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Regeneration of new forest resources

Indigenous trees in West African forest plantations: the need for domestication by clonal techniques

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ABSTRACT

Forests in West Africa have recently been disappearing at 1.2 million ha (4%) per annum, yet the area planted annually with trees was only 36 000 ha in the mid-1980s, and is now very much less. Many tree planting schemes, particularly in Cameroon, have failed because of inadequate site clearance and subsequent neglect of maintenance. Yet the yield of several species in research plots has been found to be acceptably high, and a number of species, such as *Terminalia ivorensis, T. superba, Triplochiton scleroxylon* and *Aucoumea klaineana*, can achieve an average diameter of 60 cm in 25–30 years. The economic returns from rotations of 30 years or less are highly attractive, even with poor markets for thinnings. Internal rates of return between 9% and 20% have been calculated for such stands in Cameroon. However, private sector and farmer confidence in the wisdom of tree planting is only likely to be encouraged by: (i) financial incentive schemes; and (ii) the development of techniques for selection and improvement of faster-growing and more valuable planting stock than has been available up to now. There is a particular need for an international hardwood improvement programme in West and Central Africa.

INTRODUCTION

Whilst reasonable information is available from West Africa on the yield and profitability of exotic species of *Pinus, Tectona, Eucalyptus* and *Gmelina* (Allison *et al.* 1986; Horne 1967; Lowe 1976; Kio *et al.* 1989; Ball 1992), it is more difficult to obtain reliable data on the native hardwood species which are being 'domesticated' and used in timber plantations. Three indigenous species have been planted widely in West Africa: *Triplochiton scleroxylon* (obeche, samba, wawa, ayous), *Terminalia ivorensis* (black afara, framiré), and *Terminalia superba* (white afara, fraké, limba). However, many of these plantations were established on a small scale, and few analyses exist of their establishment costs, yields and likely profitability. This paper therefore:

- considers the need for tree plantations in West Africa;
- summarises existing information on plantation yields of indigenous species;
- comments on the likely profitability of these plantations;
- describes the efforts being made by the Cameroon Forest Management and Regeneration Project to improve the management and yields of indigenous tree plantations; and
- speculates on the potential for vegetative propagation and clonal selection to increase the growth rates and marketability of native hardwood species.

DEFORESTATION AND REFORESTATION IN WEST AFRICA

The average annual rate of deforestation in West Africa from 1981 to 1985 (the most recent reliable data) was 2.2% overall, and 4.1% in closed forest. These are the highest regional figures in the world, and compare with an average annual loss of closed forest of 0.6% in Africa and a global average of 0.3% (Table 1).

Official statistics also indicate that 36 000 ha of plantations were established annually in West Africa during the mid-1980s. This figure is very small compared with the 1.7 million ha of forest which were being lost annually at the time, and it is even less significant when one considers the poor maintenance and survival of these plantations, and the fact that they were usually established in areas of existing forest. Furthermore, there is little doubt that the rate of plantation establishment has declined considerably since the mid-1980s.

Thus, although West Africa has recently suffered the greatest proportional loss of forests in the world, it has an almost insignificant replanting programme. Considerable recognition exists of the economic, environmental and social costs of unabated removal of forests. In Nigeria, for example, it is calculated that the decrease in soil fertility and water quality caused by deforestation costs more than US$5 billion annually (World Bank 1992b). However, there is no evidence of tree planting programmes being supported on a sufficiently large scale to relieve the pressure on

Table 1. Rates of deforestation and tree planting in West Africa (source: World Resources Institute 1992)

	Extent of natural forest and woodland (kha in 1980)			Annual deforestation (1981–85) (kha)				Plantations (kha)
	Closed forest	Open forest	Other woodland	Closed forest (kha)	Closed forest (%)	Total forest (kha)	Total forest (%)	
Benin	47	3 820	6 832	1	2.6	67	1.7	0
Côte d'Ivoire	4 458	5 376	15 390	290	6.5	510	5.2	6
Ghana	1 817	6 975	9 480	22	1.3	72	0.8	2
Guinea	2 050	8 600	9 000	36	1.8	86	0.8	0
Liberia	2 000	40	5 640	46	2.3	46	2.3	2
Nigeria	5 950	8 800	49 450	300	5	400	2.7	26
S. Leone	740	1 315	4 278	6	0.8	6	0.3	0
Togo	304	1 380	3 720	2	0.7	12	0.7	0
West Africa	17 267	36 306	104 690	703	4.1	1 199	2.2	36
Cameroon	17 920	7 700	15 600	80	0.4	110	0.4	1
Central Africa	170 395	11 915	71 575	307	0.2	575	0.2	3

undegraded natural forests, neither is there much consensus on how forest regeneration is best encouraged.

There are five approaches to forestry management in the humid forest zone.

Conservation schemes

These schemes often require that logging ceases, and place severe constraints on villagers' activities. Governments may be granted loan remission, and villagers given new facilities, but conservation 'exclusion zones', which do not allow local populations to utilise timber or game, are unlikely to encourage a genuine commitment to conservation among the community (Besong 1992).

Sustainable management of the natural forest

This ideal has many adherents, but few genuine practitioners. Techniques for the effective management of natural forests are poorly understood, and there are many management and economic problems. Some recent results, involving careful inventory and selection of trees to be felled, together with selective poisoning of competing low-value trees, have enhanced the growth of commercial species (by up to 6–7 m^3 ha^{-1} yr^{-1}) without excessive environmental damage (Jonkers 1987; Maitre 1987). However, the cost of felling competing trees is high, natural regeneration is often unreliable, and the yield from even well-managed natural forest in West Africa is unlikely to exceed 5 m^3 ha^{-1} yr^{-1} (Kio & Ekwebam 1987; Nwoboshi 1987), which is less than half the yield of most plantation species in the area.

Enrichment planting

This is the process of under-planting valuable species in partially cleared natural forest. It is appropriate if the forest has insufficient natural regeneration for natural forest management to succeed, but is too valuable (economically or ecologically) to be completely replaced by plantations. It also offers the opportunity to use genetically selected planting stock, or species which were not present in the original forest. Under-planting can take place in lines, as scattered groups, or in a heavily cleared forest where only middle-aged timber species of good form have been retained. Unfortunately, enrichment planting has seldom been carried out well: light-demanding species have often been established in excessive shade and weeding operations have usually been neglected (Anon 1989).

Industrial plantation after complete clearance

This has been the principal technique used in large plantation schemes financed by international lending institutions. Typical examples are the Subri industrial plantations in Ghana (Plumptre & Earl 1986), the World Bank afforestation programmes in Nigeria (Kio *et al.* 1989), and the state forestry plantations in Côte d'Ivoire (SODEFOR) (Dupuy 1985). Unfortunately, all these plantations were established in reasonably productive forest reserves, partly to gain revenue from the forest clearance, and partly because this was the only land freely available to the state. Development banks are now less keen on this type of scheme, especially if the plantations are run by state forestry organisations. There have been too many examples in the past of inefficient management, over-emphasis on planting targets, and gross neglect of maintenance operations (World Bank 1992a). The banks and aid agencies are, therefore, shifting the balance of their funding away from industrial forestry schemes (the 'forest-first approach') and towards environmental conservation, natural forest management and community forestry (World Bank 1991). However, it is in plantation programmes such as that of SODEFOR that there are genetic improvement schemes for indigenous hardwoods (see Ladipo *et al.*, pp239–248).

Community tree plantations

These have not been much practised in the humid forest zone. They are likely to take place in conjunction with farming, either as 'taungya' or in mixture with fruit trees or other perennial crops like coffee or cocoa, and therefore involve reasonably complete forest clearance. Degraded forest and derived savanna zones are most appropriate. However, community plantation schemes have often been limited by an unenthusiastic uptake of tree planting by villagers, particularly where it is difficult to define the ownership of trees on communal land (World Bank 1992a; Flint 1992). These 'people-first' schemes have met many of their targets but have not established large areas of forest because of their intrinsically small-scale approach, problems of land tenure, and a lack of motivation for farmers to plant tree crops which bring little financial benefit for many years. Thus, it is extremely encouraging that the World Bank is about to launch a pilot 'tree planting incentive scheme' in Nigeria which envisages the reimbursement (after *successful* establishment) of 75% of standard planting and maintenance costs to companies, communities and individuals who plant at least 5 ha of land (one ha in cases of environmental degradation). Individuals must possess the land title before funds can be provided, but assistance will be given with the process of land registration (World Bank 1992b).

Large-scale afforestation in future is likely to require a mixture of community and industrial planting. Both approaches have been hindered in the past by human, fiscal and institutional problems. This paper will not consider these difficulties further, but will concentrate on the technical questions which impede the introduction of a significant indigenous hardwood planting programme in West Africa, namely:

- the growth rates of plantations of indigenous species;
- appropriate silvicultural methods;
- the likely economics of plantations; and
- improvements which can be gained from the multiplication and selection of genetically superior planting stock.

YIELD OF PLANTATIONS

Information on the yield of plantations of indigenous species in West and Central Africa is sparse. Several hundred sample plots have been established in research and commercial plantations, but have often been destroyed by fire, logging and/or neglect. Results are extremely variable, with differences in soil type, planting stock, planting methods, disease attack and subsequent thinning making it difficult to draw conclusions. Most plantation research has been devoted to a small number of faster-growing species.

Terminalia ivorensis

Much of the reliable information on *T. ivorensis* (framiré) comes from Côte d'Ivoire, where infrequent measurements exist from 13 plots installed by the colonial forest service, and more regular data from 209 plots established since 1965 by the Centre Technique Forestier Tropical (CTFT) (Beligne 1985). The results are heavily influenced by initial shading, planting density and subsequent thinning, with establishment and growth being more rapid in plots which had received intensive manual or mechanical clearance of the original forest cover. *T. ivorensis* is a species which is light-demanding for maximum growth, and begins to suffer growth checks even before the tree crowns touch (Lowe 1974), indicating the need for a heavy thinning regime.

Before 1972, the CTFT plots received only partial clearance of the original forest, either using the 'line planting' technique (with 8–25 m between lines, *sensu* Aubreville 1953) or 'manual recru' (cutting the undergrowth to knee height, and poisoning the overstorey – but leaving some of the large trees in place – which was not recommended in Catinot's (1965) definition of the recru system). These plots have grown more slowly than the later 'intensive plantations' and average 8.3 $m^3\ ha^{-1}\ yr^{-1}$ by 30 years, with a maximum annual volume increment at 15 years of 9.7 $m^3\ ha^{-1}\ yr^{-1}$. The minimum rotation length with these 'extensive plantations', to reach an average diameter of 50 cm, is 43 years.

In 1972, CTFT introduced more intensive forest clearance methods. These plots recorded a maximum annual diameter increment of 5.5 cm yr^{-1} at year 3, and the average annual diameter increment is projected to remain more than 2 cm yr^{-1} until the age of 20 (Beligne 1985). The maximum annual wood volume increment of 24.7 $m^3\ ha^{-1}\ yr^{-1}$ was achieved at year 6, and the 70 final crop trees alone were increasing their volume at more than 10 $m^3\ ha^{-1}\ yr^{-1}$ by year 10. Rotation lengths can be predicted from these 'intensive plantations' of 20 years to 50 cm average diameter or 36 years to 60 cm diameter.

The average productivity of *T. ivorensis* (framiré) in SODEFOR is reputed to be 11.5 m^3 ha^{-1} yr^{-1}, although there is some doubt about whether it has been achieved in practice (Aitken *et al.* 1992).

T. ivorensis (idigbo) has also been widely planted in Nigeria. Sanders (1953) and Horne (1962) quote annual diameter increments ranging from 2.2 cm yr^{-1} for an 11-year-old plot to 1.9 for a 30-year-old trial at Sapoba. No recent yield information has been found except for a nine-year-old plantation in Imo State which has an average diameter at breast height (dbh) of 16.1 cm (Mbakwe 1990). The Nigerian *Forestry Sector Review* (World Bank 1992b) gives the expected yield of *T. ivorensis* in plantations as 10–12 m^3 ha^{-1} yr^{-1}, which is the highest of the species quoted.

T. ivorensis (emire) was widely planted in Ghana between 1930 and 1960, but yield information does not appear to have been collated (World Bank 1988). However, it is no longer regarded as a safe plantation species in Ghana because of widespread mortality observed in middle-age plantations (Ofosu-Asiedu & Cannon 1976).

In Cameroon, *T. ivorensis* (framiré) has been used in both research and commercial plantations. The ex-CTFT 1972 research plantations at Bilik (Mbalmayo Forest Reserve) have an average diameter in excess of 60 cm after 20 years for the 70 largest trees per hectare (Lawson, Perem & Foahom 1993), despite damage from a serious fire in 1983. Previous measurements had reported an average diameter increment of 4 cm yr^{-1} during the first six years (Grison 1979) and 3 cm yr^{-1} over the first ten years (Foahom 1982).

The Office National de Dévéloppement de Forêts (ONADEF) is responsible for 22 500 ha of moist-forest zone plantations in Cameroon, which date back to 1937 but were mainly planted between 1972 and 1989. Unfortunately, at least 40% of these plantations have completely failed, and much of the remainder has suffered severe growth checks due to inadequate weeding, or to planting in heavy shade. A recent provisional inventory of these plantations (ONADEF 1992; Lawson & Ngeh 1993) has enabled tentative estimates of yield to be derived. The 4120 ha of *T. ivorensis* plantations demonstrate a wide range of survival and growth rates (Figure 1).

Terminalia superba

Terminalia superba has been widely planted in Congo, where a clonal selection programme has been implemented (Koyo 1983, 1985), and Zaïre (limba), usually in association with plantains. It is also an important plantation species in Côte d'Ivoire and Cameroon (fraké), but to a lesser extent in Ghana and Nigeria (afara). Diameter growth is usually 2–3.5 cm yr^{-1} up to year 10, and is maintained above 2 cm yr^{-1} in the final crop trees to at least year 20 (Groulez & Wood 1984). Height growth is around 1.1–1.5 m yr^{-1} during the first ten years. However, rates of volume production may be lower than those of *T. ivorensis*, with 8.4 m^3 ha^{-1} yr^{-1} measured from an 18-year-old plantation in Congo, and around 7.5 m^3 ha^{-1} yr^{-1} predicted at year 40. Yields are particularly influenced by soil fertility. In Côte d'Ivoire, experimental plantations are reported to yield around 10 m^3 ha^{-1} yr^{-1} by year 15, but Aitken *et al.* (1992) quote 12.3 m^3 ha^{-1} yr^{-1} as the expected yield of the SODEFOR commercial plantations, with a final diameter of 45 cm at 25 years.

Triplochiton scleroxylon

T. scleroxylon comprises the majority of all wood exported from Ghana (wawa); it has top place in

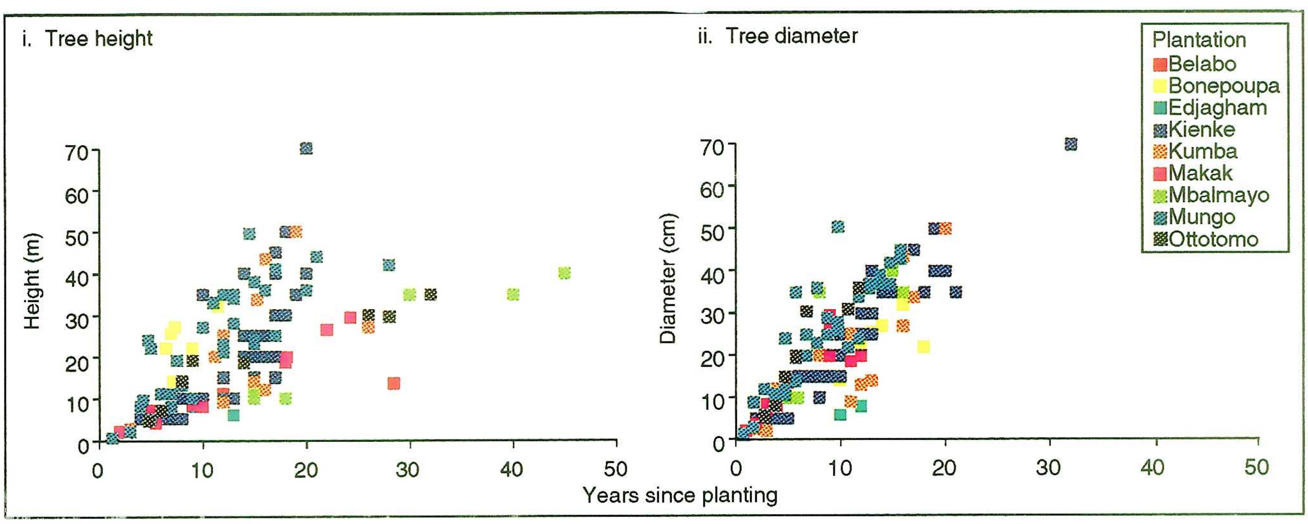

Figure 1. Tree height (i) and diameter (ii) of 118 plantations of *Terminalia ivorensis* (framiré), inventoried by the Office National de Dévéloppement des Forêts in 1990 (ONADEF 1992; Lawson & Ngeh 1993). These data were collected by a large number of teams, without adequate standardisation of methods, and should therefore be regarded as provisional

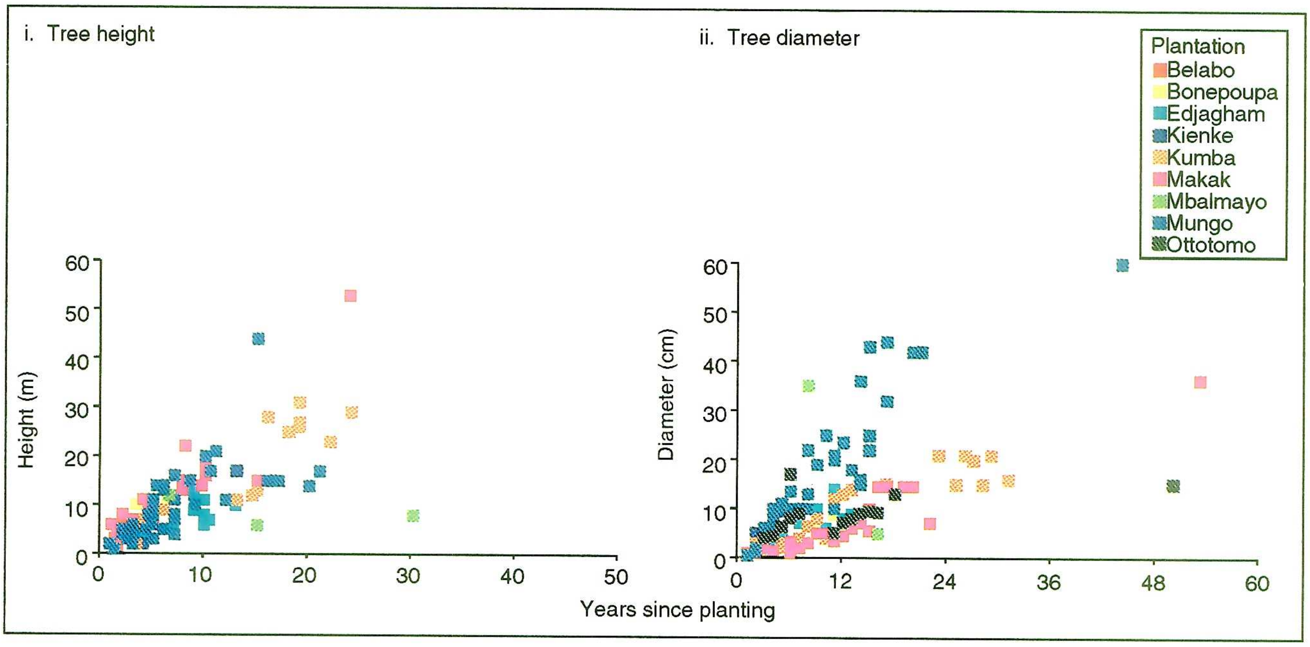

Figure 2. Tree height (i) and diameter (ii) of 112 plantations of *Lovoa trichilioides* (bibolo), inventoried by the Office National de Dévéloppement des Forêts in 1990 (ONADEF 1992; Lawson & Ngeh 1993). These data were collected by a large number of teams, without adequate standardisation of methods, and should therefore be regarded as provisional

Cameroon (ayous) and is a major component in what remains of the Nigerian (obeche) and Ivoirian (samba) forests. It has been used as a plantation species in all these countries, but never on a large scale, probably because of the difficulty in obtaining reasonable quantities of seed (Jones 1974).

In Ghana, research plots of *T. scleroxylon* (Forest Products Research Institute (FPRI) 1972) have produced high diameter increments, ranging from 1.2 cm yr^{-1} in a ten-year-old trial at Pra Annum to 3.0 cm yr^{-1} in a six-year-old trial at Subri. Generally, growth rates are in excess of 2 cm yr^{-1}.

In Nigeria, research plots have achieved 27.1 cm dbh by 29 years at Sapoba and 27.1 cm after 31 years at Gambari (Abayombi & Nwaigbo 1985). This growth rate does not seem rapid but the 100 largest stems ha^{-1} are projected to grow at an average 1 cm yr^{-1} over the first 60 years (Ball 1975).

Many more experimental plantations have been established in Côte d'Ivoire, and annual diameter increments average 1.2–2.1 cm during the first 20 years for trials in partial shade, and 1.9–3.2 cm in completely cleared areas (Dupuy & Bertault 1985). The older plantations had mean annual volume increments ranging from 4–7 m^3 ha^{-1} yr^{-1} for the sparse plantations established under cover (100–150 stems ha^{-1}), to 7–10 m^3 ha^{-1} yr^{-1} in the taungya plantations (250–350 stems ha^{-1}). The younger plantations established after complete clearance averaged 13–18 m^3 ha^{-1} yr^{-1} (175–300 stems ha^{-1}) after 13 years. No extrapolations have been made from these trials to the final expected yield and rotation length of plantations, but a yield of 12.3 m^3 ha^{-1} yr^{-1} is predicted for the SODEFOR commercial plantations, with a final diameter of 45 cm at 25 years (Aitken *et al.* 1992). Initial gains of 14–29% have been reported with genetically selected planting stock used in SODEFOR plantations (Verhaegen *et al.* 1992).

At Makak in central Cameroon, two plots of *T. scleroxylon* were established in 1936–37 at a spacing of 5 m x 20 m. After 46 years, the trees were on average 34 m high and 52.8 cm diameter. At Mbalmayo, also in central Cameroon, five experimental *T. scleroxylon* trials were established between 1966 and 1969. These recorded a mean diameter increment of 1.7 cm yr^{-1} during their first 15 years, and at year 10 the best of these trials achieved 9.5 m^3 ha^{-1} yr^{-1} (Pesme 1986). A further trial of *T. scleroxylon* has been planted at South Bakundu (SW Cameroon), using rooted cuttings without genetic selection, and has achieved an average diameter of 14 cm after only six years (N Songwe, personal communication).

Lovoa trichilioides

Around 6200 ha of *Lovoa trichilioides* have been planted in Cameroon (Lawson & Ngeh 1993), but the average yield achieved is particularly disappointing (1.8 m^3 ha^{-1} yr^{-1}): partly because it was often planted in unfavourable areas, but mainly because of excessive shade and neglect of subsequent maintenance (Figure 2). In the research trials at South Bakundu, a diameter increment of 1.8 cm yr^{-1} was achieved after 18 years (P Shiembo, personal communication), and equally good growth has also been observed for this valuable timber at Sapoba in Nigeria, where it appeared to grow more rapidly after the pole stage, and an average diameter increment of 1.0–1.8 cm yr^{-1} was recorded after 23 years (Nwoboshi 1987).

Other species

Many other native species trials exist in the humid forest zone of West and Central Africa. *Nauclea diderrichii* has been grown in Nigeria since 1918, as a nurse species for more valuable mahoganies, and as a useful species in its own right. Plantations in Sapoba, Ona and Agbodi achieved between 1.2 and 1.6 cm yr^{-1} (Nwoboshi 1987), whilst a plantation at South Bakundu has recently recorded 3.1 cm ha^{-1} yr^{-1} up to year 8 (P Shiembo, personal communication).

Mansonia altissima has also grown reasonably successfully at South Bakundu, with an average mean diameter increment of 1.5 cm yr^{-1} at 18 years (P Shiembo, personal communication), although it is rather susceptible to attacks from defoliating caterpillars (Foahom 1989). *Picnanthus angolensis* (ilomba) is fast-growing in some of the ONADEF plantations in Cameroon (average mean diameter increment frequently more than 2 cm yr^{-1}, even to the age of 40), but has not been the subject of detailed study. *Aucoumea klaineana* (okoumé) has been planted sucessfully in Ghana (FPRI 1974), and in Cameroon (Arnoux 1958; Bibani 1989), with an average diameter increment of 1.7 cm yr^{-1} after 12 years in research plots at Mangombé, and of 1.8–2.5 cm yr^{-1} in commercial plantations near Kribi (Lawson & Ngeh 1993).

Of the non-native hardwood species, *Gmelina arborea, Tectona grandis, Cedrela odorata* and *Melia composita* have been the most successful, and should not be excluded from future planting programmes, even if the preference is for native species.

THE CAMEROON FOREST MANAGEMENT AND REGENERATION PROGRAMME (FMRP)

The FMRP is a bilateral Cameroonian/British programme with a general aim of improving the capacity of Cameroon to carry out wise management and conservation of its moist high-forest areas. It started in July 1991, with an emphasis on the use of improved indigenous hardwood species in artificial plantations, and has the following specific aims.

- To examine and demonstrate the suitability of strongly contrasted silvicultural techniques for forest regeneration after logging.
- To develop a management plan for the Mbalmayo Forest Reserve.
- To provide genetically improved planting stock of selected humid forest species.
- To acquire cost data for establishment and management of plantations using different silvicultural techniques.
- To acquire data on biological changes resulting from different silvicultural treatments.
- To acquire socio-economic data on the effects of different silvicultural treatments on local populations.
- To establish an in-service training capacity in high-forest management techniques and to disseminate results to the forest sector.

The FMRP's planting programme provides an opportunity to demonstrate and study a number of silvicultural options for regenerating degraded forest. Currently these options consist of the establishment of *T. ivorensis, T. scleroxylon* or *L. trichilioides* using the:

- *manual regrowth method*, with complete manual clearance of the original canopy, and cutting of undergrowth at knee height (*sensu* Catinot 1965);
- *enrichment planting method*, with some well-formed individuals of high-value species in the 20–50 cm diameter class retained to form part of the final harvest of the under-planted fast-rotation species;
- *mechanical complete clearance method*, where large trees are felled by chainsaw and pushed by bulldozer, together with smaller trees, into windrows at a spacing of 40–50 m;
- *line planting method*, where V-shaped lines are cut at wide spacing (determined by the ultimate crown diameter of the planted trees) and existing trees are heavily cleared (*sensu* Dawkins 1966);
- *taungya method*, where FMRP undertakes forest clearance and burning, and the villagers hoe, plant and cultivate crops for an initial period of two to four years.

This study to compare silvicultural treatments for the growth of indigenous hardwoods builds on preliminary work at the same site to investigate the effects of some site preparation techniques on the physical and chemical properties of the soil (Ngeh 1989), the spore populations of endomycorrhizal fungi (Musoko 1991; Mason, Musoko & Last 1992) and the physiology of the planted trees (Eamus *et al.* 1990). The preliminary work formed part of a programme linked to the vegetative propagation of indigenous hardwoods and the development of an appropriate silvicultural system for planting clonal material (Wilson & Leakey 1990; Leakey 1991). The current investigation includes a study to determine the effects of silvicultural treatments on the populations of insects, especially the potential pests and their predators and parasites (Watt & Stork 1992). The philosophy behind this project is that, in order to maximise the productivity from genetically selected planting stock, it is important to minimise risk by the retention of biological diversity in the plantation (Leakey *et al.* 1993).

PROFITABILITY OF INDIGENOUS TREE PLANTATIONS IN WEST AFRICA

Ideally, forestry plantations should demonstrate a higher return on capital investment than other commercial alternatives, and/or a more rewarding use of farmers' time and land than alternative crops. There are complications, however. What is a realistic rate to discount future expenditure and revenue? How will the market for timber and thinnings change in the future? Can one account for the risk of fire or disease? Should the balance sheet include environmental conservation and secondary products like bush meat, wild fruits, medicines, rattan, and rafia? An initial attempt has been made at the macro-economic scale in Nigeria to estimate the annual environmental costs of forest clearance (World Bank 1992b). The study concluded that Nigerian sustainable net national productivity has been reduced annually by US$750 million due to lost timber production, $2 billion due to soil degradation, $1 billion due to water contamination, $10 million because of the loss of wildlife, $1 million due to the loss of fisheries, $100 million owing to gully erosion, and $150 million through coastal erosion.

It is not easy to find good records of the cost of plantation establishment and management in West or Central Africa (Skoup & Co 1989; Djomo 1987). Reasonable information is often collected for short periods, but changes of personnel and a lack of standard accounting and coding systems limit the continuity of data collection.

The FMRP aims to collect financial information in parallel to yield and environmental data, and has made an initial estimate of the profitability of four of the silvicultural systems which are being examined experimentally, together with three options under consideration (Table 2). Comparisons of profitability can be made using the internal rate of return (IRR) on capital investment (the aggregate return of all revenues and expenditures over the lifetime of a plantation). This measure emphasises that greatest profitability is achieved when initial costs are minimised and incomes are generated as rapidly as possible (either from early commercial thinnings or by shortening rotation length – perhaps through genetic (clonal) selection).

All the figures derived in Table 2 are speculative: cost keeping has been unreliable; the density and richness of the existing forest are averaged; the effect of silviculture on yields has not been adequately described; and much uncertainty surrounds future timber prices. Nevertheless, estimated IRRs appear to be in the order: manual regrowth < mechanical regrowth < complete clearance < shade trees and cocoa line planting (*sensu* Aubreville 1953) < taungya < short-rotation exotics. The reliability of these assumptions will improve as the FMRP gathers more information. It is not yet possible to eliminate any of the silvicultural options on economic grounds as different options are more appropriate in differing circumstances.

Short rotations of exotic species, like *Gmelina arborea*, have high apparent IRRs, and could possibly be integrated with current fallow rotations. However, they are dependent on markets developing for small roundwood, which will take some time in a country like Cameroon because forest products are still plentiful, there is little market for exotic species, and as yet there is no operational pulp mill.

Taungya offers the advantages of reduced weeding costs and a possible early enhancement to growth as the trees respond to the nutrient pulse provided by wood ash. However, taungya systems require a good relationship between foresters and villagers, and particularly strict control against fires. Taungya is often held to work best when land is in short supply.

Line planting

- 'Francophone', *sensu* Aubreville (1953) (eg Grand Layon), may be carried out where some of the existing high-value trees are preserved to generate thinning revenue and contribute to the final yield. This method is appropriate if the exisiting forest is relatively rich, but management exclusively for natural regeneration is not appropriate.
- 'Anglophone', *sensu* Dawkins (1966), is appropriate where it is carried out in degraded forests. This system aims to produce a virtual monoculture of the plantation species (ie removing all trees which are taller than the arms of a right-angled 'V' centred on each of the planting lines).

The mechanical complete clearance method is unlikely to be applicable where much forest cover remains. It involves the complete destruction of existing forest, and the scraping by bulldozer of felling debris into windrows. Planting operations are cheaper and easier after this type of ground preparation, but large windrows may make 10–20% of the area unplantable. Edens (1992) calculated a favourable IRR (Table 2) based on optimistic yield assumptions from early studies in Côte d'Ivoire (Dupuy 1986). However, more recent work there does not confirm that the SODEFOR plantations created using this method have achieved greater yields that those from older manual regrowth plantations (Aitken *et al.* 1992).

Table 2. Preliminary estimate of the profitability of different silvicultural options for the humid forest zone of Cameroon (source: Edens 1992)

Options		Assumptions (costs in Cameroon CFAs)	Total costs ('000 CFAs)	Total revenue	IRR (%)	Comments
1a	Short rotation and fallow cycle (single rotation)	*Gmelina arborea* planted at 3 m x 3 m density, seedling cost 70, 10 days ha^{-1} for prep & planting, no thinning, survival 75%, 8 yr rotation, 2–3 coppice rotations possible, MAI* 18 $m^3\ yr^{-1}$, 2 MD* weeding $ha^{-1}\ yr^{-1}$, sawing efficiency 22%, logging cost 30%, sawing & marketing cost 40% on ex-mill price of 61 000 m^{-3}	153	530	18.6	20% lower yield reduces IRR to 15.1% Market for small sawlogs exists in Nigeria, but not yet in Cameroon. This option could fit into the normal bush/fallow cycle
1b	Two rotations	10 days ha^{-1} pruning & weeding at end of 1st cycle	208	106	20.9	20% lower yield gives IRR of 17.7%
2a	Taungya (no payment to farmers)	*Terminalia superba* planted at 9 m x 9 m spacing, delivered seedling cost 100, supervision costs 10 000 in yr 1, 5000 in yrs 2–5 & 2000 thereafter, average MAI 9 $m^3\ yr^{-1}$, standing value 20 720 m^{-3}, 35-year rotation with thinning at yr 22, farmers' revenue not included, but weeding costs excluded	140	664	15.5	This spacing requires very good planting stock 9 m x 4.5 m spacing would allow earlier thinning
2b	Taungya (medium payment to farmers)	As above but with farmer payments of 25 000 for planting and maintenance of 5000 yr^{-1} for 1st 8 years	221	6640	13.2	This payment may ensure better weeding
3	Shade tree crop	Cocoa understorey which yields from yr 10–50. Plantation on field assumed. 1st thinning at 14, 2nd thinning at 25, 3rd thinning at 35 (to 50 trees ha^{-1})	–	–	Approx 10	Cocoa needs early shade. Many thinning and farmer compensation options can be costed
4a	Manual recru (fully manual)	Planting *Terminalia ivorensis* at 5 m × 5 m spacing. MAI of 9 $m^3\ yr^{-1}$, man days assumed (in yr) are 51(yr1), 3(yr2), 7(yr3), 7(yr4), 6(yr5), 6(yr6), & 1 thereafter, thinning at yr 25	378.5	7589	8.9	Removal of total overstorey but maintenance of controlled shrub layer
4b	Manual recru (semi-mechanical)	Brushcutters reduce labour input by 66%	339.5	7589	9.2	Labour costs are high in Cameroon
5	Mechanical recru ha^{-1}	Caterpillar undertakes initial partial clearance @ 30 000 ha (assuming 100 ha minimum)	–	7589	9.2	
6	Line planting (grand layon)	Lines planted at 10 × 5 m spacing with overstorey largely cleared but 3 valuable species retained in 40–60 cm diam class, 3 in 20–40 cm diam class & 6 in 5–20 cm diam class. Thinning at 20 yrs with 10 m^3 of high-value species & 20 m^3 of whitewood, final cut at 40 yrs gives 360 m^3 & 5 m^3 of mahogany	119.5	7948	13.6	Establishment costs are lower because of wide spacing. Early thinning revenue valuable
7	Complete clearance	Mechanical clearance of site, windrows burnt and re-raked, total machine costs 290 000 ha^{-1} (based on Ivory Coast experience), intensive weed control. Total establishment costs 506 000 ha^{-1}. MAI 12.5 $m^3\ yr^{-1}$. Thinnings at yr 3, 6, 9, final cut at yr 20	597	6453	10.3	IRR highly sensitive to preparation cost and yield changes. More risky option

*MAI, mean annual increment: MD, man days

Shade trees and perennial crops could be an attractive option for community forests, and may also provide a means of establishing trees among illegal cocoa plantations in forest reserves. Shade trees are best above cocoa, but moderate shade can also be tolerated by coffee and a number of important crops like yams, cocoyams and pineapple. The growth increment of widely spaced timber trees will be considerable, though regular pruning is required to maintain good form in species which are not naturally self-pruning.

A modified form of the *manual regrowth* method has been the main method of forest regeneration used recently in Cameroon. Non-commercial species and all trees under 60 cm dbh were normally felled to waste or poisoned. Planting operations were, therefore, extremely labour-intensive, often involving up to 200 man days ha^{-1} or £400 ha^{-1} (Lawson 1993). In practice, resources were often not available for sufficient initial poisoning or subsequent weeding, and the majority of plantations have failed or been severely checked. Nevertheless, the manual regrowth method may remain the favoured option in circumstances where salvage felling is carried out immediately before planting, and where the environmental and economic risks of mechanical clearance are not acceptable.

The estimated internal rates of return are encouraging, particularly for the short-rotation (18.6%), taungya (15.5%) and line planting systems (13.6%). However, the models include only modest assumptions for supervision and overheads. Before the dissolution of the previous state forest regeneration agency in Cameroon (ONAREF), plantation overheads were running at 350%, not including headquarters costs (Lawson 1993). Whilst the new state regeneration organisation (ONADEF) may be more efficient than its predecessor, it is likely that funding agencies will in future favour private sector planting rather than supporting bureaucracy. Unfortunately, there are few spare resources in the private sector of most West and Central African countries, and little industrial or farmer confidence in tree planting. Even the favourable IRRs given below are unlikely to be sufficiently large, or free from risk, to encourage large-scale planting without the impetus of carefully directed incentive schemes.

IMPROVEMENTS IN YIELD AND PROFITABILITY THROUGH CLONAL SELECTION

Ladipo *et al.* (pp239–248) have reviewed the development of forest tree improvement programmes in West and Central Africa over the past 25 years. Considerable advances have clearly been made with the development of vegetative propagation techniques for important plantation species, and some native multipurpose trees. Clonal seed orchards have been established in several countries, and efforts are being made to develop disease-resistant clones and juvenile tests which predict the likely branching pattern of clones in later life.

Populus, Pinus and *Eucalyptus* lead the way in demonstrating yield improvements through the selection of superior clones: a good example being the Aracruz *Eucalyptus* plantations in Brazil (Zobel, Van Wyk & Stahl 1983), where the 100 best clones have more than doubled the production of unimproved stock. However, few clonal trials have yet been established and protected to demonstrate these potential gains with West African species. With *Triplochiton scleroxylon*, Leakey and Ladipo (1987) suggest that selecting clones with above-average volume and stem form would improve yields by 31%. Choosing the top 10% would increase yields by 81%. Research in clonal propagation has been underway in Côte d'Ivoire since the 1960s (Bonnet-Masimbert 1970), but the first controlled comparisons of the yield and form of clonal *versus* unselected material were established in 1987, and now cover some 24 ha (Verhaegen *et al.* 1992). After only two years, the clonal material averaged 14% greater height increment, but the above-average clones averaged a 40% height advantage. These apparent genetic gains are similar to those attained at the same age in Nigeria (Ladipo *et al.*, pp239–248).

In Cameroon, the tree improvement component of the Forest Management and Regeneration Project has restored the Parc de Bouturage facilities established under a previous World Bank programme at a 7 ha site in the Mbalmayo Forest Reserve. An area containing 240 m^2 of mist beds, 40 non-mist propagators (120 m^2), coppice-bed areas, and a drip irrigation system for up to 4 ha of stockplants has now been established. Approximately 0.4 ha has been planted with 357 clones of *Triplochiton scleroxylon*, 129 clones of *Lovoa trichilioides* and 24 clones of *Terminalia ivorensis*; 1700 *T. ivorensis* plants have been established as stockplants.

Following the ideas of Russell and Libby (1986), and the advice of Leakey *et al.* (1993), the FMRP is adopting the following low-technology strategy for clonal collection, selection and testing.

Collection of germplasm

Seed collection has concentrated on *Triplochiton scleroxylon*, and 16 provenances are now represented, including two from Nigeria. Collections will be extended to other species and countries. In Cameroon, a bounty payment to villagers is made for seed (from identified trees) when it is delivered to forest offices. In addition, cuttings have been collected from the stumps of 20 *T. scleroxylon* plus-trees identified in plantations of different ages. Attempts have also been made to locate shoots growing on the cut stumps of superior trees which were selected by exploiters. However, the inventory information currently kept by logging companies does not locate stumps sufficiently accurately to allow them to be relocated.

Nursery screening

The first stage of a clonal selection programme is underway, using a test which measures the response of seedlings to decapitation at 60 cm and the standardisation of leaf number to two leaves. The number of lateral shoots produced in standardised conditions and the time required to reassert apical dominance appear to be well related to the growth and form of the tree after four years (Ladipo, Leakey & Grace 1991a, b), and it is hoped that they will also be so in later life. This predictive test is being used to select 2% of the 14 000 *T. scleroxylon* seedlings currently in the nursery, which will be established as stockplants and used in the field screening phase.

Field screening

The FMRP's 1993 planting programme for *T. scleroxylon* (50 ha) is being used as a second-stage screening for clones identified in the predictive test. A 14 ha 'research zone' will be planted with 20 clones (from ten different provenances), replicated twice in each of five silvicultural treatments. The 46 ha 'demonstration zone' will also be used for clonal planting but not on a replicated planting pattern. Thus, a larger number of clones, with fewer ramets per clone, will be screened for field performance in lines of 20 trees. The lines will be labelled at the time of planting.

Field testing

This phase, which has not yet commenced, will involve replicated clonal plantings with those clones which have performed well in the previous phases. Field testing requires a significant land area and needs large numbers of ramets per clone in a randomised experimental design.

Clone to silviculture matching

Clones may respond differently to planting in partial overhead shade (enrichment planting), in full sun (complete clearance), or where side shade from herbaceous vegetation is encouraged (line planting, manual recru, taungya). The FMRP will gain some information on possible clone/silvicultural interactions from the statistically designed planting in the 'research zone'.

Clonal demonstration lines

Small, and unreplicated, plantings are planned close to the FMRP's headquarters to demonstrate to farmers and other visitors the differences in growth rate and stem form between selected clones and unselected seedlings.

Germplasm bank

Clones and plants of seedling origin which are not incorporated into the project's clonal planting programme will, however, be established and maintained as a gene bank.

Clonal seed orchards

A tree breeding programme is not planned at this stage under FMRP. However, in order to permit genetic recombination between selected clones, it is the intention to establish a clonal seed orchard of main species (*Terminalia ivorensis, Triplochiton scleroxylon* and *L. trichilioides*) using five to ten ramets of each of the most successful clones.

CONCLUSIONS

It is clear that good genetic material is continuously being lost as forests are selectively cleared of the most valuable species and individuals. Natural regeneration is often inadequate to sustain continuous production. Viable seed is difficult to obtain for some species, and of doubtful genetic quality for others. However, considerable scope exists for extraction licences to be linked to regeneration activities. It is hoped that, through the results of FMRP, logging companies will see the commercial potential of establishing plantations of domesticated hardwoods, and distributing selected seed and improved clones to villagers.

Given the threat to the forest gene pool, the promise of a renewed private planting programme, and our ignorance of propagation techniques and growth potential of many potentially important species, it is more than ever necessary to co-ordinate national germplasm collection and breeding efforts on native hardwood trees through a regional hardwoods improvement programme, similar to that proposed by Leakey and Grison (1985). This programme should not be narrowly based on two or three fast-growing species, but should include a range of timber and multipurpose species (eg *Baillonella toxisperma, Garcinia kola* and *Prunus africana*).

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