tested in field trials to identify which are genetically superior. Trials of this kind have to test thousands of clones are therefore very expensive. For a variety of reasons, one approach may be more appropriate than the other in a given situation/species, as follows:

(a) Phenotypic selection. This approach will almost certainly ensure some genetic gain for relatively little effort and expense, but may fail to identify the best individuals, because, in the wild, survival to maturity is strongly influenced by chance, and large, well-formed trees may already have been removed by loggers. The situation in plantations, and in provenance and progeny trials is probably different, because all plants have a similar opportunity to survive and become established. However, there is some evidence to suggest that the dominant phenotypes are strongly determined by competitive forces between trees (Ford, 1976). Thus, as in the case of *T. scleroxylon* in Ivory Coast, selections from plantations should take into account not only the performance of the individual, but also the relative performance of its nearest neighbours. When trees are selected within both natural and man-made stands, the chosen trees are usually felled, or otherwise stimulated to induce the formation of easily rooted coppice-type shoots from near the base of the trunk. The subsequently derived clones are then re-evaluated in field trials. Attempts in the Congo to initiate rejuvenated clones of *Terminalia superba* by grafting mature scions on to seedling rootstocks have not been very successful.

(b) Clonal selection. In this approach, a large number of seedlings, preferably from a wide range of good provenances, have to be vegetatively propagated and established in clonal trials. This approach was taken in Nigeria with *T. scleroxylon*, primarily because the wild population had been subjected to heavy selection by loggers, leaving a dysgenic population. It is a laborious process and clonal rankings can change with time. However, in relatively fast-growing tropical trees, preliminary selections can usually be made after a few years, provided the selection process continues and the selections made are reviewed and verified. Furthermore, new selection criteria, such as wood quality, must be added as the selection process progresses.

In an attempt to find a more efficient and less expensive way of screening large numbers of *T. scleroxylon* seedlings, Ladipo *et al*. (1991 a/b; 1992) have developed a Predictive Test which can be applied to large and genetically different populations of seedlings in the nursery. The test is based on the strong correlation between the numbers of branches per metre of mainstem (*ie*. branching frequency) and stem volume after 5 years in several hundred clones in field trials. The test itself determines the strength of apical dominance in each seedling by simply decapitating young plants and growing them under carefully controlled standardised conditions. Studies have determined that the strength of apical dominance in seedlings is strongly related to branching frequency in 5-year-old plants in the same clonal trials. This nursery-stage screening allows the elimination of the least desirable seedlings prior to large-scale vegetative propagation and field testing. This predictive screening should also allow much larger and genetically more diverse batches of seedlings to be assessed for their genetic potential, than can be achieved by field trials alone. It is important to recognise that there are 23 different branching architectures in tropical trees (Hallé et al., 1978), each of which will have differences in the ways in which variation in apical dominance is expressed. *T. scleroxylon* conforms to the most common of the architectural models (Rauh's model), as thus the test probably has wide applicability. The test has also been used in *Cedrela odorata* L. to identify potential clones, which will respond to attacks by the Shoot tip moth (*Hypsipyla* spp.) by forming a single replacement leader, rather than a large number of heavy branches (Newton *et al*., 1995).

Clonal silviculture

An investment in tree improvement, particularly at the clonal level, should imply the existence of the highest standards of silviculture in order to reap the rewards of the genetic potential. This is often the case, but there is the problem that relatively little is known about the silviculture of indigenous species plantations and even less known of their ecology. A large-scale monoculture of these indigenous species obviously carries the risk of creating imbalance in the food chains of the ecosystem, which may result, for example, in the explosion of an insect population to pest proportions. In West Africa, site preparation techniques prior to establishing commercial plantations of *Terminalia ivorensis* A. Chev. range from bulldozer clearance that removes all the vegetation and does considerable damage to the soil, to one where the bulldozers leave much of the ground vegetation and a number of pole-stage trees (Eamus *et al*., 1990; Lawson, 1994). Similar ecologically-sensitive systems as the latter are also used when establishing short-rotation *Gmelina* coppice under standards at Subri Forest Reserve in Ghana (Plumptre and Earl, 1986). In this case, galleries of natural forest are also left in the valley bottoms. The likely advantages of these approaches, particular where clonal forestry is to be applied are that species diversity is retained, so minimizing the risks of an ecological imbalance. Importantly also, it is probable that the leaching of nutrients is minimized by retention of the fine root mat, which also sustains the mycorrhizal flora (Mason *et al*., 1992). Observations suggest that, due to effects of this sort, tree growth is considerably faster in areas where site damage is minimized. In contrast, the damage done at totally cleared sites is often worsened by the establishment of a highly competitive monoculture of the serious weed *Eupatorium odoratum,* which suppresses tree growth.

The future

The basic propagation techniques of vegetative propagation and clonal selection are now at a stage where they can relatively easily be modified to suit other species and situations. Future developments are therefore likely to depend more on economic decisions than on technical issues. Future trends are likely to involve:-

- a shift towards clonal projects by organizations already in plantation forestry;
- the start of tree improvement programmes for species that can specifically benefit from:-
  - the application of clonal techniques to hybrid progenies,
  - the elimination of constraints, such as the dependence on scarce seed supplies - *eg*. Dipterocarps like *Shorea macrophylla*, which can now be easily propagated (Lo, 1985)
- the start of programmes where clonal selection opens up opportunities not readily attained by traditional breeding; for example the selection of single-purpose clones of multi-purpose agroforestry species (Leakey *et al*., in press).

Clonal approaches to forestry and agroforestry are likely to expand in the future as benefits attributable to improved yield and quality of tree crops become more important commercially.

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