

Timber plantations in the humid tropics of Africa

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by

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PREFACE

The clearing of tropical forests continues at a fast pace. Certain countries in the humid tropics have over the past few decades lost the greater part of their forest cover. In addition to paying attention to sustainable management of the remaining forests, it is essential to greatly increase efforts in reforestation in most tropical countries in order to relieve pressure on these forests and to provide raw materials for present-day use.

Through its considerable experience in many humid tropical African countries, the Centre Technique Forestier Tropical (now CIRAD-Forêt) is in an excellent position to provide an overview of available knowledge in commercial forest tree plantations in these countries. Such an overview is presented in the present paper. The authors describe common techniques used and lessons learned from a great number of field trials carried out over the past years in the closed tropical forest zone of Africa, and provide information on species selection and reforestation techniques.

The present document includes two main parts, one on enrichment planting and one on reforestation on cleared lands. It records the evolution in forestry techniques in this regard, and discusses a range of associated issues related to forestry in the humid tropics.

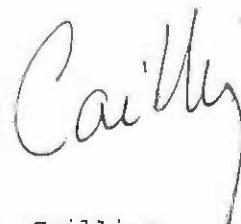
It is clear that the problems of deforestation cannot be solved through an isolated, technical approach. Many related economic, social and institutional questions will need to be addressed in order to adequately shoulder the challenge and to ensure the conservation and development of the tropical forests.

Recognizing the value and importance of recording available information for the benefit of Africa as well as ecologically similar zones in other tropical regions, FAO agreed to publish the present document prepared by the CTFT in its Forestry Paper series.

FAO sincerely thanks the Centre Technique Forestier Tropical for the cooperation which led to the preparation of the present document. Special thanks go to the two main authors, Messrs B. Dupuy and G. Mille, for their outstanding work.



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CHAPTER I

HISTORICAL SURVEY

The first foresters responsible for managing tropical forests (1900-1905 in Nigeria, 1925-1930 in the other African countries) had the impression that the closed tropical forest was inexhaustible and that nature itself took care of replenishing its capital. However, the progress of knowledge on the composition and functioning of this ecosystem has disillusioned managers and, most important, convinced them of the need for human intervention in the regeneration process.

The great diversity of environments and the lengthiness of response times in forestry experiments, with their necessary replications, did not make the task of the pioneers of tropical forestry any easier. Nonetheless, the will to progress was rapidly translated into the application of theories that were to divide the forestry world by opposing the concepts of natural and artificial regeneration.

At the same time, these disagreements enabled knowledge to evolve separately.

There exist a great number of methods based on natural regeneration. The basic principle is "to gradually permit light to reach the ground floor in order to trigger the germination of fallen seeds and stimulate the growth of pre-existing plants languishing under the canopy" (R. CATINOT, 1965). These methods may be divided in two main groups, according to their immediate objective:

- improvement techniques which do not immediately seek natural regeneration; in this case, stand homogeneity will be the easier aspect to regenerate (improvement of Okoumé stands in Gabon, standardization according to height and standardization in Zaire);
- techniques aimed at the immediate use of natural regeneration (improvement of natural stands in the Côte d'Ivoire, tropical shelterwood system in Nigeria and Ghana).

Without going into detailed analysis, it appears that the limitations of these practices are due to:

- the difficulty of systematically applying and controlling the right dosage of light for saplings;
- the wide scattering of activities, and, as a corollary, the long duration of the actions, which leads to a dilution of human and financial efforts.

It was thus easy for those who supported artificial regeneration to claim that it is more efficient and less costly to concentrate operations in the field over a shorter period of time, and with systematic (hence stricter and easier) control. The deliberate choice of the field of action and of the species was another positive element.

The goal was to create a new forest by replacing the pre-existing stand more or less rapidly and radically, while regularizing its structure by planting one or two dominant species.

In the next section we shall examine the evolution of methods whereby a natural forest can be replaced with a high-yield artificial stand; they range from relatively limited enrichment to complete replacement following total clearing.

1 - DEFINITIONS

1.1 + Plant formations

Before beginning a study, it is important to make sure that the technical language is understood by everybody. It is therefore necessary to define the terminology employed or refer to commonly used and known definitions. In this case, we are concerned with tropical African plant formations. These were inventoried and defined at the Yangambi (Zaire) meeting of experts in 1956.

Here we shall briefly describe the formations involved in plantation works undertaken in the various countries of western and central Africa (R. LETOUZEY, 1969).

Closed forests are those in which the crowns of trees and shrubs touch. The existence of such formations directly depends on the climate. They may be grouped as follows:

+ Rain or moist forest

"A closed stand with trees and shrubs of varying height; no grasses on the ground, but often suffruticose plants and, more rarely, non-graminaceous, broad-leaved herbs."

The climate is constantly warm and moist; annual average temperature ranges from 20 to 27°C. The annual saturation deficit is weak; its monthly value varies little.

Within the category of moist or rain forests we have:

- * Moist evergreen forest, where most trees bear leaves all year long. Cumulative annual rainfall ranges from 1 600 to 2 200 mm. The dry season is 2 to 4 months long.
- * Moist semi-deciduous forest, where a great number of trees lose their leaves during part of the year. Annual rainfall ranges from 1 200 to 1 600 mm; the dry season lasts 4 to 6 months.

+ Dry closed forest

"A closed stand with trees and shrubs of varying height (though usually shorter than in moist forests); most upper-storey trees lose their leaves during part of the year (in exceptional cases they may remain green all year round: this is known as dry evergreen forest); the undergrowth consists of evergreen and deciduous shrubs, and clumps of grasses are found here and there on the ground."



Degraded forest before reforestation

The climate is characterized by one or two rainy seasons with an annual rainfall R ranging from 1 000 to 1 600 mm. The dry season may last 4 to 8 months.

The qualitative floristic composition of these forests also differs, as well as certain quantitative aspects regarding their potential in terms of commercial species.

The plant formations described above constitute the area in which artificial enrichment operations have been concentrated.

Almost all of the earliest trials (dating back to around 1910) were conducted in moist evergreen forests.

1.2 - The concept of enrichment

Contrary to what the foresters who first tackled tropical forests at the start of this century may have believed, the standing volume they contain is not very large. It is in the order of 250 to 300 cubic metres per hectare.

If one refers to the purely merchantable volume, the figures fall sharply. On average, they range from 5 to 25 cubic metres per hectare, according to the degree to which the forest is exploited, the commercial value of its specific composition, and the minimum accepted logging diameter.

This last factor has varied considerably over time. When forestry services first began operations, it applied to a relatively limited number of species. However, the services soon became concerned about the stands' loss of value and the need to prevent it.

The main concern was thus to define and finalize appropriate forestry actions to increase or at least maintain the commercial-timber potential of natural stands. Within the general framework of forest management, the goal was to ensure high yields, as homogeneous as possible. Enrichment became the way to save forests, and two fundamental options took shape to implement it, dividing, as we have seen, the advocates of natural regeneration and artificial regeneration.

Here we shall discuss only methods which are applicable to fairly large plantations.

Forest, or "enrichment," plantations aim to introduce into a more or less transformed forest environment the valuable species which will eventually constitute its essential output. Additional output may come from pre-existing valuable species, or those which have appeared due to natural regeneration.

The earliest operations were quite cautious, and involved only the few species sure to find outlets in the export market [Niangon: *Tarrietia utilis*; Sipo: *Entandrophragma utile*; Mahogany: *Khaya* spp.; Sapelli: *Entandrophragma cylindricum*; Okoumé: *Aucoumea klaineana*; Iroko: *Chlorophora excelsa*]. The intention was to "encourage and help nature, to hasten its work."

Intervention on original natural forests was subsequently intensified for commercial reasons (broadening the range of regularly exported species) and silvicultural reasons (better knowledge of the characteristics and reactions of the relevant species).

Enrichment planting techniques may be classified according to the degree of intervention and alteration of the original ecosystem. Starting with minimal interventions - planting widely-spaced straight lines which did not overly disturb the environment - these techniques have evolved towards the gradual destruction of the pre-existing natural forest.

The original term "enrichment" has thus acquired a connotation that is both more destructive and more intensive, inasmuch as it is very difficult, if not impossible, to transform the forest ecosystem into a more productive system without resorting to methods that result in a totally new ecosystem. In such cases, the intervention is actually a conversion plantation.

For its part, the FAO Committee (1969) on Forest Development in the Tropics (FDT) recommended the following terminology:

- II - Enrichment plantation: group or line planting, of varying intensity, designed to improve the percentage of desirable species in natural forests, without eliminating existing useful trees. Natural regeneration forms a significant portion of the crop at maturity.
- Conversion plantation: a plantation aiming at total replacement of pre-existing natural vegetation with a completely new man-made forest."



Yapo, Okoumé and Niangon mixed forest, 25 years old (1963)

2 - EVOLUTION OF METHODS: FROM ENRICHMENT TO TOTAL REPLACEMENT

Many methods have been tried out with more or less success, and they have evolved over time, sometimes with few distinguishing features, so that we find transitions rather than sharp boundary lines among them.

We shall briefly describe these methods in the order of their increasing transformation of the original forest.

2.1 - The line-planting method

This is an extensive method which translates into a fairly slow-going enrichment that produces stand homogenization only in the long term, after at least two rotations.

It consists of opening parallel and equidistant lines in the forest and planting nursery-grown seedlings of commercial species at regular intervals. The point is to give the trees the benefit of extra light while remaining in a forest environment:

- all vegetation is eliminated from a 2 metre-wide strip;
- seedlings are planted in single file at 2, 2.5 or 5-metre intervals;
- the lateral canopy is destroyed more or less intensely;
- the seedlings are thinned out early to ensure their survival and avoid overly drawn-out tending.

The method has evolved over time, and the distance between lines is now 20 to 25 m, leaving 8 to 10 metres between the treetops of adjacent lines. At the same time, all trees that form a thick and low canopy which would prevent light from reaching the strip are girdled.

2.2 - The modified line-planting method

In the preceding method, the narrowness of the lines allows a relative light of only 7-8 percent. The behaviour of the species involved was not well understood at the time these actions began. It was only when their light requirements were confirmed and taken into account that it became necessary to:

- limit the competition of the undergrowth for light by widening the lines, though not excessively, and still planting only one row of seedlings in each line;
- increase incidental light by lowering the height of the inter-line stand (devitalizing it with plant hormones).

With a line 5 metres wide and an inter-line stand whose height has been reduced to 15 cm, the result is 25 percent direct light and 35-40 percent lateral, for a total of 60 to 65 percent relative light.

The goal is to allow the saplings better initial growth by limiting competition at an early age.

In practical terms, the technique is as follows:

- lines are 5 m wide and set 10 to 20 m apart, according to the chosen enrichment rate;
- within the line, all trees whose diameter is less than 15 cm are manually cut down at knee height; this makes it possible to preserve a forest micro-environment at ground level while ensuring protection against invasion by undesirable pioneer species such as the Aga umbrella tree (*Musanga cecropioides*);
- throughout the forest, all trees whose diameter is larger than 15 cm are killed by felling or girdling. The largest trees are often girdled or poisoned. Trees whose diameter is less than 5 cm do not much disturb lateral illumination;
- transplants are set in single file within the lines, at 3 metre intervals;
- saplings are cleaned manually (climbers), and regrowth is kept below their tops.

Thanks to this method, it is possible to obtain about fifty well-grown valuable trees per hectare, though permanent surveillance and energetic intervention are required to ensure their protection against natural competitors.

2.3 - The plot method

This method, used by Belgian foresters in Zaire, is derived from the technique used by Anderson to reforest Scottish heaths.

In this technique, the species which are to regenerate are introduced with high-density plantings. Saplings are uniformly distributed over widely separated plots of equal area. In practical terms:

- temporary nurseries are created beneath the forest, to accustom the transplants to growing in the shade;
- 4 x 4 m squares are marked off, measuring 10 m from centre to centre in the four cardinal directions;
- all climbers and herbaceous undergrowth are eliminated from the squares, leaving shrubs intact;
- the different forms of the desired species (seedlings, stumps and so on), are planted very close to each other;
- once the transplants have taken hold, the shrubs are gradually eliminated, as is, very cautiously, the overstorey.

The goal of this method is to avoid disturbing the ecological environment and immediately recreate the forest state for the newly-introduced species, while distributing the plots widely for economic reasons.

The relative light thereby obtained at the level of the saplings hardly ever exceeds 5-10 percent.

2.4 - The undergrowth method

This method is based on partial manual destruction of the canopy at planting time.

Contrary to what we shall see further on, the objective here is to preserve the lower storey, or undergrowth, between one line and the next, in order to accommodate species which cannot take broad sunlight immediately after planting, for instance the Sipo (*Entandrophragma utile*).

Accordingly, the method consists of devitalizing trees that make up the overstorey, opening planting lines, and temporarily preserving part of the undergrowth between lines, then eliminating it gradually as the transplanted seedlings grow.

2.5 - Total and gradual destruction of the forest by devitalization

Under this method, the pre-existing forest is destroyed without the mechanical intervention which would scrape the soil away and allow secondary light-demanding species to grow back too fast.

2.5.1 - The regrowth method

Upon planting, the seedlings are given maximum light, while the soil is protected by preserving regrowth of shade-tolerant species. By covering the ground, the regrowth prevents the development of the Aga umbrella tree (*Musanga cecropioides*) and other weed species.

This method includes the following operations:

- all trees with a diameter below 15-20 cm are cut down manually at knee height and left where they fall, without being burned. They are too small to require any cross-cutting;
- trees which cannot be cut down are immediately devitalized with plant hormones. In actual fact, these trees, gradually eliminated by poisoning, at first form a thin canopy. Once dead, their fall can cause significant damage to the plantation saplings; saplings are transplanted at equal 4 to 6-metre intervals in straight lines reopened manually in the regrowth;
- manual tendings, repeated over a 5- to 8-year period according to the species' rate of growth and targeting Aga umbrella trees in particular, keep the regrowth below the tops of the valuable species.

2.5.2 - The Martineau method (1930-32)

This method is more on the order of dense planting under forest cover. It cautiously introduces valuable species under a gradually-destroyed canopy. This was one of the first closed-plantation methods conceived for African tropical closed forests, and is designed to replace the heterogeneous forest with a stand consisting only of commercial species.

This technique consists of:

- manually destroying all undergrowth with bole diameters less than 10 cm;
- transplanting 2 500 seedlings/ha, then thinning out the saplings;
- gradually destroying the main canopy by girdling at intervals of one, two and five years after planting. Supplementary light is then ensured by sweeps made every five years starting from the tenth year.

Contrary to the preceding method, this proceeds by creating a closed plantation beneath a canopy, with gradual thinning after planting.

2.5 - Total destruction of the forest before planting

The whole forest canopy is removed in a single operation, in order to give the transplants full light right from the start.

2.6.1 - The Taungya method

Plots in government-owned forestland are temporarily granted to farmers to establish an association of forest trees and intercrops.

The goal here is to associate agriculture and forests. Farmers benefit by having the use of the land for several years, foresters by lower plantation and tending costs.

Tree spacing depends very much on the choice of interplanted crop; usually greater than 5 x 5 m.

Saplings transplanted by one or the other partner thus profit from good growth conditions during the two or three years of the cultivation period, after which the forestry service resumes tending operations for as long as necessary.

This agro-silvicultural system, which usually favours the forestry side, is an economical way to reforest land that might otherwise be lost to the forest domain in the longer run.

In exchange for their work, farmers have the right to till and dispose of their crops, and may have social benefits or economic incentives as well. Their main advantage is temporary access to the forest and its fertile land. The Taungya method has produced good results in areas where fertile land is scarce.

2.6.2 - The Limba method

The Limba (*Terminalia superba*) grows in full sunlight, very straight, and does not need to be pruned. It is therefore unnecessary to preserve accompanying regrowth or plan very close plantations.



Old Framiré plantation (20 years old) at Sangoué

The pre-existing forest is completely destroyed so that the transplants can get well rooted before the dry season sets in. In this technique:

- all trees with a diameter inferior to 30 cm are felled manually;
- all trees with a diameter above 30 cm are girdled or poisoned;
- all residues are burned;
- planting lines are opened in the burnt wastes;
- Limba stump plants, 1-1.5 m tall, are planted at definitive intervals of 12-14 m or, if future selection is planned, semi-definitive intervals of 6 x 12 m.

2.6.3 - Methods based on mechanized deforestation

The preceding method was adapted to plantations of Okoumé (*Aucoumea klaineana*), the only difference being mechanization of the clearing process.

Trees with a diameter inferior to 30 cm are felled by bulldozers whose power is appropriate for the kind of original growth; larger trees are devitalized. Remnants are windrowed and burned, and the transplants are set between the windrows. The choice of planting intervals is more varied, since the ground is totally cleared. Tending operations are important but less vigorous, because the soil has already been scraped.

This method is now used for many other species as well: *Terminalia ivorensis*, *T. superba*, *Samba* (*Triplochiton scleroxylon*), and so on. Today, more powerful equipment makes it possible to fell all trees mechanically.

3 - EXAMPLES OF APPLICATION OF THE METHODS DESCRIBED

Soon after the establishment of forestry services in western Africa, resource managers brought to notice the problems caused by the heterogeneous composition and regeneration of Africa's tropical closed forests. Artificial enrichment and environmental homogenization operations were therefore undertaken in the various countries involved.

3.1 - Côte d'Ivoire

Starting in 1930-31, tightly-spaced forest plantations were established in the Yapo forest, about fifty km north of Abidjan (Martineau method). An area of 90 ha was enriched with Niangon (*Tarrietia utilis*) wildings planted at 2 x 2 m intervals, for a total of 2 500 trees per hectare. The area is the natural environment of this species. Other species such as Mahogany (*Khaya ivorensis*), Dibetou (*Lovoa trichilioides*) and Tiama (*Entandrophragma angolense*) have also been introduced in small proportions.

A 1985 inspection of the plots showed that the results, though not spectacular, were relatively satisfactory. On two plots covering an area of 23 ha, the residual density of the Niangons (*Tarrietia utilis*) is 90 to 130 plants per ha (diameter over 30 cm); the trees often seem weak. From observations made over the lifetime of these stands, it appears that:

- The original canopy was definitely removed too late. Several trees belonging to secondary species still dominated the 30-year-old stand.
- The stand was first thinned when it was already 25-30 years old. At that advanced age, the remaining trees can no longer react dynamically, and may be too weak to survive bad weather (greater risk of windfalls).
- The endings were carried out regularly during the first eight years, and irregularly thereafter.

A few years later, for economic as well as other reasons, line planting was started. The lines were set 10 m apart, with planting intervals of 5 or 2.5 m along the lines (making a total of 200 or 400 transplants per ha).

Until 1948, the plantations had benefited by a regular spacing of 25 m between lines, with planting intervals of 2 or 2.5 m along the lines, making a total of 160-200 transplants per ha. The transplanted species were still Niangon (*Tarrietia utilis*), Mahogany (*Khaya ivorensis*), and Dibetou (*Lovoa trichilioides*), with the addition of Framiré (*Terminalia ivorensis*) and Bossé (*Guarea cedreto*). About 11 000 ha were treated in this way.

Mixed methods have also been used to enrich plots where natural regeneration was considered insufficient. In particular, Mahogany (*Khaya ivorensis*) has been planted at intervals of 10 x 5 m, with a certain degree of flexibility that enables each transplant to benefit from the best living space that can be obtained with a minimum of intervention on the original forest.

The Taungya method has been used in different periods, but only to a very limited extent in closed forest areas.

Trial species were Fraké (*Terminalia superba*), Framiré (*Terminalia ivorensis*) and Samba (*Triplochiton scleroxylon*). Initial results were promising, but became very uneven at a more advanced age. Better results were achieved in savanna areas, particularly with Teak (*Tectona grandis*), Gmelina (*Gmelina arborea*) and Cassia (*Cassia siamea*).

Since the 1960s, preference has been given to plantations in cleared areas. This technique has been chosen particularly for light-demanding species such as: Fraké (*Terminalia superba*), Framiré (*Terminalia ivorensis*), Samba (*Triplochiton scleroxylon*), Teak (*Tectona grandis*), Cedar (*Cedrela odorata*), and so forth.

3.2 - Nigeria

Nigeria's foresters became concerned at an early date to ensure the artificial regeneration of closed forests. Since 1916, loggers have been required to plant 24 saplings for each felled adult tree; a praiseworthy requirement in itself, but difficult to monitor because of the far-ranging operations and operators it entails. The transplants could not be systematically defended from natural vegetation, and few traces of them remain.

The line-planting method was used during the 1930s, but with few variations as regards placement and, most important, with little attention to tending and light dosage. It has thus been impossible to draw any interesting conclusions from these efforts.

Later on, towards the 1950s, the Taungya method was employed on a large scale for both short-rotation species such as *Cassia siamea* and *Eucalyptus* spp. and longer-lived species such as Teak (*Tectona grandis*), *Terminalia* spp., and Bilinga (*Nauclea trilesii*).

Plantations consisted of mixed or pure stands.

In mixed stands, shade-tolerant species - essentially Mahogany¹ - were introduced, with a 4-metre spacing for short stump plants or, sometimes, for striplings (whole trees with only the two terminal leaves left on).

In pure stands, the spacing became 6 x 6 m, especially for the introduction of Bilinga and *Terminalia* spp. One overall tending is carried out the second year, and saplings are thinned out only once before the sixth year.

A clearing is planned for the 11th year, or earlier if necessary.

At present, plantings needed to re-establish destroyed forests are made in full sunlight on totally-cleared areas and mechanically-prepared soils.

3.3 - Cameroon

Artificial enrichment was launched quite early in this country, particularly in the Mbalmayo forests and the Makak-Nyong reserves, and it has been pursued in other regions.

In the Mbalmayo forest, the line-planting method has been employed since 1932 for species such as Ayous (or Samba: *Triplohiton scleroxylon*), Mahogany (*Khaya ivorensis*), Sapelli (*Entandrophragma cylindricum*), Bibolo (or Dibetou: *Lovoa trichilioides*), and so on.

After 18 years, only 48 percent of the transplanted saplings were still standing, but there was a significant additional amount of natural regeneration which brought the number of valuable trees up to 75 percent of those planted. Moreover, the contribution from natural regeneration led the forestry services to change their enrichment method, encouraging natural regeneration. This was done on one-hectare plots in conjunction with controlled cultivation. These plots, grouped in 100 to 300-ha sections, were bounded by lines planted with Mahogany (*Khaya ivorensis*), Sapelli (*Entandrophragma cylindricum*) and Bibolo (*Lovoa trichilioides*).

In the Makak-Nyong reserve, 2 500 ha were planted in the period from 1932 to 1949 with the following species: Sapelli (*Entandrophragma cylindricum*), Mahogany (*Khaya ivorensis*), Bibolo (*Lovoa trichilioides*), Iroko (*Milicia excelsa*), Bossé (*Guarea cedrata*), Ayous (*Triplohiton scleroxylon*), Kosipo (*Entandrophragma candollei*), etc.

¹ Mahogany (*Khaya ivorensis*, *Khaya anthotheca* and *Khaya grandifolia*) tolerate and grow faster in full sunlight.

Here too, the line-planting method was not very suitable for strictly light-demanding species. The best results were achieved with Mahoganies (*Khaya* spp.), Dibetou (*Lovoa trichilioides*) and Sapelli (*Entandrophragma cylindricum*), in decreasing order.

In the coastal area of the south, Okoumé plantations have been established along the same lines as the enrichment programmes of neighbouring Gabon.

Around 1975, the wide-line method was used again on an experimental basis in the eastern semi-deciduous forest (Belabo) and the coastal closed forests. Five-metre-wide lines were set 15-20 m apart, with 3-metre intervals between trees along each line. The undergrowth was cut down at knee height, and all trees with a diameter over 20 cm were girdled or poisoned.

The species planted were *Terminalia ivorensis* and *T. superba*, *Entandrophragma cylindricum* and *E. utile*, *Khaya ivorensis*, *Triplohiton scleroxylon*, *Tarrietia utilis*, *Afzelia africana*, *Lovoa trichilioides*, etc.

3.4 - Congo

In this country, attention focused early on the Limba tree (*Terminalia superba*) because of its rapid growth and the quality of its wood.

In 1937, closed plantations were made on small plots to serve as arboreta.

Later, line plantings were made, with the transplants set at 10 x 5 m intervals. These initial experiments showed that the Limba tree can grow straight and is self-pruning. At the beginning of the 1950s, it was therefore determined to plant it at the definitive spacings of 12 x 12 m or 12 x 14 m.

The Limba, a light-demanding species, requires completely open space. This was provided in two stages:

- the chosen ground, already heavily logged, was totally cleared along a largely open strip;
- tall stump plants were transplanted;
- the trees of the upper canopy were girdled the following year;
- the lines were cleaned five times the first year and three or four times the second year, to keep the crowns of the transplants free from other vegetation and to prevent creeper invasions. This method was later replaced with planting in full sunlight after mechanized forest clearing and soil preparation.

3.5 - Ghana

The line-planting method has also been used in evergreen closed forests, in areas where extremely heavy forest logging left no hope for natural regeneration.

Lines are opened 1.80 m wide and 20 m apart, and climbers growing within 5 metres of both sides of the line are eliminated. The canopy is gradually reduced by poisoning, enough to give the saplings light without much risk of stimulating climber growth with surplus light. The transplants are spaced 5 m apart, and are at least 1 m tall, to avoid being damaged by wildlife. The species planted are Mahogany (*Khaya ivorensis*), Sapelli (*Entandrophragma cylindricum*), Tiama (*Entandrophragma angolense*), Niangon (*Tarrietia utilis*), and so forth. For Mahogany and some other species, the results obtained with line-planting are better than with close spacing.

Block plantations have also been created with Framiré (*Terminalia ivorensis*) and Niangon (*Tarrietia utilis*), spaced at intervals of 5 x 6 m. Towards the end of the 1960s, large areas were enriched (about half of them with the Taungya method and half with the regrowth method) with species such as Samba (*Triplohiton scleroxylon*), Framiré (*Terminalia ivorensis*), Teak (*Tectona grandis*), Cedar (*Cedrela odorata*), and so forth.

3.6 - Zaire

As regards this country, it is necessary to distinguish methods applied within the framework of extensive programmes from those used on an experimental basis. In effect, Belgian scientists were very active in this work before Zaire's independence, mainly at the Yangambi site. Many techniques were tested, including the following:

Enrichment by uniformization at ground level

This method is a special application of the silvo-agricultural system and differs from the Taungya method in that saplings belonging to valuable species are identified and preserved at the time the land is put under cultivation (essentially with banana-trees at first, then coffee, then cocoa), simultaneously planting some one hundred *Terminalia superba* per hectare. The stand resulting from this method should be a heterogeneous secondary forest whose overstorey includes, besides *Terminalia superba*, the valuable species that were spared when the land was put under cultivation, as well as economically important species that regenerated naturally.

Where there was no regrowth of valuable species, the simple forest/banana method was applied. After the land was cleared, generally without burning, Limba trees were planted at 6 x 12 m intervals intercropped with banana trees. The period of cultivation was supposed to be limited to 5 or 7 years. It was often extended with permanent coffee and cacao plantations which are still to be found there today. The Limba plantations have seldom been thinned out; exploitation begins after 40-45 years, when their average diameter reaches 60 cm.

Line enrichment

This has also been tested at different intensities. Experience has shown that this method is better suited for enriching fairly open formations, or even fallows, than established forests which are exploited little or not at all. This method has produced good results with fast-growing, light-demanding species, which develop a normal shape even when isolated (*Terminalia*

spp., for example). In 1987-89, limited line-planting programmes were resumed in the Mayumbe forest reserves.

Success has been very limited, for want of the resources needed for intensive forestry care.

Wide-strip planting

Strips 10 m wide and 25-50 m long are cut every 50 m (10 ares per hectare) and planted with one principal species (*Entandrophragma*, *Autranella*) plus accompanying species, at intervals of 4 x 4 m, 2 x 2 m or 1 x 1 m.

Direct seeding in narrow strips after thorough cleaning

This method consists of meticulously cleaning strips 2 m wide and 20 m apart, cleared of all natural root tangle. Six seeds per m² are planted every 2 m (*Entandrophragma* spp., *Milicia excelsa*, *Tarrietia utilis*, *Ceiba* spp., *Khaya* spp.). Results vary according to the species. Growth is quite comparable to that obtained with line planting, but seeding allows higher density and a somewhat better shape than transplanting, the possibilities of quality wood yields are greater, and the latitude for selection by thinning is wider.

The plot method

This method, inspired by Anderson's plots, originally consisted of planting large plots, sized from one to many ares, under stands of Aga umbrella trees (old wildland); the undergrowth was cleared and seedlings were planted with spacing varying from 4 x 4 m to 1 x 1 m. The results achieved, especially with spacing of 1 x 1 m or even 2 x 2 m, prompted Belgian foresters to develop the tightly spaced plot method (E. MAUDOUX, 1958). This method aimed to combine the biological advantages of tightly-spaced planting with the lower costs of extensive enrichment methods. Small groups of saplings are transplanted or sown fairly close together, with the groups widely scattered over the area to be enriched. This principle has been adapted to different environments and has produced good results in open environments (moors, open savanna, deforested land), but in closed forests it has met the same difficulties of canopy opening, regrowth control and plant tending encountered in line planting, with the additional problem of widely scattered sites, which makes accessibility more difficult.

Enrichment in clear felling areas

This method is used only in areas fully exploited for fuelwood or lumber. The forest fallow is enriched with valuable species by planting light-demanding species such as *Terminalia superba*, *Milicia* (*Chlorophora*) *excelsa* and so forth, uniformly spaced at 10 x 10 m or 15 x 10 m. It is hoped that regrowth will guard the valuable trees introduced. Problems in controlling this regrowth and tending the planted saplings have appeared with this method as well.

In conclusion, of all these methods tested in actual practice, only the first two - the "uniformization at ground level" or "Limba method," and the "line enrichment" method - have been applied to fairly extensive areas,

especially in Mayumbe, but were later abandoned for historical reasons. It has not been possible to obtain recent information on their results.

3.7 - Other countries: Guinea, Sierra Leone, Liberia

The other West African countries have applied, on a relatively modest scale, techniques tested or perfected elsewhere.

In Guinea, line enrichment has been carried out in several reserved forests, but it has not been possible to learn either the extent or the results of these plantations.

In Sierra Leone, various natural stand improvement techniques have been used. On the one hand, techniques favouring natural regeneration, such as the Tropical Shelterwood System (TSS) also used in Nigeria and Ghana, have been applied at a rate of many hundreds of hectares a year; at the end of the 1950s, the area so treated amounted to 4 000 ha. On the other hand, methods involving planting in the strict sense were applied on about 5 000 ha in 1960, but statistics do not distinguish among intensive planting, Taungya method, under-cover planting and line planting. The results are not known. However, methods which were too extensively spread out, line enrichment in particular, were abandoned at the beginning of the 1960s due to strong agricultural pressure on the land.

Lastly, except for a few trials, no natural forest improvement or enrichment system has been established in Liberia. As of 1977, the Forestry Development Authority's plantations covered 5 500 ha (pines, Teak, Gmelina, etc.).

4 - KNOWLEDGE ACQUIRED

4.1 - The light factor

In the forest environment which interests us here, it soon became clear that light was the growth-limiting factor affecting saplings. It is true that this fact was not apparent in the forest environment, though A. Aubreville had noted that "Growth depends in very large measure on the quantity of light received by the crown. Obviously no one could doubt this, but within the constantly moist and warm tropical rain forest environment it was thought that plants could develop even under poor light."

Initially inadequate knowledge of the behaviour of economically valuable species underestimated the importance of light. Research and the development of forestry techniques subsequently showed that results depend essentially on the amount of light, especially for young plants.

Though light helps the growth of newly-introduced species, it also powerfully stimulates a whole range of invasive species whose development is very damaging to the saplings. Particularly aggressive pioneer species, such as the Aga umbrella tree, tend to occupy opened areas very fast.

The care of saplings thus requires a good balance between light dosage and keeping natural vegetation at a suitable distance.

4.2 - Choice of species

The earliest enrichment operations were carried out at a time when the number of economically valuable species (those which had a permanent market) was limited. Accordingly, these were the species to which priority was given to enrich forests to which they were native but which had been greatly impoverished by intensive logging, or to increase the value of stands where they were absent: Mahoganies (*Khaya spp.*), Niangon (*Tarrietia utilis*), Sipo (*Entandrophragma utile*), Sapelli (*Entandrophragma cylindricum*).

Two factors then broadened the choice: on the one hand, the number of commercial species increased; on the other, foresters realized the need to use light-demanding species for plantations. *Terminalia spp.*, Teak, Gmelina and so forth thus appeared. However, priority is still given to valuable commercial species which, even if only small numbers survive after strict selection, often more natural than human, greatly enhance the per hectare value.

With canopy still relatively thick, the introduction of Mahoganies, Niangon, Dibetou, Tiama, Sapelli, Sipo and Samba accordingly continued. Gradual clearing enabled foresters to introduce even more light-demanding species such as *Terminalia spp.* and Okoumé.

Total replacement has also led to the introduction of fast-growing species yielding secondary-grade timber but with shorter felling cycles. This is the case of pine (*Pinus caribaea*), Gmelina and Eucalyptus trees, whose initial uses for lumber or fuelwood may evolve towards that of commercial timber.

The Taungya method has also made it possible to plant species such as *Terminalia*, *Samba*, *Cassia*, Teak, Gmelina, and so forth, in cleared areas with no competition.

4.3 - Results

The saplings which have survived in the various trials are those which have benefited from better lighting and intensive clearing of the natural vegetation.

Generally speaking, enrichment operations have not been a complete success. The earliest line plantings suffered from a overly thick canopy and from strong undergrowth and regrowth competition. When the lines were widened, however, competition, especially from climbers, became very intense. Tending and cleaning operations became very numerous and repetitive. The more light is given to introduced plants, the more necessary it is to control the development of potential competitive vegetation (even more so in the regrowth method, where accompanying vegetation must never be allowed to get the upper hand).

The success of the various methods has thus been influenced by the foresters' perseverance in protecting the trees they have planted; however, their perseverance has often been curbed by the lack of personnel and money. Thus there are limits to this technique, which, as regards extensive forest treatment, should be applicable to large areas with a very low financial investment in material and human resources per unit of area. Paradoxically,

it has become almost as costly as intensive plantations which concentrate high productivity in small areas.

Many forestry operations and investments were interrupted during the Second World War, and disorganization of the services ensued. Nature thus gave free rein to spontaneous competition, which has seldom been favourable to introduced species, except for the more pioneer varieties such as Okoumé or Terminalia spp., which were able to free themselves from undergrowth thanks to strong initial growth.

The Taungya method could according be thought the most effective, since practically total clearing and permanent and total tendings are necessary for the survival of associated cultures. But this method, which African farmers have always found limiting, has not been developed as widely as hoped. It has been used mainly in open forests and savannas for various reasons: accessibility, facility of clearing and, most important, lack of available farmland. This method has created some good stands of Teak, Gmelina and other species in Côte d'Ivoire, Nigeria, etc.

Extensive methods enabled large areas to be treated annually. In the end, however, tending operations became so great as to be incompatible with the resources available. On the other hand, the enrichment method is based on the determination to maintain a heterogenous stand structure by conserving part of the natural forest. The management of multispecies stands established this way is highly complex and difficult.

This is why enrichment techniques have evolved towards conversion plantations permanently established on totally cleared land. Natural heterogenous forest is thus replaced by high-yield, monospecific even-aged stands.

The main result of these experiments is that they have made clear what factors limit the techniques:

- costs of technical, human and financial resources that are incompatible with extensive treatment of large areas;
- lengthy follow-up and works needing long-term supervision and repeated intervention;
- economic and demographic development of tropical African countries, which makes it difficult to reserve large tracts of land for low-yield uses. Forests are subjected to intense clearing by a rural population that is growing exponentially.

In this connection, it should be noted that due to clearing for agricultural use, a large part of the older plantations vanished before reaching logging age.

CHAPTER II

RECENT TECHNIQUES AND ORIENTATIONS: REFORESTATION IN CLEARED AREAS

The technical and economic difficulties evidenced in all enrichment operations have led foresters to prefer total replacement.

Considerations regarding the evolution of the need for raw material (timber as well as lumber and fuelwood) induced officials to intensify the re-establishment or creation of useful resources. The objective is now to seek optimal economic return per unit of area, hence to concentrate investments in time and space.

The method selected inevitably implied total elimination of pre-existing formations by mechanized clearing, followed by more or less close planting, which also permitted further use of machinery for tending operations. This technique has the advantage of being applicable to any site, through a careful choice of terrain and species.

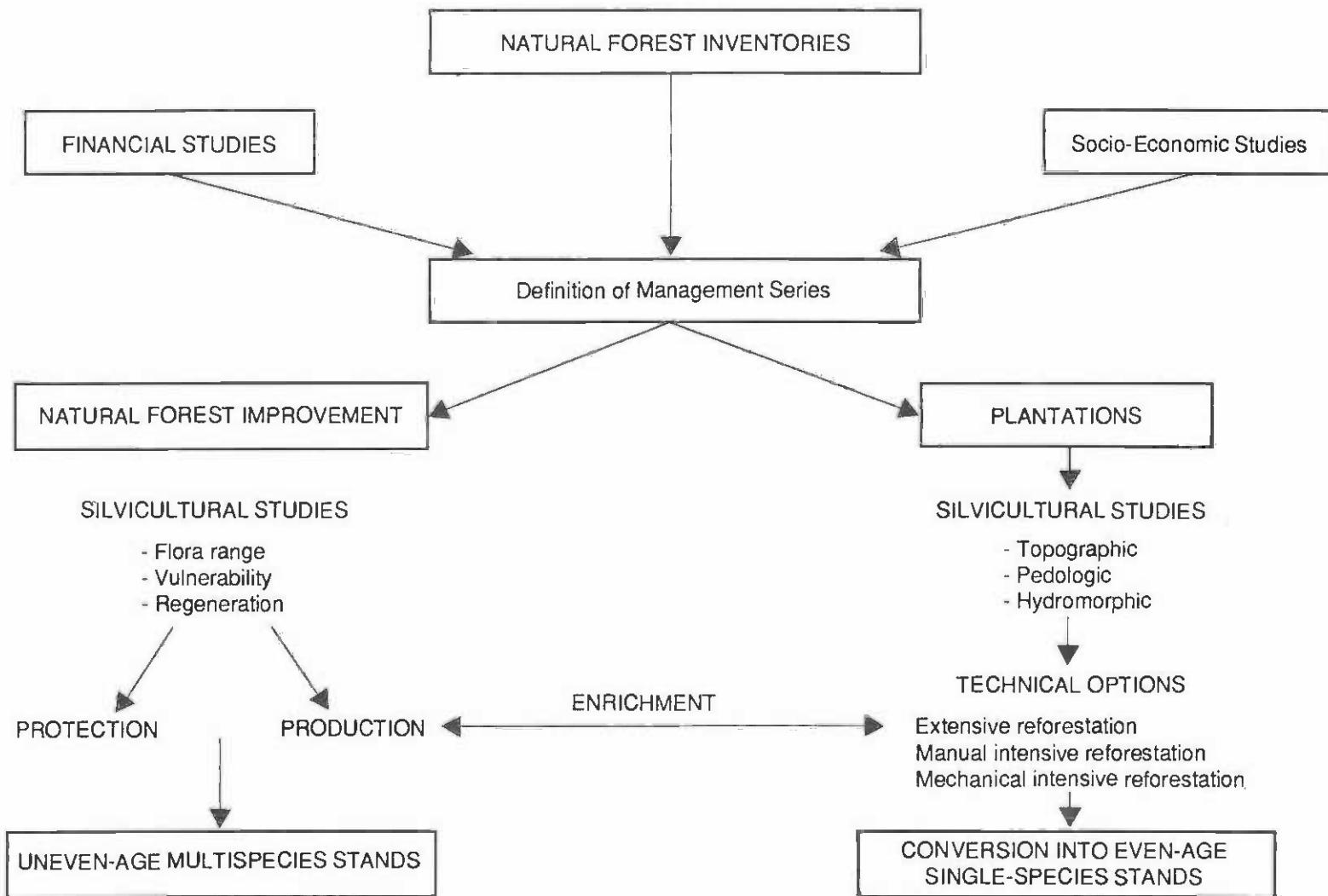
The extension of these new, usually monospecific, ecosystems has advanced with the modernization of mechanical equipment, and also with demographic pressure on natural forests. The greater need of farmland accelerates the disappearance of natural forests by considerably shortening fallow periods between plantings on the same site. The competition for land implies the limitation of wood-producing areas, together with a necessary intensification of artificial regeneration.

In West Africa, Côte d'Ivoire is one of the countries which has suffered the most from degradation of its forest resources by impoverishment and disappearance. In 1986, it was said that 300 to 400 000 hectares of productive forest were being destroyed every year. Reforestation actions in this country thus started quite early. The first plantations on areas that had been cleared mechanically began in 1965. Total bulldozer clearing with windrowing of the remains was adopted for Teak in 1968 and for other species (Framiré, Fraké, Samba, etc.) in 1977. This experience has made it possible to develop techniques for preparing both soil and seedlings. Large-scale actions have been undertaken in other countries as well, including Nigeria, Gabon and Congo.

The purpose of this chapter is to briefly review the principles underlying the most widely-used techniques of industrial reforestation. More specialized studies and works, for instance "The Forester's Handbook," provide details, specifications and techniques for all the phases involved in establishing a stand.

1 - FORESTRY TECHNIQUES

The principal factor to master when planting in a moist forest environment is light. However, this is no problem if it is decided to install a light-demanding species on a terrain whose original vegetation has been completely removed.



1.1 - Choice of sites

Theoretically, the site chosen for reforestation should be in perfect harmony with the requirements of the species that is to be transplanted. In actual fact, however, this choice is based on many kinds of criteria: technical, legal, socio-cultural and political.

All decisions are based on the physical conditions (relief, soils, rainfall, etc.), which will be reviewed in detail below when we examine the principal species reserved for timber plantations. However, financial, social and political problems are often associated with these background conditions, and sometimes even override them.

In the case of mechanized industrial reforestation, there is no doubt that an extensive area (several hundred hectares at least) is required for the investment to be profitable. To avoid the disappointments of the past, it is necessary, in this case, to plant more than one species. Each section of homogeneous ground must have an appropriate new "guest" assigned to it.

When preparing a reforestation plan for medium or long-rotation species, the first step is to list all constraints. The policy decisions which initiate such projects must nevertheless aim at a proper match between species and environment, knowing that the period of occupation will be long and that competition for land remains strong.

From a more technical point of view, it is important to recall that before undertaking any reforestation project, planners must try to assess the environment in which the future stand is to grow, and aim to preserve or even improve site characteristics.

1.1.1 - Appropriate sites for commercial reforestation

The decision to assign a given site for intensive reforestation operations takes several different parameters into consideration (DUPUY, 1987) :

- The wealth of the natural formations. If there are natural forests sufficiently rich in valuable species, the possibility of managing them should be considered first.
- The vulnerability of the area. In ecologically fragile areas, it is necessary to avoid heavy intervention and give preference to managing natural formations or to non-mechanized methods of reforestation.
- Sites to be reforested must be easily accessible so that timely intervention and timber removal are possible in any season.
- The soil must be fertile enough to allow stands to develop harmoniously.

| SITE CHARACTERISTICS | ALLOCATION |
|--|--|
| <ul style="list-style-type: none"> - Rich pre-existing forest stand - Vulnerable or not vulnerable - Poor fertility | Management of natural stands |
| <ul style="list-style-type: none"> - Poor pre-existing forest stand - Vulnerable but accessible - Medium to good fertility | Commercial reforestation Intensive manual methods |
| <ul style="list-style-type: none"> - Poor pre-existing forest stand - Not vulnerable and accessible - Medium to good fertility | Commercial reforestation Intensive mechanized methods |
| <ul style="list-style-type: none"> - Poor pre-existing forest stand - Vulnerable - Poor fertility - Poor accessibility | Management, possible with protective reforestation using extensive methods |

1.1.2 - Criteria for choosing intensive-reforestation sites

* The climatic, topographic and edaphic features of sites chosen for reforestation must be such as to encourage satisfactory tree growth. Little or no investment should be put into sites where some factors would limit stand growth.

* Accessibility of the planted area is a parameter that cannot be overlooked, for it is important only in reforestation per se, but also in the follow-up (tending, thinning, wildfire protection, etc.) and in taking out harvested products.

Sites which are difficult to reach (steep slopes, swampy areas, etc.) require preparatory works of considerable entity or difficulty which are often incompatible with production targets.

* Suitable edaphic conditions are necessary for successful plantations. Surface soils that are unevenly textured and chemically poor must be avoided. The same is true for hydromorphic soils.

Intensive mechanized reforestation must be reserved mainly for areas with gentle slope and favourable soil (depth, physical characteristics, water balance, etc.), where there no longer exist natural formations which would justify management plans.

* It is obviously better to concentrate investments on the most fertile sites. Since establishment costs are high, the goal must be maximum return on investment. A good compromise between material production and the product's economic value must be sought. A fertile site allows higher short-term yield and improved stock.

Once the reforestation site has been identified, the next step is to summarily assess the different areas within it. The fact that mechanized clearing is now widespread must not obscure the fact that this method must sometimes be adapted to actual site conditions.

The basic parameters to consider are:

- slope
- soil depth
- soil texture.

Slope

It is difficult to establish a precise threshold above which erosion becomes a considerable risk, since this depends on many parameters (rainfall, soil, slope length, etc.). When the incline is over 15 percent, mechanized clearing must be ruled out.

Generally speaking, where the ground is not flat and clearing is mechanized, windrows must be oriented perpendicularly to the slope to limit erosion.

Useful soil depth

If trees are to grow harmoniously, the soil must be deep enough to allow the development of a balanced root system.

Soils are seldom homogeneous along the length of a slope; in particular, it is easy to encounter:

- shallow soils characterized by the existence of hardened upper horizons (hard pan, laterite);
- very gravelly, percolating soils on mounds and plateaux;
- hydromorphic soils with an asphyxiating layer present for several months of the year at less than 50 cm from the surface in depressions and areas subject to flooding.

These rather unfertile soils are easy to identify, and are often connected with a particular topographic position. If intervention is indispensable, foresters must fit their site preparation and reforestation techniques to these conditions by:

- subsoiling soils with hardened horizons
- draining of wet areas, etc.

It must be remembered, however, that these methods are costly and must be used sparingly.

The existence of a gravelly horizon may affect soil fertility.

The presence of coarse particles influences the physical characteristics of the soil, particularly by increasing its macroporosity.

The following parameters must be considered:

- the percentage of coarse particles
- the thickness of the gravelly horizon
- the lay of the gravelly horizon.

If the proportion of coarse particles is greater than 30-40 percent, it is important to take the depth of the gravelly horizon into account. If it exceeds 30-40 cm, with the proportion of coarse elements over 50 percent, soil fertility is very low.

The negative influence of a gravelly horizon is mitigated if it lies beneath other horizons that have no coarse particles, are balanced in texture and are at least 40-50 cm deep.

Soil texture

Sandy and clayey soils are particularly vulnerable because of their uneven texture.

- Sandy soils are very permeable; often they are heavily leached and lack organic and mineral matter. Their capacity for water retention is low. The surface horizon, which contains very little humus, must not be scraped for any reason whatsoever when reforesting.
- Clayey soils are often asphyxiating and easily compacted. It is inadvisable to extract stumps from these soils mechanically, or allow the frequent transit of equipment.

These parameters should not be considered separately, since they can offset each other. The presence of coarse particles in clayey horizons improves their permeability. A clayey horizon lying between sandy horizons slows down water percolation. The presence of a water-bearing stratum at medium depth may be favourable on sandy soil but unfavourable on clay.

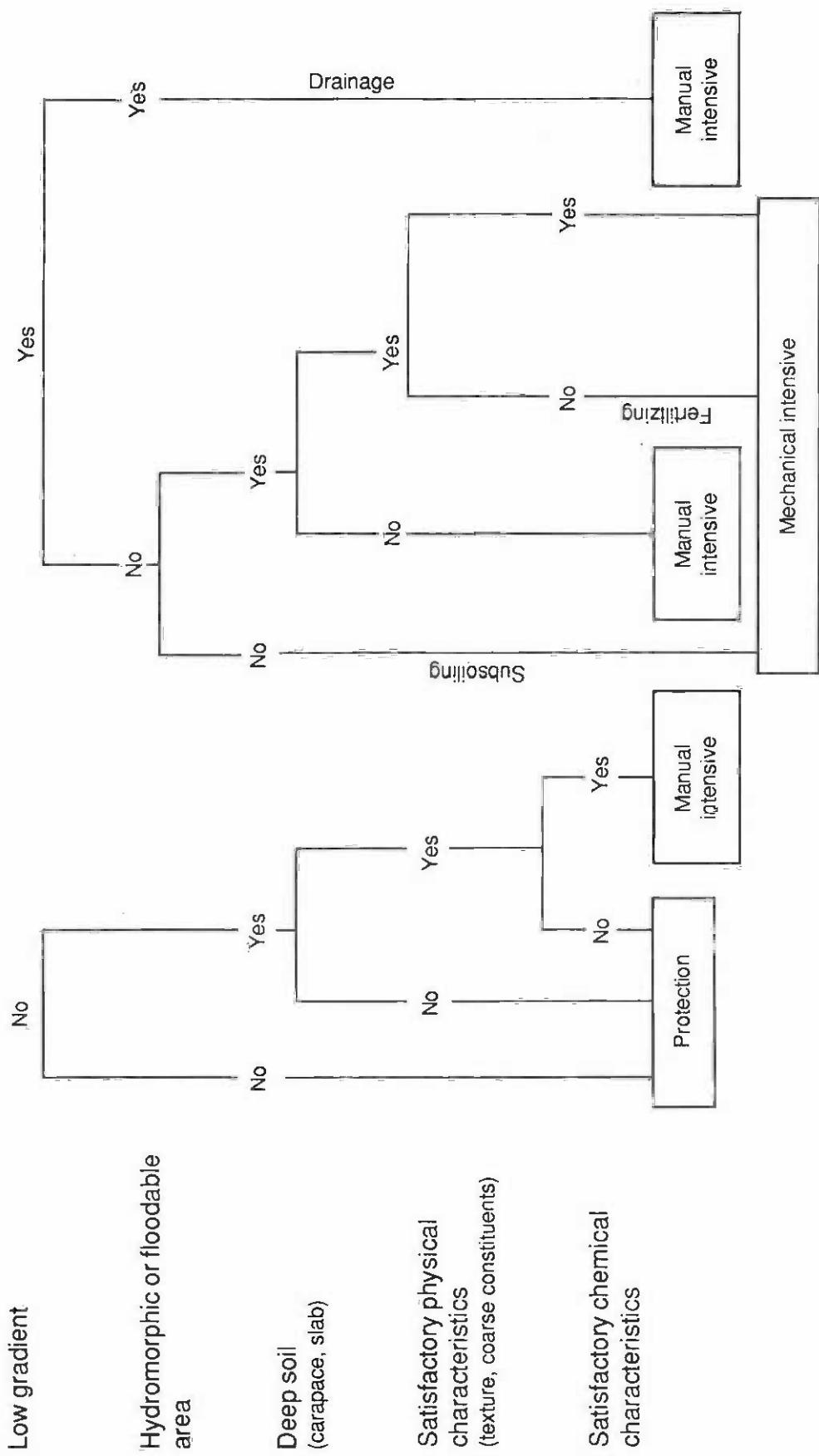
Soil fertility

This depends on all of the preceding factors plus chemical composition, which is itself directly related to the bedrock. Certain limiting factors may appear at this level, such as pH, salinity, presence of limestone, etc., and accordingly condition the choice of species for planting.

Before undertaking any reforestation project, it is necessary to try to assess the growth environment of the future reforestation and aim to preserve and even improve site characteristics.

Satisfactory tree growth depends on the harmonious development of root and aerial systems. The root system has to provide the tree with sufficient water and minerals, as well as stability. To do so, it must be able to reach at least one metre down.

OPTION CRITERIA IN A REFORESTATION SERIES



The existence of factors which could limit the growth of the root system must be carefully taken into account; their neglect may result in failure. In some cases, commercial reforestation may be unfeasible; protection may be much more advisable.

An adequate light regime fosters proper development of the aerial system.

1.2 - Nurseries

The production of plant material is one of the fundamental steps influencing future yield. Choices are made at the levels of genetic potential and of seedling husbandry technique.

The material must be perfectly adapted to production targets: volume, size, shape, etc. Generally speaking, experiments have made it possible to select the best species and provenances. Nevertheless, there is still need for progress in the field of genetic improvement; as we shall see, this appears clearly from the current orientation of research.

The choice of propagation and husbandry methods meets certain well-known technical criteria. We shall not go into details in this document; readers are referred to specific reports and educational texts. However, some of the broad principles will be mentioned.

The propagation of plant material is based on two methods:

- the traditional sexual route: seeds
- the vegetative route: cuttings.

1.2.1 - Plants produced from seeds

The first difficulties encountered by a sapling transplanted for reforestation are:

- getting through transplant shock by adjusting its root system to the new substrate as quickly as possible,
- fighting competition from adventitious vegetation and regrowth, particularly severe in closed forest areas.

To deal with competition, the ideal is to transplant fair-sized seedlings with their root systems intact, so that vegetation can recommence rapidly.

Accordingly, two kinds of seedlings may be prepared:

- bare-rooted
- ball-rooted.

* Bare-rooted seedlings

This method of preparation has been and still is the most widely used in the areas examined in this document.

Bare-rooted seedlings may be prepared in different ways before planting:

- Full stem. Transplanted when 2 metres tall. All leaves except for the terminal cluster are eliminated. Roots are shortened to just 10-20 cm.
- Tall stump or half stem. Unlike the full stem, all un lignified parts are eliminated.
- Short stump. The stem is cut down to 7-10 cm. The taproot is left about 10 cm long.

* Seedlings with substrate left around their roots

Various containers and supports have been tested over the course of reforestation history.

Polyethylene bags are the type most widely used today. Inexpensive, easy to store and handle, they come in different sizes and can be used for all species. However, since roots cannot pass through them, the seedling's growing period and, accordingly, its size must be limited to avoid deformation.

* Plant protection precautions

Environmental conditions in closed forest areas often force nurserymen to deal with plant protection problems which must be solved quickly to avoid jeopardizing the year's production.

Preventive treatment may be applied to limit risks.

For species sown in boxes and sensitive to damping-off, it highly recommended to disinfect the soil beforehand, by either:

- sprinkling it with Formol (0.1 l/m²). Treated soils must be kept covered for two weeks, then left open to the air for another two weeks: the minimum time span between treatment and seeding is thus four weeks;
- methyl bromide treatment (gas injection under cover). In this case, the seeds are sown two weeks later. In view of the toxicity of this substance, precautions must be taken in applying it.

Curative treatments may also be necessary:

- To control fungi, essentially in seedboxes, spraying with Benlate or Viricuivre (1 g/10 litres of water) is very effective.
- To control insects that attack plant collars and/or roots (termites, crickets, grasshoppers, etc.), the recommended treatments are

spraying with Dieldrin (in 2% solution) and the use of poisoned bait (Dieldrin 2% mixed with meal).²

- To control defoliating insects (caterpillars, coleoptera), spray with 0.3% Decis.³ For sucking insects (plant lice, scale, etc.), spray with malathion or vamidothion; for drilling insects, apply methyldathion.
- To control molluscs (snails, slugs, etc.), place methaldehyde-based substances on their paths.
- To control rodents (rats, etc.), place Coumarin-based bait on their paths. But rodents very often avoid ground from which the rass cover has been completely removed.

* Lastly, there is the rare possibility of sowing the seeds directly in the planting area. This technique requires soil preparation such as to permit fast germination and minimal regrowth competition. Most important, it involves intense and repeated early forestry work (cleanings, tendings, thinnings) to achieve a stand density compatible with yield objectives. The cost of these operations often cancels out any savings achieved at the moment of planting.

1.2.2 - Plants produced from cuttings

Irregularity in fruit-setting and/or the existence of improved planting stock may direct reforesters toward vegetative multiplication, in particular large-scale planting of cuttings.

To date, two methods of planting cuttings have been mastered perfectly.

* Growing cuttings in frames

This technique has been particularly successful with Samba trees (DELAUNAY, 1978).

The frames (200 x 90 x 60 cm) are covered with a sheet of plastic, which ensures a greenhouse effect.

The growth medium is a 20-25-cm deep layer of sand (diameter 1 to 2 mm) or sawdust. Underneath is a 25-cm layer of pebbles (diameter 3 to 4 cm) at the bottom of the frame to ensure drainage. The planting stock, spaced 80 x 60 cm, is irrigated with 5-7 mm of water a day. One plant provides an average of 5 cuttings/harvest, with 4 harvests a year.

² Since Dieldrin is no longer manufactured, and is banned in many countries, it has been replaced for termite control by Carbosulfanbased Suxon. HCH, lindane and so forth are used against grasshoppers.

³ The names of most of the products mentioned here are registered trademarks. Other substances with the same basic active principle may be used.

Cuttings are herbaceous, 8-12 cm long, with collar diameter 6 to 12 mm. Two or three leaves, half cut off, are preserved. To disinfect the stock before planting in the frames, each cutting is dipped in a Benlate solution (0.05%), and the base is then impregnated with a hormone solution (Exuberone, etc.) which activates rhizogenesis.

The water input is 1 litre/m²/day for sawdust and 4 litres/m²/day for sand.

The frames are protected by a horizontal and vertical shading system. The cuttings are transplanted under shade when the root system is about 3 cm long. They are gradually tapered off and hardened by reducing the shading and the frequency of watering (once every two days at 7 or 8 weeks after transplanting).

* Mist-grown cuttings

The principles of this method of growing cuttings are identical to those described above, except for the process of water distribution.

The growth medium is coarse sand which is misted continuously during the daytime. Misting may be interrupted during the night, depending on air humidity. The cuttings are kept shaded for a few days, then the shades are removed. They are tapered off and hardened by adding fertilizer to the mist (300 grams of fertilizer/10 litres of water/1 000 cuttings), and temporarily restoring the shades.

The hardening-off stage ends 8 to 10 weeks after the cuttings were harvested, and they may then be transplanted to sacks or beds.

1.3 - Preparation of the site and planting

1.3.1 - Preparation of the site

The goal is to completely free the ground of its original vegetation in order to facilitate mechanized operations and give future transplants maximum light with minimum competition.

Reforestation is generally carried out in degraded moist evergreen or semi-deciduous forest formations.

In humid savannah areas, there is less standing timber than in closed forest areas, and the work is easier.

Total deforestation is therefore carried out by extracting the stumps with crawler tractors (CATERPILLAR D8-300 CV type) equipped with tree pushers or anchor chains. Merchantable logs have already been hauled out. The remaining stems, stumps and detritus are windrowed. These operations are carried out at the end of the rainy season that precedes the planting year; this allows the detritus to weather through a dry season and the windrows will accordingly burn more easily. The windrows are set back to leave as much ground as possible for planting. Windrowing is done with crawler tractors (type D8 to D6, depending on the vegetation), usually equipped with rootrakes. Stumps that cannot be extracted may be levelled with a tractor-mounted cutting blade (Rome KG type). However, this is a laborious and costly operation.



Site prepared before planting

Grading and ploughing are recommended when possible.

One of the drawbacks of this method is that the soil is compacted by the frequent transit of heavy-duty equipment. But even more serious is the risk of removing the fertile topsoil. This work must therefore be conducted so as to avoid scraping the planting area.

Access tracks and plot boundaries are created at the same time, in the following approximate lengths:

For 100 hectares: 4 km of plot boundaries
2 km of main tracks
2 km of secondary tracks

Firebreaks are created in the ratio of 2 km every 100 hectares of plantation; they are approximately 100 m wide and are accessible by unpaved roads.

This is the only method employed today for industrial plantations, whether of timber, as in the Côte d'Ivoire (Terminalia, Samba, Teak, Gmelina), fuelwood, as in Togo (Eucalyptus), or pulpwood, as in Congo (Eucalyptus).

However, we must distinguish between plantations in closed forest areas (Côte d'Ivoire, Gabon, Cameroon, etc.) and in the humid savannah (Congo, Togo, etc.).

The means employed to prepare the site and the relevant costs are much less significant in the second case.

1.3.2 - Planting

After the site has been prepared for planting, sections are laid out for the future trees. Conventionally, this is done by lining out successive squares of 100 trees with compass and stakes; if necessary, stakes may also be set to mark exactly where the holes are to be dug.

The holes are dug with a hoe just a few days before planting, since the rain quickly fills them up again.

As a pre-emergence treatment, the ground may be sprayed with a herbicide before the rainy season begins.

Depending on the nature of the transplants, they must be handled more or less delicately when transported from the nursery to the planting site. Special precautions must be taken with bagged plants, whose well-protected root system must not suffer any shock before transplantation. It is imperative to remove the plastic bag before planting, and to cut back the lower part of the root system so that it will develop properly. No such problem arises with biodegradable supports.

Localized fertilizer inputs may also be advisable during transplant to optimize the saplings' initial growth. However, in the absence of any generally-applicable research findings, it would be premature to offer recommendations for industrial reforestation in closed forest areas. Planting density is an important silvicultural parameter which varies according to the species. It is the result of a compromise between:

- the silvicultural requirements of each species planted;
- economic constraints.

Planting density must be such as to create a stand effect where:

- the canopy closes up rapidly, in order to limit the development of adventitious vegetation;
- the stand's training impact for individual trees (shape, pruning) is ensured.

There are minimum densities which satisfy these imperatives; they depend on the architecture of each species and the way it grows.

These problems will be dealt with in greater detail when we examine cultivation rules.

Generally speaking, the method of large-scale mechanized planting includes the following steps:

- Logging
- 500 x 500 m plots are line-cut
- Felling by bulldozer and timber recovery
- Windrowing the remains in parallel rows 30-80 m apart
- Burning windrows
- Narrowing windrows
- Grading the strips between the windrows, and ploughing if possible
- Staking out
- Planting

It is particularly important that these operations be properly scheduled according to the succession of dry and rainy seasons. Poor timing may cause delays that often last as long as a whole year and jeopardize the results of the operations which have already been completed.

As a practical example, the reforestation schedule for Côte d'Ivoire is shown on the next page.

2 - THE TECHNICAL-FINANCIAL EVALUATION

Natural stand transformation techniques are directed at degraded forest stands, whose canopies are often full of gaps.

These stands are felled and replanted. Clearing intensity may vary according to means and objectives.

The sole imperative is to completely suppress the overstorey.

2.1 - The manual regrowth method

This is based on the following two ideas:

- Total suppression of the overstorey by devitalization or felling.
- Cutting back the undergrowth which is to co-exist with the trees to be planted.

The succession of operations is as follows:

- Devitalization or felling of trees whose diameter is over 15 cm.
- Manual coppicing of the undergrowth.
- Planting.
- Tending (for 5-6 years).
- Thinning.

Planting intervals correspond to a density of 300-400 stems per ha.

2.2 - Association of reforestation and agriculture (Taungya)

In certain cases, particularly in populated agricultural areas, the Taungya method may be applied.

This technique consists of introducing forest transplants on plots where annual crops are also grown, at first over the whole plot, then only between the lines of trees. Farmers must abandon the land definitively after two years of consecutive cultivation.

Originally, clearing and preparing the site were the farmer's responsibility.

ANNUAL SCHEDULE OF WORKS FOR A COMMERCIAL REFORESTATION SITE IN COTE D'IVOIRE

The figure is a grid diagram for a 12-month planning period. The columns are labeled with the months: J, F, M, A, M, J, J, A, S, O, N, D. The grid consists of 12 columns and 12 rows. Horizontal lines are drawn across the grid at various intervals, and vertical lines are drawn down the grid at various intervals. The intersections of these lines form a grid of small rectangles. Some of these rectangles are filled with solid lines, while others are left empty. There are approximately 100 filled rectangles in total, distributed across the grid.

RATIOS PER HECTARE OF PLANTATION
(Preparation for the regrowth method)

| | Man-days | 300 HP crawler (hours) | 80 HP tractor (hours) | Chainsaw (days) |
|-------------------------------|--------------|------------------------------|-----------------------------|--------------------|
| PREPARATION/PLANTING | | | | |
| Infrastructure | 2.5 | 0.6 | 0.4 | |
| Line cutting | 2.0 | | | |
| Climber cutting | 5.0 | | | |
| Undergrowth preparation | 25.0 | | | 4.0 |
| Poisoning | 6.0 | | | |
| Nursery | 4.0 | | 0.1 | |
| Planting | 20.0 | | | |
| Firebreak | 0.2 | 0.1 | | 0.5 |
| TOTAL | 64.7 | 0.7 | 0.5 | 4.5 |
| TENDING Year 0 to 8 | 52 | | | |
| TOTAL | 116.7 | 0.7 | 0.5 | 4.5 |

Today, as clearing has become more and more mechanized, it is often carried out by reforesters themselves, and the "farmer's forestry role" is reduced to tending the tree plantations in exchange for a temporary grant of land use.

The farmer/forester association is successfully employed in certain industrial reforestation areas where, after the trees have been planted, the land is temporarily granted to farmers for one (or two) cycles of non-permanent food (or industrial) crops.

The goal is to lighten the weight of the item "tending young plantations" by assigning it to the farmers. In exchange, they have the use of a growing area that has already been completely cleared.

Interplanted crops are thus raised during the planting year, and sometimes the following year as well.

In pre-forest and semi-deciduous moist forest areas, the following crops are suitable for association:

- cotton
- groundnuts
- rain-fed rice
- maize
- bananas
- sorghum, etc.

The area granted to each farmer cannot exceed a few hectares, ten at most.

2.3 - The mechanized method

This method is based on the following operations:

- Mechanized clearing with bulldozers.
- Windrowing the remains with bulldozers.
- Grading (tractor).
- Planting (manual).
- Tending (manual + mechanized).
- Thinning (manual).

Planting intervals vary from 2.5 x 2.5 m to 3.75 x 3.75 m, depending on the species.

RATIOS PER HECTARE
(Preparation with the mechanized method)

| | Man-days | Crawler | | Tractor | | | Chainsaw (days) |
|-----------------------------|-------------|------------|------------|------------|------------|------------|--------------------|
| | | 300 HP | 140 HP | 120 HP | 80 HP | 45 HP | |
| PREPARATION/PLANTING | | | | | | | |
| Infrastructure | 2.5 | 0.6 | | | 0.4 | | |
| Line cutting | 2.0 | | | | | | |
| Felling | 0.4 | 3.5 | | | | | |
| Burning | 0.5 | | | | | | |
| Windrowing | 0.4 | 1.8 | 2.2 | | | | 1.0 |
| Soil preparation | 0.2 | | 2.0 | | 0.8 | | |
| Nursery | 2.5 | | | | | | |
| Planting | 4.0 | | | | 0.1 | | |
| Firebreak | 0.2 | 0.1 | | | | | 1.5 |
| TOTAL | 12.7 | 6.0 | 4.2 | | 1.3 | | 2.5 |
| TENDING | | | | | | | |
| Year 0 to 8 | 35 | | | 1.0 | | 5.0 | |
| TOTAL | 47.7 | 6.0 | 4.2 | 1.0 | 1.3 | 5.0 | |

2.4 - Technical evaluation

Manual methods consist of the total elimination of small-diameter woody growth, which is cut and burned. Only large trees of no commercial value remain, and these are poisoned (regrowth method) or simply girdled (Taungya). After planting, therefore, a certain number of trees are still standing; most are dead, but some survive devitalization treatments.

Branches and trunks gradually fall, causing damage to the population of young transplants. Planted at densities of 300 to 400 stems/ha, about 2/3 of the transplants survive after 5 years.

If regrowth thrives, a woody under storey, shrubby at first, then arborescent, forms again very quickly. These manual methods require considerable labour, particularly after planting time; all tending operations are manual.

The need to intensify reforestation operations has led to the increasing mechanization of many jobs.

When clearing involves felling all pre-existing trees and windrowing the remains, tractors can circulate freely during planting and thinning, so these operations can be at least partly mechanized.

As to labour requirements, comparing the two reforestation methods:

- for site preparation, the ratio is 1 to 9 in favour of mechanized methods;
- for planting, the ratio is 1 to 3, again in favour of mechanized planting.

Unfortunately, this kind of preparation implies the destruction of the humus horizon, particularly during windrowing, as well as the explosion of a very vigorous light-demanding regrowth.

In practice, manual and mechanized tending requirements are very burdensome during the first six years: it is necessary to allow for 6 tractor-hours/ha and 35 man-days/ha for mechanized methods. At the same time, the anticipated growth gain is around 30 percent in favour of mechanized methods.

In fact, the principal advantage of mechanized methods is their reduction of labour requirements for site preparation and planting: operations for which only a short amount of time is available. By the same token, mechanized methods make it possible to speed the pace of reforestation.

On the other hand, as regards costs per planted hectare, the ratio is 1 to 2 in favour of manual methods. The possibility of intensifying reforestation operations through mechanization must not obscure the problems created thereby:

- The small size of the transplanted saplings (bagged plants only a few months old) means that tending operations must be carried out with the greatest care.
- Scraping of the humus layer is an unfavourable factor, especially in areas with fragile soils.

- The establishment of very large single species plantations weakens the ecosystem, particularly as regards plant protection; the recent attacks of defoliating caterpillars on Fraké plantations in Côte d'Ivoire are an example.

With several years of experience to reflect upon, it appears that this reforestation method must be used with discretion if it is to remain valid.

It is important to take the following considerations into account:

- On fragile or steeply sloping soils, it is pointless, or even harmful, to destroy a pre-existing forest: re-establishing a forest stand by full reforestation on mechanized tracts is too chancy.

It is always advisable to manage such stands whenever possible. If not, reforestation must be planned with the least possible mechanization.

- The creation of very large single species tracts must be avoided. Foresters may use mixed stands of two species and at the same time create a mosaic of plots where the mixed unit becomes the monospecific plot.
- The importance of tending is fundamental, especially during the first four years.
- It is essential to keep to the thinning schedule. A delay of several years may cause a 20 to 40 percent loss in yield and proportionally lengthen the rotation period. Once the stand is definitely established, it must be remembered that the ratio between planting density and definitive density is about 1 to 10. If reforesters think they can then rest at ease, they had better recall all the operations still to come: thinning, designation of final crop trees, pruning, and so forth.

It must be noted that the manual and mechanized methods also differ as to planting density. In the mechanized method, the absence of an arborescent lower storey with a training role means that planting densities must be higher, to ensure that the canopy closes up rapidly.

By the same token, the first thinning must be effected earlier. Competition appears earlier on a mechanized plot with 700 stems/ha than in a manually planted plot where 250-300 stems/ha survive a few years after planting. In the same way, on a mechanized tract the stand will have to be thinned more often to reduce it to the final density.

Each of these methods has its advantages and disadvantages:

| Method | Advantages | Disadvantages |
|------------|---|--|
| Regrowth | <p>Minimum disruption of the environment.</p> <p>Fast re-establishment of an arborescent lower storey with a training role.</p> <p>Low planting cost.</p> <p>Low material investments.</p> <p>Later initial thinning, due to low planting density.</p> | <p>Poisoned trees can fall on to the young transplants.</p> <p>The initial growth of the transplants is average.</p> <p>Only limited areas can be reforested each year, due to the amount of labour required.</p> <p>Mechanization of tending operations is impossible.</p> |
| Taungya | <p>Forester/farmer association.</p> <p>Low initial planting and tending costs.</p> <p>Minimum material investments.</p> <p>Good initial transplant growth thanks to farmers' tilling of the soil.</p> | <p>Financial problems.</p> <p>Uncertain protection of saplings.</p> <p>The method is limited to small, often widely-scattered areas.</p> |
| Mechanized | <p>Considerable mobilization of wood potential (timber/biomass).</p> <p>Disappearance of all pre-existing vegetation.</p> <p>Mechanization of many jobs, hence much smaller labour requirements.</p> <p>Good initial growth of the saplings.</p> <p>Considerable areas can be reforested each year.</p> | <p>Considerable artificialization of the environment. Arborescent lower storey absent, replaced by a low grass and shrub layer.</p> <p>Adventitious plants hard to control; repeated tendings necessary in young plantations.</p> <p>Considerable material investments.</p> <p>High planting cost.</p> <p>Early thinning required because planting density is higher, to ensure the re-establishment of a continuous arborescent cover.</p> <p>Repeated thinnings.</p> |

2.5 - Financial assessment

One of the goals of reforestation is wood harvesting. This obvious fact should not obscure the numerous effects of the establishment of plantations in the environmental sphere (maintenance of the afforestation rate, soil protection, water regulation, etc.), the social sphere (job creation, forest/agriculture relationship, etc.), and the economic sphere (the wood, self-sufficiency, etc.). It is always difficult to assess and quantify these macro-economic regional parameters.

The standpoint adopted here is that of the owner of the forest, whether a governmental entity, a private company or an individual.

Forests represent a financial investment, so the proper thing is to try to estimate the profitability of an investment in reforestation.

Experience shows that the main factors affecting the costs and benefits of a reforestation project are as follows:

- Land preparation is a very large cost factor in moist forest areas where standing growths to be cleared represent a considerable volume of wood from unexploitable secondary species. This volume normally amounts to 300 m³/ha. On the other hand, the recovery of areas which have already been deforested may generate considerable savings.
- Planting success depends primarily on carrying out a rigorous tending programme. Little margin can be expected on this item. The problem lies in applying the working calendar, on which the future of the plantations depends.
- The application of a correctly scheduled thinning plan conditions optimum plantation growth. Any delay entails a growth loss and, by the same token, a longer rotation cycle.
- The market price for wood is certainly the most difficult parameter to estimate; in particular, it will depend on the quality of the wood and the size of the annual market (volume of potential supply).

The internal rate of return is estimated by considering a number of assumptions.

- concerning preparation cost per hectare, which varies according to the natural wooded state, planting method, etc.;
- on the length of the felling cycle, which depends on fertility, compliance with a correct thinning calendar, etc.;
- on the market price per cubic metre of harvested wood.

The following example involves Fraké plantations in Côte d'Ivoire.

For an average plantation cost of 450 000 F CFA/ha, corresponding to average conditions of industrial reforestation, the internal rate of return (IRR) varies with the market price per cubic metre as follows:

| Price per cubic metre | Felling cycle | | |
|-----------------------|---------------|----------|----------|
| | 25 years | 30 years | 33 years |
| 10 000 F CFA | 6.02 % | 5.03 % | 4.54 % |
| 15 000 F CFA | 7.89 % | 6.55 % | 5.92 % |
| 20 000 F CFA | 9.23 % | 7.65 % | 6.92 % |
| 25 000 F CFA | 10.28 % | 8.50 % | 7.69 % |

2.6 - Overall assessment

A brief examination of the technical characteristics of manual and mechanized reforestation methods shows their respective limitations in closed forest areas:

| | Manual method | Mechanized method |
|------------------------------------|--------------------------------|----------------------|
| Type of transplant | Tall stem, 12-18 months old | Bagged, 4 months old |
| Density | 300-400 stems/ha | 700 stems/ha |
| Planting | | |
| Man-days | 65/ha | 13/ha |
| Crawler tractor | 0.7 hours/ha | 10.2 hours/ha |
| Tractor | 0.5 hours/ha | 1.3 hours/ha |
| Power chainsaw | 4.5 hours/ha | 1.5 hours/ha |
| Tending | | |
| Man-days | 52/ha | 48/ha |
| Tractor | | 6 hours/ha |
| Thinnings | 2 | 3 |
| Reforestable area (/concession) | 200-400 ha/yr | 1 000-2 000 ha/yr |

The main advantage of the manual method is its low cost, but it is highly labour-intensive and does not allow large areas to be worked each year.

The mechanized method allows considerable areas to be reforested each year, but requires substantial investments and early initial thinning.

The considerable labour requirements rule out industrial reforestation projects by manual methods. Planting cost is on the order of 250 000 F CFA/ha plus supervisory costs with manual methods, and about 450 000 F CFA/ha plus supervisory costs with mechanized methods.

At the same time, the yield from mechanized plantations is around 30 percent higher, thanks to the intensification of cultivation techniques.

As to the market price of standing timber, a low estimate of 10 000 F CFA/m³ seems reasonable for average grade wood. Higher prices may be obtained for better grade wood. The average price of 15 000 F CFA/m³ (standing) is taken as the working standard.

Under these average conditions, the internal rate of return for well-managed mechanized plantations is about 7 or 8 percent.

The I.R.R. ranges from 5 to 9.5 percent, according to plantation success and growth.

Where manual methods are used, the I.R.R. will be slightly lower: from 4.5 to 8.5 percent, with an average of 6 to 7 percent.

3 - PRINCIPLES FOR INTENSIVE REFORESTATION

The establishment of commercial timber plantations represents a considerable financial investment whose purpose is to produce a given category of wood products with an optimum return on the investment.

The goal is to produce a considerable amount of high-grade timber in the shortest possible term.

3.1 - Constraints for intensive reforestation

Numerous constraints must be taken into account.

1 - Site productivity is a determining factor in the rate of return from forest investments.

The study of site potential is a necessary preliminary step to choosing an area for reforestation. The choice must be justified by the possibilities the site offers for satisfactory growth. If the site is mediocre, the investment must be smaller. If the site is good, the choice will be oriented toward intensive silvicultural options.

2 - The profitability of the investment conditions the choice of species to use in reforestation.

The logging age for a given diameter must make it possible to achieve a satisfactory economic return. Slow-growing species should be rejected in favour of those with the shortest possible rotation periods.

3 - The goal is to produce a considerable quantity of timber.

A compromise must be sought between obtaining the significant individual sizes pertinent to a timber target and maintaining sustained stand production.

4 - The timber produced must be of good quality.

The choice of species, provenances and silvicultural techniques should be aimed at eventually obtaining timber whose quality will justify the investment.

5 - Wood resources must be easy to mobilize.

Stand accessibility is an important parameter. It is essential to be able to reach the stands, carry out all the necessary forestry operations and remove the product easily.

3.2 - Basic principles

The principles governing intensive reforestation are as follows:

1 - The choice of the reforestation site must justify the investment.

Sites chosen for reforestation must have climatic, topographic and edaphic characteristics that will foster satisfactory tree growth. Sites where there exists a factor that would limit stand growth deserve little or no investment.

The parameter of accessibility is significant not only as regards reforestation per se, but also for forestry care (tending, thinning, forest-fire protection, etc.) and mobilization of the output.

Sites that cannot be reached easily (steep slopes, low-lying areas, etc.) require considerable or difficult site preparation work that is often not very compatible with a production target.

Proper edaphic conditions are essential to plantation success. Surface soils that are uneven in texture and chemically poor should be avoided. The same is true for hydromorphic soils.

Intensive mechanized reforestation should be used primarily on areas with gentle slopes, favourable soils (depth, physical characteristics, water balance, etc.), and no natural formations that would call for management instead.

On sites at risk (for climate, soil, topography, etc.), forestry intervention should be slight and preference given to intensive and extensive manual methods of reforestation.

2 - Silvicultural rules are linked to profitability.

A compromise must be sought between the economic value of the reforested area and its yield in volume per hectare. Producing maximum volumes implies high densities of small trees with younger

logging age, greater establishment costs and lower financial returns.

The aim is to achieve maximum individual growth while keeping standing stem densities low enough to limit competition.

Planting intervals should be adapted to obtain well-shaped trees whose canopy will limit the development of adventitious vegetation.

Thinnings should be early and vigorous, in order to encourage initial growth and limit the number of these operations.

A fertile site will support a higher density of standing stems of a particular diameter than a less fertile site.

3 - The expected forestry investment must be geared to the site.

It is preferable to concentrate investments on the most fertile sites, particularly as regards:

- the introduction of high-performing selected planting stock;
- the choice of species according to their merchantable value;
- pruning, fertilization, and so forth.

These last two items are still in the realm of the future, but should allow appreciable quantitative and qualitative gains.

4 - The future of a tree is decided during its initial years.

A tree's quality and growth are determined by the application of early and repeated care:

- good-quality (origin, size, health, etc.) planting stock must be used;
- tending operations must be carried out before the stand is attacked by adventitious vegetation;
- the stand must be thinned before tree growth slows down significantly, in order to take maximum advantage of the initial growth phase, when increases are most significant.

5 - Silvicultural factors are interdependent.

It is useless to try to improve the final yield by acting on just one factor and at the same time overlooking eventual constraints.

The main factors are:

- site
- planting stock
- tending
- thinning

Each of these factors must be taken into equal consideration in order to achieve a satisfactory end result.

6 - The logging cycle depends on the site.

The more fertile a site, the more likely it is to produce a large quantity of wood in the short term.

To avoid lengthening rotation cycles, logging diameter should be adapted to site fertility.

Accordingly, the logging diameters chosen for a poor site should be smaller than for a good site.

RECOMMENDATIONS

Commercial reforestation is an investment. Priority is given to sites that are accessible, not vulnerable, fertile, and containing natural formations that cannot be managed.

The choice of reforestation method depends on the area's vulnerability.

The intensity of forestry operations and logging age must be adapted to the degree of fertility. Priority is given to investments (planting stock, fertilization, thinnings, etc.) on fertile sites, where expected profit is higher.

Silvicultural factors are interdependent, and none of them should be neglected (site study, appropriate planting stock, tendings, thinnings, etc.).

The tree's future depends on its initial years. Tending quality strongly conditions the stand's potential value. Delays in thinning can never be made up.

From the economic standpoint, it is better to aim for a standard yield rather than a maximum yield per hectare.

Logging age depends on the site's fertility. An excessively long rotation period on a mediocre site must be avoided, bearing in mind that a commercial timber target requires a logging diameter of at least 40 cm.

Logging age must thus be a reasonable compromise between technical and financial constraints.

7 - Logging diameter influences the mobilizable volume of timber.

The objective of producing commercial timber allows the logs to be exploited up to an end cutting point of about 20 cm.

Current exploitation rates of around 80 percent rule out logging diameters of less than 40 cm.

3.3 - Limits on the introduction of plantation species

In establishing commercial timber plantations, areas reforested for production forests must have the right soil characteristics.

In particular, plantations should not be established on the following types of soils:

- shallow soils underlain by a laterite or gravel horizon less than 60-80 cm deep; the available soil depth must allow the root system to develop harmoniously;
- sandy-textured and fast-draining soils (slopes and knobs) which cannot ensure a sufficient water supply to transplants, particularly during very dry years;
- very hydromorphic soils that tend to asphyxiate plant roots;
- highly water-retentive clayey soils; these must be ruled out altogether, particularly when the reforestation species is introduced at the limits of its natural range.

Foresters may then resort to creating protection plantations, or plantations of construction timber, depending on the particular case.

For any given area, the principal limiting edaphic factor to be considered seems to be the water balance. One of the main causes of failure in man made forests is that the transplants do not receive enough water, especially at a young age, when the stand is being established.

On the other hand, one must be sure to introduce the various species only in areas that are ecologically appropriate. The following table shows the areas where the various species grow naturally, and the bioclimatic conditions required for commercial afforestation.

TABLE OF CLIMATE-VEGETATION RELATIONS
(Côte d'Ivoire)

| Regions | Lower Côte d'Ivoire | Middle Côte d'Ivoire | Pre-forest Côte d'Ivoire | SubSudanese Côte d'Ivoire |
|--|--|---|--|--|
| Natural plant formations | Moist evergreen forest | Moist semi- deciduous forest | Guinea savannah Closed forest | Wooded shrub savannah Woodland Dry forest |
| Climate | 2 rainy seasons 2 200 <P< 1 600 mm dry months: 2 - 4 | 2 rainy seasons 1 200 <P< 1 600 mm dry months: 4 - 6 | 1 to 2 rainy seasons 1 000 <P< 1 600 mm dry months: 6 - 8 | 1 rainy season 1 000 <P< 1 600 mm dry months: 8 |
| Commercial reforestation species | Niangon Okoumé Badi Framiré Gmelina Pines Mahogany | Fraké Framiré Samba Cedrela Teak Gmelina Pines | Teak Gmelina Pines | Gmelina |

P : annual rainfall expressed in mm/year

Dry month : month in which total potential evapotranspiration (P.E.T.) is higher than cumulative monthly rainfall (R) (ELDIN 1971).

Dry season : series of consecutive months with a water deficit: P.E.T. > R.

| Species | Natural range | | | | Commercial reforestation area | | |
|----------|---------------|-------|------------|------|-------------------------------|--------------------|----------------|
| | Rainfall | | Dry months | | Rainfall minimum | Dry months maximum | Type of forest |
| | max. | min. | min. | max. | | | |
| Teak* | 4 000 | 1 100 | 0 | 8 | 1 100 | 8 | E to SG |
| Fraké | 1 800 | 1 300 | 4 | 6 | 1 400 | 6 | SD |
| Framiré | 2 500 | 1 300 | 3 | 6 | 1 500 | 5 | E to SD |
| Samba | 2 000 | 1 100 | 4 | 7 | 1 300 | 6 | SD |
| Cedrela* | 2 500 | 1 200 | 2 | 6 | 1 400 | 6 | E to SD |
| Gmelina* | 4 500 | 700 | 0 | 8 | 1 100 | 8 | E to SG |
| Badi | 3 000 | 1 500 | 2 | 6 | 1 400 | 6 | E to SD |
| Pines* | 4 200 | 700 | 0 | 6 | 1 000 | 6 | E to SG |
| Niangon | 2 200 | 1 800 | 2 | 4 | 1 800 | 4 | E |
| Okoumé* | 3 500 | 1 500 | 1 | 4 | 1 800 | 4 | E |
| Sipo | 2 500 | 1 400 | 2 | 5 | 1 600 | 4 | E to SD |
| Cordia* | 5 000 | 1 000 | 0 | 5 | 1 600 | 4 | E to SD |

E : Evergreen; SD : Semi-deciduous; SG : Sudano-Guinean

* : species introduced in Côte d'Ivoire

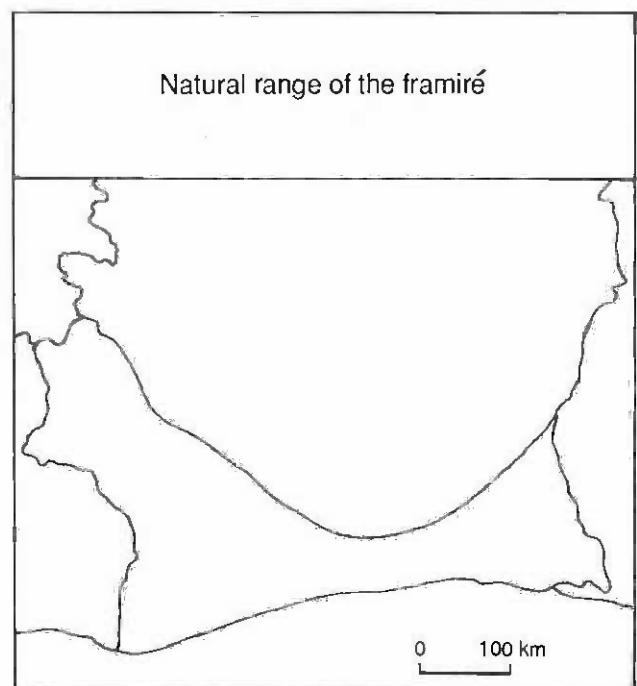
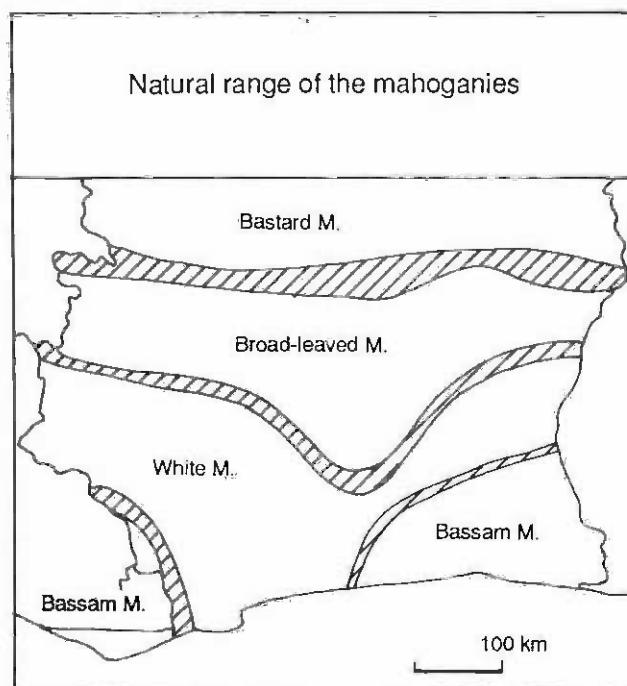
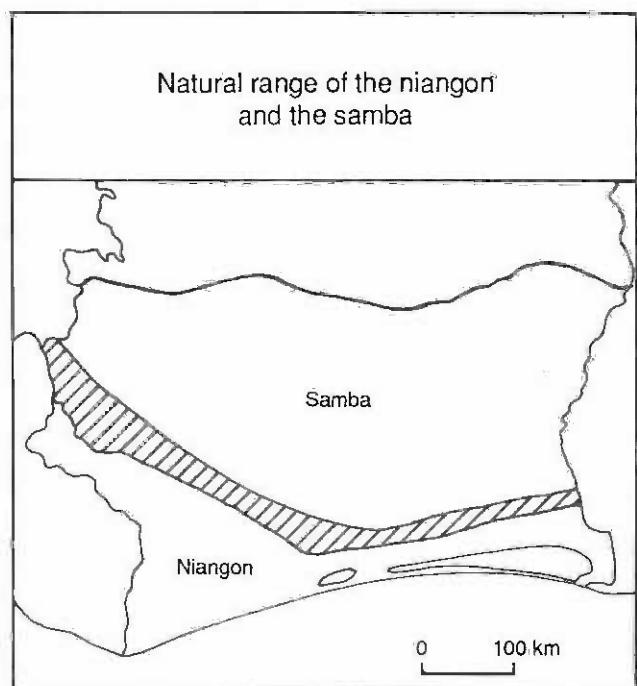
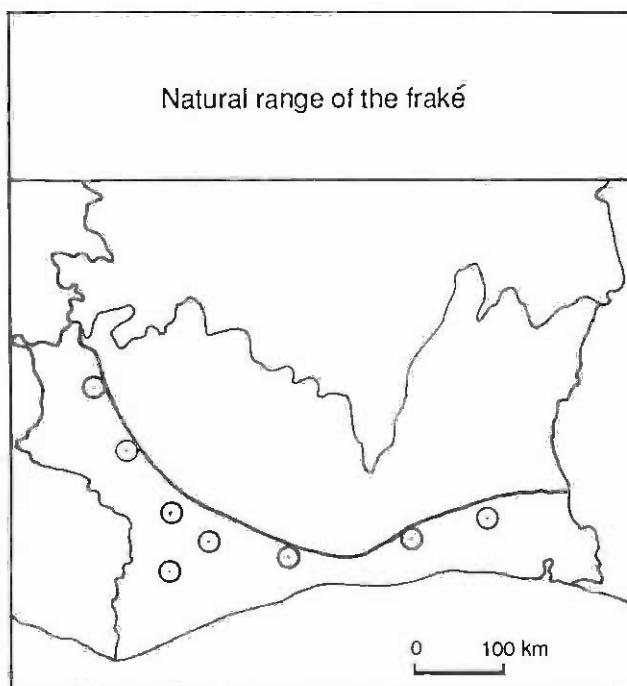
Note that these are average figures which must in no case obscure the existence of cyclic climate variations which may jeopardize the success of reforestation. Reforestors must therefore also consider the relationship between the distribution and the intensity of annual rainfall, as well as the maximum duration of dry seasons; these are limiting climate factors that influence the choice of species to plant.

The minimum densities to observe when transplanting are as follows:

| Density | Species |
|----------------|---|
| 1 500 stems/ha | Teak |
| 1 100 stems/ha | Niangon, Gmelina, Pines, Cedrela, Okoumé, Badi |
| 700 stems/ha | Framiré, Fraké, Samba |

When high planting densities are called for, reforestors are often tempted to reduce them in light of economic constraints (planting cost) and technical constraints (minimum spacing required for mechanized tending).

RANGES OF SOME COTE D'IVOIRE SPECIES



 Range overlaps

 Range extensions

Based on Guillaumet (Orstom)

In the case of species such as Teak, genetic improvement is directed toward selecting late-ramifying individuals or provenances (see forestry data sheets). Consequently, the stand effect in young age is fundamental to allow the most favourable interactions influencing such parameters as the straightness of the future buttlogs. To avoid reductions in the value of future stands, it therefore seems important to try to adapt reforestation techniques so as to allow for the silvicultural constraints inherent in these high planting densities.

3.4 - General silvicultural rules

3.4.1. - Clearing

Reforestation after total or partial clearing implies modification of certain biotic parameters:

- At soil level, the sudden removal of all woody cover changes the terms of the water balance. Rainwater is no longer intercepted by the woody cover; evapotranspiration and infiltration are reduced, erosion providing the incentive for local erosion.
- Burning the debris instantly releases the stored mineral potential. Leaching shortens the span of time during which this input can be used to reconstitute the stand.
- The initial composition of plant life is completely altered by the elimination of all pre-existing species.
- Sunlight at ground level surges from around 10 percent to 100 percent. These new site conditions correspond to the ecological niche of pioneer light-demanding species.

Due to the total destruction of the cover, foresters are obliged to plant light-demanding reforestation species that can survive out in the open from the moment they are planted.

In addition, competition for the cleared space directs the forester's choice toward species with fast initial growth. These species must be able, with the help of growth-encouraging silvicultural operations, to free themselves as quickly as possible from the influence of the natural regrowth.

From the very moment the ground is laid bare, it is rapidly invaded by light-demanding flora. This natural flora competes directly for water and light with the species chosen for reforestation.

These competing species may be divided into five groups (MALLET, 1983):

- Shrubby dicotyledons, such as:
 - * *Musanga cecropioides* (Aga umbrella tree) in moist evergreen forest areas.
 - * *Trema guineensis*, *Solanum torvum*, *Solanum verbascifolium* in moist semi-deciduous forest areas.

- *Eupatorium odoratum*, a subs spontaneous plant which invades clearing very rapidly and can form a continuous layer 1-1.50 m high in a few months.
- Dicotyledonous creepers (*Pueraria phaseolides*, *Centrosema pubescens*, *Ipomea* spp., etc.), which use the planted saplings as supports and thus deform or even smother them by overrunning them completely.
- Tall monocotyledons (up to 2 m) such as *Rottboelia exaltata*, *Panicum maximum*, *Sorghum* spp., etc., which can smother the young transplants.
- Medium-height monocotyledons (up to 1 m) such as *Digitaria* spp., *Brachyaria* spp., *Paspalum conjugatum*, *Eleusine indica*, *Panicum laxum*, etc., on shallow soils.

After planting, the saplings are very rapidly rivalled by these light-demanding adventitious plants.

These adventitious plants possess considerable potential for colonization: the re-establishment of a continuous layer of vegetation on totally bare ground takes no more than a few months. The initial growth rate of a forest transplant is slow in comparison (0.5 to 2 m/year).

Without silvicultural intervention, the majority of the young transplants will be eliminated by adventitious plants.

Two methods are used to control adventitious vegetation:

- the mechanical method,
- the chemical method.

3.4.1.1 - Mechanical method

This method combines manual mowing and the destruction of vegetation by tractor-drawn equipment.

Between planting lines, where there is room for a tractor to pass, a tractor-drawn roller-grinder or roto-grinder destroys woody and grassy vegetation. This method must be used only where slopes are very gentle (below 10 percent), and only between the lines.

Depending on the amount of grass cover on the plot, the following equipment is used:

- Roller-grinder with a 1.50 m swath, drawn by a 45 HP tractor, for lightly overgrown plots (young plots 1 to 3 years old). The machine can clean roughly 1.5-2 hectares per hour.
- Roller-grinder, 2.5 m wide swath, drawn by a 120 HP tractor, for heavily overgrown plots with woody regrowth (plots 3 to 6 years old). The machine can clean roughly 1.5-2 hectares per hour.

CHRONOLOGICAL SEQUENCE OF SILVICULTURAL OPERATIONS

| OPERATION | YEAR | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 12 - 15 | 30 - 40 |
|-----------------------------|------------------------------------|---|-----|---|---|---|---|---|---|---------|---------|
| Chemical tending | - Line - Interline - Windrow | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Mechanical tending | - Line - Interline - Windrow | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Manual tending | - Line - Interline - Windrow | 1 | 3/5 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| Climber cutting | | | | | | | | | | | |
| Selection of standing trees | | | | | | | | | | | |
| Thinning | | | | | | | | | | | |
| Pruning | | | | | | | | | | | |

(2): Two or three tending and climber cutting operations between the ages of 7 and 15 years as preliminaries to thinning and/or pruning.

- Bladed roto-grinder powered by the tractor engine (120 HP), for plots heavily invaded by woody regrowth. The machine can clean roughly 0.5-1 hectares per hour.

Cleaning operations on the line itself are performed by hand with a bush knife (2 man-days per gross hectare).

The same holds for narrowing windrows (2 man-days/gross hectare, or 220 m of windrows/man-days).

The frequency of complete cleaning sweeps required for correct tending depends on the dynamics of the adventitious vegetation. It ranges from 5 sweeps a year (shrubby dicotyledons) to 8 sweeps a year (Eupatorium odoratum). One or two operations a year are needed to narrow windrows.

3.4.1.2 - Chemical method

The composition and growth of adventitious flora can be controlled with herbicides. Two kinds of treatment should be planned (MALLET, 1983):

- Pre-emergence treatments before planting in order to retard the appearance of weeds and to curb their further development.
- Adventitious vegetation control treatments after planting retard the growth of such vegetation and/or modify their composition.

- Pre-emergence treatments

- These are carried out at the end of the dry season or beginning of the rainy season, when the planting site has been cleared of all debris and the weeds are not yet established.
- The recommended active substance is DIURON, at rates of 2.2 to 2.5 kg of A.S./ha. This dose is effective on adventitious plants, and entails no phytotoxic risk through residues on the young transplants. It is particularly effective against bushy dicotyledons.
- The treatment is carried out with ramp sprayers drawn by a 80 HP tractor (1.8 to 2.3 ha treated per hour; 0.2 to 0.3 man-days/ha). The tractor advances at 3.5 km/hour and sprays the mixture at the rate of 240 litres per treated hectare with liquid pressure of 1.5 kg/cm².
- The ground can be planted one month after treatment, thus postponing initial tending for about 6-7 months and obviating the need for two or three manual/mechanical tendings during the first year.

- Adventitious vegetation control treatments

- For contact herbicides to be most effective, the vegetation must be about 40 cm tall prior to treatment. In practice, the herbicide is applied about one month after the weeds have been cut back mechanically or manually.

- The active substances recommended for inter-line treatment are M.S.M.A. (Monosodium methyl arsenate) mixed with 2.4 D (2.4 dichlorophenoxyacetic acid) in the dose of 2.9 + 1.1 kg of active substance/ha when the adventitious flora consists of both dicotyledons and monocotyledons.
- For dicotyledons, especially Eupatorium, the recommended active substances are PICHLORAME mixed with 2.4 D (0.13 + 0.48 to 0.26 to 0.96 kg A.S./ha), or TRICHLOPYR + 2.4 D (0.2 + 0.86 kg A.S./ha).
- For graminaceous flora, the recommended active substance is DALAPON (6.5 kg A.S./ha).

To treat windrows colonized by shrubby dicotyledons and/or Eupatorium, the best results are achieved by jet spraying (with a tractor-drawn sprayer) a solution of PICHLORAME + 2.4 D (0.16-0.23 + 0.6-0.9 kg A.S./ha) or TRICHLOPYR (0.5 kg A.S./ha) in 350 litres of water per treated hectare.

- Saplings can be treated only when they are tall enough that the herbicides do not come into contact with the leaves. This kind of treatment can be recommended only if the lowest branches are about 1-1.50 m above the ground. No spray must touch the trunks. Taking phytotoxicity risks into account, these are the precautions to follow:
 - Spraying must be aimed and at low pressure.
 - The trees must be tall enough and the boles mature enough.
 - There must be no wind while the treatment is under way.

Treatment, effected with portable or tractor-drawn sprayers at 300 litres of water per hectare saves many traditional tending operations (roller-grinder + bush knife). The PICHLORAME + 2.4 D mixture modifies the nature of the adventitious flora to the benefit of monocotyledons (*Brachyaria*, *Paspalum*, etc.).

The value of herbicides depends on how much they cost to apply. In fact, the profitability of such treatments must be analysed periodically to take account of sometimes rapid changes in costs.

* Recommended method

Adventitious vegetation can be successfully controlled by alternating chemical and mechanical treatments.

Pre-emergence treatment before planting retards weed establishment.

During the first year, the transplants are still too small to be treated with herbicides, which can be applied only to windrows; lines and inter-line areas must be cleaned manually and/or mechanically.

Starting the second year, manual and mechanical methods of cutting back the vegetation and controlling it with herbicides should be used in combination, according to the nature of the vegetation.

In fact, it is important to strike a balance between:

- control of adventitious vegetation, and
- the presence of as continuous a woody and/or herbaceous layer as possible, in order to reduce erosion.

3.4.2 - Artificial pruning

This operation is performed to obtain timber with small, clean knots from species whose natural pruning process is inadequate, and it helps improve the quality of the harvested wood.

Artificial pruning is recommended only for species which do not develop epicormic buds when the trunk receives more light.

The operation consists of eliminating dead and/or live branches from a portion of the lower trunk. Pruning must be done early in order to optimize the production of wood without large knots.

Pruning is done by hand, taking care not to wound the trunk or strip the bark. Saws (handsaws or long-handled saws) or hand-lever shears are the ideal pruning equipment.

Pruning is preferably carried out in the dry season. Maximum pruning height in industrial plantations is 6-7 m, which corresponds to the limit to which a rigid single scale can be kept to on a plot consisting of several dozen hectares.

Artificial pruning is an optional operation left to the forester's discretion.

It involves two or three successive sweeps which, for reasons of rationalization, should be combined with silvicultural operations.

- The first pruning is done when the trees are still young (2 to 4 years). All of the trees are pruned up to 2-5 metres, to a height not exceeding half of their full height.
- After the final crop trees have been designated and the stand has been thinned, only the future timber trees are artificially pruned any further. The pruned height should be no more than two-thirds of the tree's full height.

The calendar and pace of artificial pruning operations depend on the characteristics of each species (architecture, growth, etc.).

The following schedule may be suggested:

| | Fraké | Framiré | Samba | Cedrela |
|-------------|---------|---------|---------|---------|
| 1st pruning | 2 years | 4 years | 4 years | 4 years |
| 2nd pruning | 4 years | 4 years | 7 years | 6 years |
| 3rd pruning | 7 years | 7 years | - | - |

3.4.3 - Thinning

The thinning regime is based on the results of the TFTC's various experimental facilities (CCT-Plots, ground control facilities, Marynen, Nelder, etc.).

In light of the significant increments reported, the thinning regime of monospecific plantations is characterized by:

- early thinnings;
- the often considerable amounts of wood removed during thinning;
- a thinning pace that enables the stand to reach its definitive spacing as quickly as possible.

This thinning regime corresponds to a type of silviculture that aims to obtain maximum yield at the end of rotation; the relationship between wood quality and growth rate is not quantified.

As a general rule, thinnings are made at the lower levels, to the advantage of dominant trees.

The definitive structure of monospecific stands is most often of the monolayer type; in fact, overshadowed trees are eliminated. The final density is such that tree spacing eliminates or considerably reduces competition among individuals.

One of the problems posed by thinnings is how to use the wood thus produced, as these are small trees.

At present, there are several options that depend on the nature and size of the thinned trees:

- For wood produced by initial thinnings of medium-rotation timber plantations (Fraké, Framiré, Cedrela, etc.), which is often characterized by low durability or low heating potential, no use is envisaged in the short term.
- If the wood has good heating potential or is fairly durable (Teak, Badi, etc.), it can be used as firewood or construction wood (stakes, poles, etc.).
- If the thinned stems are over 20 cm in diameter, they can be used for posts or small sawn timber; however, this possibility depends on outlets in local markets.

3.4.4 - Designation of final crop trees

To optimize forestry operations, a certain number of stems may be designated to make up the future stand. The number of trees so designated varies according to the species. It often corresponds to the final density plus the number of trees to be harvested in the last thinning.

The designation age depends on the way each species grows. In fact, the trees' definitive architecture must be sufficiently apparent (by ramification,

bifurcation, etc.) to enable the choice of the ones fittest to supply intermediate and final products.

After the final crop trees have been designated, silvicultural operations (thinning, pruning) aim mainly to benefit these trees.

The choice of trees depends on two parameters:

- their phenotype, which must be optimal;
- their even distribution over the whole plot.

For example, the following figures are suggested for some medium- and long-rotation reforestation species:

| Species | Framiré | Fraké | Cedrela | Samba | Gmelina | Teak |
|--|---------|-------|---------|---------|---------|---------|
| Final density (stems/ha) | 70/90 | 70/90 | 100/120 | 100/120 | 90/100 | 100/160 |
| Logging diameter (cm) | 50/60 | 50/60 | 50/60 | 50/60 | 50/60 | 45/55 |
| Predesignation age (years) | 4 | 4 | 6 | 4 | 6 | 10 |
| No. of trees to designate (stems/ha) | 200 | 200 | 200 | 200 | 200 | 250 |

It is sometimes necessary to make roads to haul out the wood resulting from thinning operations.

If the windrows have totally disappeared by natural decomposition about ten years after planting, it is recommended to use the lines they leave for this purpose.

Otherwise, if there is an accumulation of heavy, long-lasting wood, it may be decided to thin the central line systematically during the initial operation. In this case, the following procedure may be suggested:

- systematic thinning to open removal roads (a central line) during the initial operation;
- designation of final crop trees;

- in subsequent thinnings, gradual elimination of stems not selected by selective thinning, in order to obtain top-grade intermediate and final products.

3.5 - Dendrometric parameters

The silvicultural rules set forth for each of the species described in this paper were established on the basis of numerous data gathered over the whole lifetime of the stands concerned. Trees planted at experimental facilities or in industrial stands were measured repeatedly.

Our purpose here is not to go extensively into the theoretical and methodological approach to the dendrometric description of stands and to the development of management tools. This information is treated in depth in many specialized works (see Bibliography).

Nonetheless, it seems necessary to recall some of the fundamentals and the path that led to the development of forestry rules.

3.5.1 - Dendrometric characteristics of stands

The measured or calculated indicators correspond to the standard definitions in this field, and are designated with their standard symbols.

- The site is a "tract of forest with homogeneous ecological conditions and a homogeneous stand where the same silviculture may be practised throughout, and where it may be hoped that the yield from a particular species will range within given limits" (PARDE-BOUCHON, 1988).
- The productivity index ("Ip") is the main characteristic of this homogeneous ensemble called the site. The index value quantifies the site's inherent potential for the production of wood, also known as xylogenic capacity or degree of fertility. This potential depends mainly on the nature of the soil, but also on other factors relating to climate (rainfall, hygrometry, light, etc.) and to the stand itself (seed provenance, site preparation, pace of tending, wildfires, etc.).
- Stand density ("N") is the number of standing trees per hectare.
- Stand age ("t"), expressed in full years, is the number of growing seasons⁴ elapsed since transplanting the saplings.
- Basal area ("B") is the sum of the cross-sections of all the trees in the stand at the height of 1.30 m above the ground. It is expressed in m² per hectare:

$$B = \frac{\sum C^2}{4 \pi}$$

Where C = individual circumference (girth) at 1.30 m.

⁴ A growing season may include two rainy seasons if the climate regime is divided in this way.

This indicator is useful in monitoring the development of the stand as a whole. It makes it possible to define stand status for given species and to rapidly compare different stands. A slowdown in its rate of increase shows that the plantation's productive capacity is becoming saturated and thinning is needed.

- Dominant height is closely linked to site quality, hence to the productivity index, which it is used to calculate. The standard symbol is "H_{dom}," but to make things easier we shall use the symbol "H_d".

This indicator represents the average height, in metres, of the 100 largest trees in a hectare. It is of particular interest because it is little influenced by thinning, especially of small and medium-sized stems at the lower level.

- The average height ("H_g") of a stand is defined by the height of its "average tree," which is, artificially, the average basal area tree. Its cross-section at 1.30 m is:

$$\frac{B}{N} \quad (B: \text{basal area}; N: \text{number of trees/ha})$$

This indicator is very similar to dominant height, except that it varies according to lower-level thinning. It is therefore a stand characteristic that depends on the specific silvicultural practices. The same is true for:

- The mean girth ("C_g") and the mean diameter ("D_g") of the stand, which corresponds to the mean basal area at 1.30 m.

$$C_g = \sqrt{\frac{\sum C^2}{N}} \quad \text{and} \quad D_g = \frac{C_g}{\pi}$$

$\sum C^2$ = sum of the squared girths of N trees/ha

International standards measure tree girth at the height of 1.30 m above the ground. In Côte d'Ivoire's teak plantations, initial measurements were made at 1.50 m. It was therefore necessary to keep to this measurement height (provisionally), in order to have homogeneous data for yield tables.

The value often taken as average girth:

$$C = \frac{\sum C}{N}$$

which is systematically slightly less than C_g, should be avoided because it leads, among other things, to further underestimation of B.

- The spacing factor "S" expresses, as a percentage, the ratio of average spacing among trees at dominant height in the same ensemble.

$$S \% = \frac{e}{Hd} \times 100$$

"e" derives from the stand's residual density N :

$$e = \sqrt{\frac{10\ 000}{N}} \quad \text{or} \quad e = 100 \times \left(\frac{1}{N}\right)^{0.5}$$

Assuming a square distribution,

$$\text{then } S \% = \frac{10\ 000}{Hd} \left(\frac{1}{N}\right)^{0.5}$$

Note: The spacing factor is calculated differently by different authors; assuming a hexagonal distribution, it becomes:

$$e^* = \sqrt{\frac{10\ 000}{N \times 0.866}}$$

Either value may be used, since their ratio is constant: $e/e^* = 0.931$

In the following paragraphs we shall use the square distribution value, for reasons of simplicity in calculation.

This factor is an essential stand characteristic that is much more objective than simple density at a given age, because it describes stand status at a precise stage of development (expressed by Hd), integrating both site fertility and plantation age.

The spacing factor defines, so to speak, a feature of the stand (it decreases over time), and quantifies thinning intensity (positive variation with stem elimination).

Wood production, the objective of reforestation operations, is expressed in terms of wood volume and increments.

Several different kinds of volume can be assessed, depending on the target. Researchers use a whole range of indicators to describe stand potential: total volume, bole volume, mainstem volume, heavy-timber volume, woody biomass volume, timber volume, etc.

Forest managers concerned with well-defined production, in this case commercial timber, need to use only the indicators relating to technological and economic constraints such as:

- Mainstem volume (abbreviated to HWV) is the volume of wood with bark (stem + branches) in the interval from the lower cut (at ground level unless the base of the tree is deformed) to the upper cut, where the girth is 22 cm (diameter 7 cm).
- Standing volume "V" is the total HWV of all standing trees (before or after thinning) per hectare, expressed in m³/ha.

- Thinning volume is the HWV of trees removed by thinning, expressed in m³/ha.
- Timber volume (abbreviated to TV), in m³/ha, is the volume of wood with bark in the interval between the foot of the tree and the upper cut at the diameter of 30 cm. This factor corresponds to current timber use requirements (sawing, slicing, peeling).
- Total volume, or "V_{tot}," is the sum of the standing volume "V" at a given age plus the volume extracted in previous thinnings. It too is expressed in m³/ha.
- Mean annual increase, or "m_i," is the yearly average of the total yield beginning in the stand's first year of existence:

$$m_i = \frac{V_{tot}}{t} \quad \text{expressed in m}^3/\text{ha/year}$$

where t = age in years.

- Current annual increase is the yearly average of total yield over a given period of one or more years, for example between age x and age y:

$$i_{x,y} = \frac{V_{x,y}}{x - y}$$

where $V_{x,y} = V_{tot}$ at age y - V_{tot} at age x

Mean increase expresses overall yield, whereas current increase gives an spot image of production at any given age.

3.5.2 - Volume tables

Forest managers always have the problem of assessing the intermediate and final material yield of a physical object which is determined by the targets set for the stands (timber, heavy wood, pulpwood, etc.). The quantification of current and average increments in this material provides essential indicators for forest management.

Managers must therefore be able to rapidly estimate the appropriate volumes at the various stages of the stand's life.

For this purpose, volume tables have been developed on the basis of data gathered from existing stands.

* Measurement of tree volume

Tree volume has been measured on both standing trees, by climbing them, and felled trees. The chosen total volume is calculated by adding up the volumes of fictitious segments, generally 1 m long.

This volume depends on the kind of cut, which may be:

- by size:
 - + mainstem, diameter 7 cm
 - + other sizes, 20 cm, 25 cm, 30 cm, etc.
- by shape:
 - + crown cut, located at the point where a fork or a verticil of large branches originates. This cut defines a bole volume;
 - + merchantable cut. This corresponds to the limit up to which merchantable timber can be obtained.

The reference diameter or girth is measured at the height of 1.30 m. For certain species, when buttress height reaches or exceeds 1.30 m, the girth is measured above the point where the buttresses end, and this is taken as the reference parameter.

Measurements include bark, and the calculated volumes therefore correspond to the volumes of wood plus bark.

* Table calculation

For each species studied, volume tables have been developed for the various research and management targets.

The methods used in preparing these tables, and the mathematical choices and constraints involved, are perfectly described in specialized works to which the reader is referred. For specific studies, details are available in TFTC working documents on forestry studies of species for which there are plentiful data, especially time series.

The simplest and most reliable of the chosen formulas, which entail no standard deviation, are parabolic:

$$V = a + b D^2$$

$$\text{or } V = a + b D + c D^2$$

V : expressed in m³

D : diameter at 1.30 m, expressed in metres.

Although the curves corresponding to these two formulas may seem no different at first glance, to avoid deviation it is necessary to choose the simplest one, as long as the other presents no significantly smaller residual deviation (CAILLIEZ-BLANC, 1979).

The models are generally adjusted by weighted regression. As is evident, they are mainly single-entry tables. In practice, forest managers must reconcile the precision of their assessment tools and the economic aspect of their operations. They must rapidly obtain reliable quantitative data, often over wide areas, and accordingly often have to shorten measurement periods. Research shows that although the use of two-entry tables (diameter and height) gives more precise data, the improvement is not significant enough to justify the greater cost of field operations.

* Use of volume tables

For each species, tables are prepared on the basis of a rather limited number of sample trees, which determine the validity of the tables themselves. Accordingly, these should be used only within the limits so defined.

Where yield tables can be compiled (Teak, Fraké, Framiré, etc.), volume tables are usually the last step. The validity range of these tables is therefore linked to particular size spreads and well-defined fertility classes.

The user's choice of volume table depends on the assigned target.

The mainstem volume widely used as a working basis in this text is a conventional reference.

Bole volume figures are generally much closer to the volume that can actually be mobilized as timber. When the technical limitations on use of the raw wood material are well known, it is advisable to use a size cut volume. If it is necessary to calculate timber volume, this corresponds to the 30 cm-diameter cut.

3.5.3 - Yield tables

Forest managers must assess and plan the yield of their stands. Accurate data (inventory, volume tables, etc.) and a forecast quantification tool must therefore be available. Yield tables meet these requirements.

The yield table gives a picture of the probable evolution of an even-aged monospecific stand over time. It thus makes it possible to estimate several of the presumable dendrometric characteristics (number of increment stems, basal area, mean diameter, volume, increment, etc.) according to age and dominant height, and is effective for both standing trees and subsequent thinnings.

The data refer to hectares and are set out according to periods of time which may be either standard or corresponding to the thinning cycle.

Yield tables are compiled:

- by species
- and, for each species, by climate zone.

Within each homogeneous climate zone, the tables distinguish among several "fertility classes" and describe the average evolution of stands to which a given type of silviculture is applied.

Applied to their reference region, the tables provide figures that are probably accurate enough to:

- develop considerations on a species' growth and behaviour in a stand;
- be used to support stand management or regional economic studies.

3.5.3.1 - Construction of provisional yield tables

The amount of detail in a yield table depends on the nature of the available data. Data are gathered on permanent and temporary plots established in stands representative of different silvicultural stages.

A growth simulation model can then be built and used to forecast the evolution of a stand to which average silviculture is applied.

The provisional character of these tables is linked to the extrapolation of certain curves, particularly for age groups that are not yet represented in certain fertility classes.

Yield tables apply only to regular stands of a single species. They cannot be used for mixed stands, where there exist complex growth conditions which have not yet been studied.

The tables are compiled for given geographic regions. They can be applied beyond their reference area only with the greatest caution, because changes in the conditions of the stands' growth environment influence tree growth.

The figures given in the tables are average values. They represent average growth trends for a given species in pure even-aged stands in a given geographic area.

Behavioural and silvicultural treatment variations are taken into consideration within the limits of the sampling effected. Tables so developed cannot account for local growth variations restricted to small areas: the goal of sampling is to identify average trends not overly influenced by particular cases.

The various functions that describe stand status are based on a mix of observations made before, between and after thinnings.

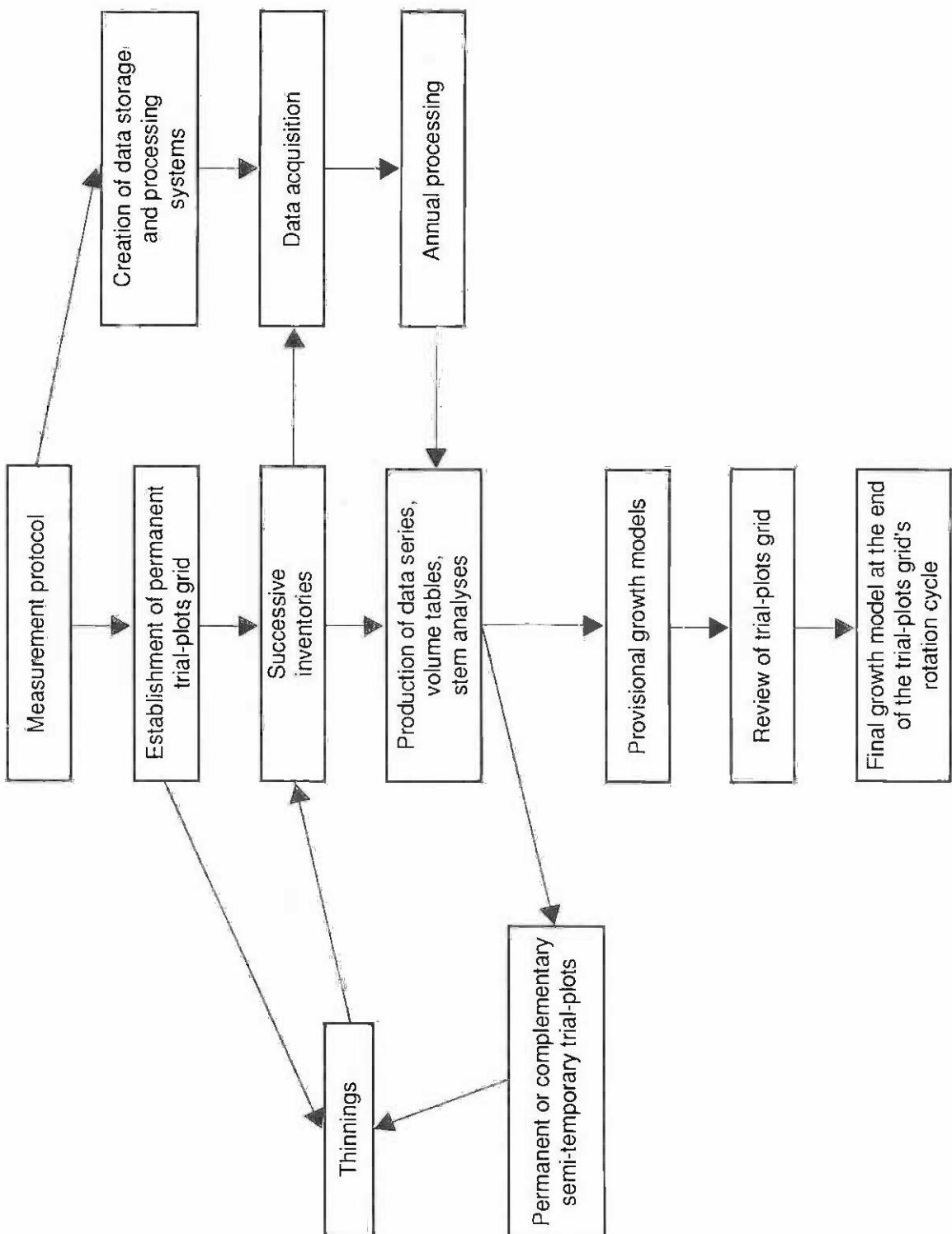
The yield table construction method is based on the following empirical laws:

1. The yield per area unit of an even-aged stand depends directly on its dominant height, and the total yield in volume obtained for a given dominant height is not influenced by the number of years needed to reach this height (PARDE, 1961).

This observation makes it possible to classify stands according to dominant height at a given age, and also to define productivity classes.

2. The increase in an even-aged stand's basal area and volume remains identical within a wide range of different thinning systems (PARDE, 1961). Or, more restrictively (MARSH, hypothesis): "On a given type of site, the growth of a thinned stand with N stems/ha and ground area G (or volume V) is equal to that of a unthinned stand that has always had N stems/ha, at the age when with those N stems/ha, it attains the basal area G (or the volume V)."

FLOWCHART OF PRODUCTION TABLE CONSTRUCTION OPERATIONS



It is then possible, starting with an ensemble of silvicultural operations applied to the stands, to extrapolate growth laws for a theoretical thinning intensity halfway between two consecutive thinnings intensities actually applied to the sampled stands.

The construction method used is the one developed by DECOURT (1972), which considers three ratio systems:

Silviculture-independent ratios

HO: (Age, fertility)

As a general rule, final density of average-rotation species is on the order of 70-90 stems/ha. Consequently, it is necessary to reconsider the traditional definition of dominant height (average height of the hundred largest stems/ha) as a function of stand density after the last thinning.

Dominant height is defined as the average height of the 50 largest trees per hectare. The dominant height at a given age is a good indicator of site fertility. As such, it makes it possible to define productivity classes.

Dendrometric ratios

Hg: (HO, density)

Dominant height is a function of site density and fertility. For a given density and age, it will be ever greater as the site is more fertile. Similarly, the number of dominated trees on a dense stand, on a given site and at a given age, will be greater than if it had been heavily thinned out.

This ratio represents the influence of site and silviculture on the trees' average height.

Cg: (Hg, density)

Mean girth is related to average height and density. This ratio reflects the influence of thinnings on stand girth growth for a given fertility. Depending on whether a stand has or has not been thinned out before the appearance of competing vegetation, the trees' average girth increment will be larger or smaller, within the biological growth limits of each species.

V: (Cg, N)

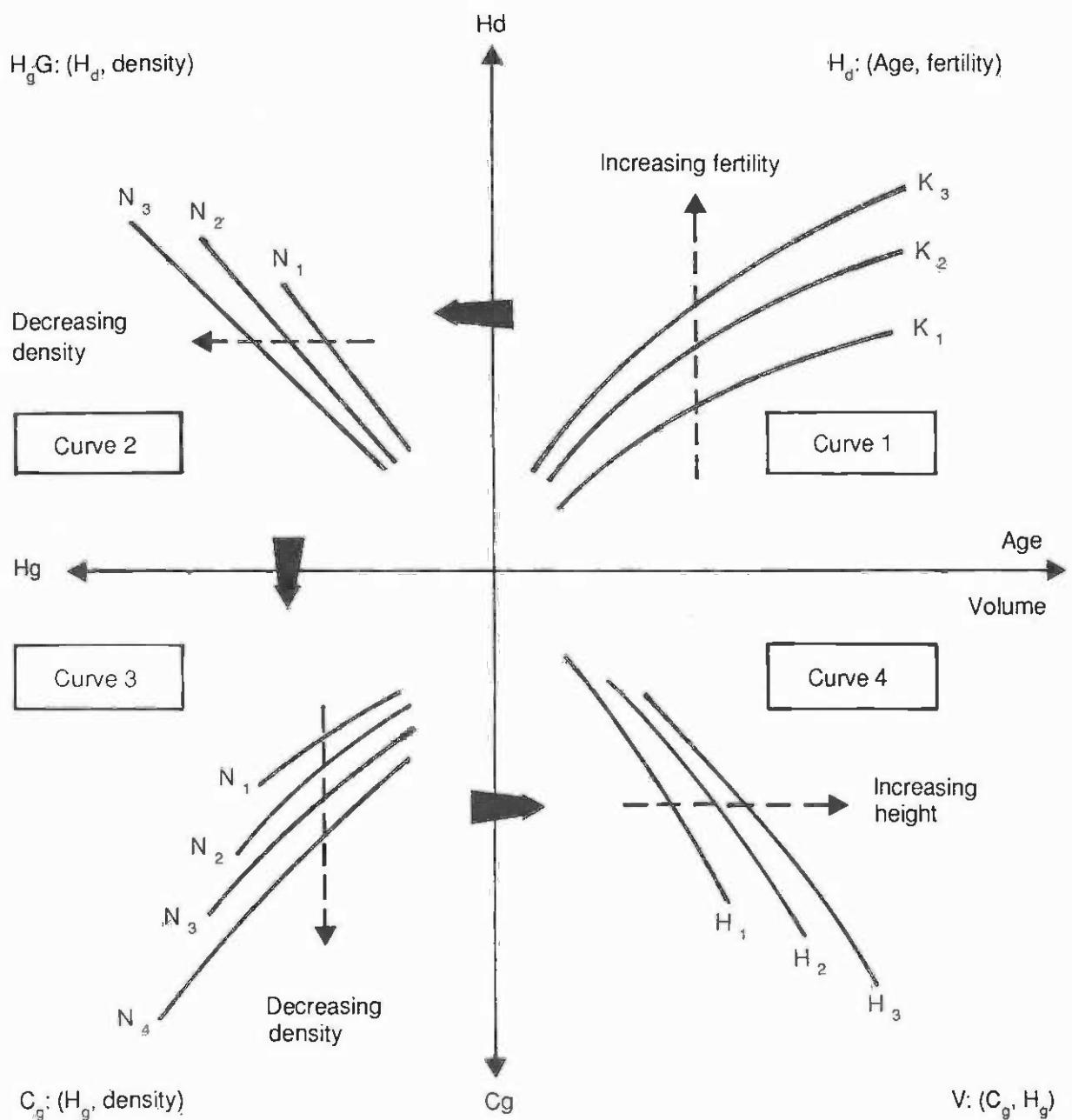
The compilation of a volume table is essential to assess wood volumes at different moments of the stand's lifetime.

Forestry rules

These define thinnings quantitatively and qualitatively, as a guide to foresters. In particular, the following points are specified by means of the usual dendrometric parameters:

- thresholds of thinning operations (G, S%, HO);
- intensity of the various thinnings (Ge, Ne);
- their cycles (A).

CHAIN DIAGRAMS REPRESENTING A PRODUCTION TABLE



3.5.3.2 - Establishment of the various ratios

Hd ratio (Age, fertility)

This ratio is often the most complicated to obtain. It is traditionally found through successive measurements made over several years on permanent plots. However, due to the insufficiency of the data gathered at permanent facilities, it is often necessary to use methods which make it possible to assess dominant height variations over time quickly and accurately. This is the reason that stem analyses have been effected.

Multiple regression methods are used to construct the set of fertility curves which translate the height/age/fertility index ratio.

These methods may be used to adjust a set of fertility curves when the fertility index "Ip" or the fertility class of each plot can be determined before adjusting the model.

This productivity index is a brief descriptor of the potential of a given stand, with its own history, in a given location.

Average height ratio (Hd, N)

The average height of a stand at a given age depends on both site fertility and standing population density.

For a given age and site fertility, the dominant height will be ever greater as the stand is increasingly thinned out. Thinning fires more often affect dominated trees, and thus have a positive influence on the total height average of the trees that are still standing.

Girth evolution (Hq, N)

Average girth increment (C 1.30) in a stand is influenced by the site's fertility and by the kind of silviculture applied to the stand.

Volume V tables (Hq, Cq, N)

These are usually mainstem volumes; coefficients are often calculated to go from mainstem volume to volumes that correspond to different cuts.

3.5.3.3 - Description of silvicultural practices

The silvicultural rules defined for each species vary according to a certain number of ecological, technical and economic factors. They must be considered as indications that are adequate to direct but not compel forestry work.

To describe in practical terms a silviculture applied to a given species, the following points must be specified:

- planting density, which makes it possible to obtain a good general configuration of young plantations with the appearance of an early "stand effect";

- times for thinning operations. These may be defined by thresholds of age, dominant or average height, average height increase, etc. Thinning is carried out when these thresholds are reached;
- operation intensity. This is the number of stems which are to be left standing when the stand reaches a given dominant height. The Hart-Becking factor may be used;
- the nature of the thinnings, characterized by the ratio K:

Average volume of the tree removed by thinning

Average volume of the tree before thinning

for a given thinning intensity, the higher the K ratio is, the higher the thinning;

- rotation length as a function of exploitable diameter. The value of the exploitable diameter influences the number of standing stems to be saved after the last thinning. The higher the exploitable diameter, the more intense this last thinning will be; the "vital space" needed for a tree's optimum development increases according to its growth.

The optimization of these parameters is a compromise among the characteristics of each species, in particular its reactions to variations in light (growth habit, pruning, epicormic buds), and the technological and economic constraints.

Thinnings may be described by means of the following parameters:

- dominant height before thinning;
- the number of stems before and after thinning, which may be specified by the spacing factor before and after thinning:

$$S = e/Hd \quad \text{with} \quad E = (10\ 000/N)^{1/2}$$

This factor, by means of the dominant height deviation, makes it possible to integrate site fertility and stand age.

- The rate of removal expressed in basal area:

$$g^r = \frac{\text{stand's basal area before thinning}}{\text{stand's basal area after thinning}}$$

These ratios were established from studies of competition and of thinning systems.

Economic constraints are integrated with the suggested silviculture at the level of the nature of the products mobilized during thinning and of the adopted profitability rate, which determines the exploitable diameter for a given fertility.

3.5.3.4 - Compilation of yield tables

Yield tables are compiled in stages, according to available data.

* Intermediate tables

The first stage is the one that makes it possible to suggest silvicultural rules for a given species. These tables describe stands to which an experimental silviculture is applied *a priori*.

The modelling is static, and only allows very limited extrapolation. Stand status is expressed in terms of age, fertility class and stand history.

These methods are static in the sense that thinnings have no driving role in the model, and that silviculture varies only with the application of certain kinds of well-characterized treatments that are already present in the data (ALDER, 1980).

* Provisional tables

When the quantity of available data is adequate and represents a sufficient number of different cases of configuration (permanent plots monitored for many years), it is possible to construct a static simulation model with which to accurately forecast the growth of a stand to which various silvicultural treatments are applied.

In particular, provisional yield tables make it possible to model different thinning regimes according to fertility.

The provisional character of these tables is related to the extrapolation of certain curves; this is so particularly for age classes that are not yet represented in certain fertility classes.

* Definitive tables

The application of certain kinds of silviculture within a system of permanent plots tended up to the end of the rotation period makes it possible, as in provisional tables, to establish definitive tables without extrapolation for certain treatments. Growth is simulated with static silvicultural models, and the time factor is a parameter controlled from the moment of planting to the end of the rotation period.

The suggested models may be dynamic: these too are based on expected current growth in terms of average diameter, ground area or volume as a function of stand density, age and fertility. In making these yield projections, one either integrates the growth function mathematically, or adds up by iteration over the years. However, to express the effects of density, dynamic models require a great quantity of data that give a good representation of extremely diverse densities.

3.5.3.5 - Validity limitations of yield tables

Yield tables concern only even-aged stands made up of a single species.

Yield tables cannot be applied to mixed stands, where there exist complex growth conditions that have not yet been studied. Similarly, the existence of many age classes within the same stand make it too heterogeneous for this classification.

The tables are established for a given geographic region. They can be applied beyond their reference area only with the greatest caution. In fact, changes in the growth environment may well influence the manner of tree growth.

The figures set down in the tables are mean figures. They represent average trends in the growth of a given species, in pure even-aged stands, in a given geographic area. These stands are subjected to a well-defined ensemble of silvicultural practices.

Particular variations in behaviour are taken into consideration within the limits of the sampling effected. Tables so developed will not be able to account for local growth variations restricted to small areas: the goal of sampling is to identify average trends that are not overly influenced by particular cases.

The forecast of a stand's growth must be made within the sampling carried out. Extrapolations beyond sampling limits are subject to error.

CHAPTER III

SILVICULTURAL RULES FOR THE PRINCIPAL REFORESTATION SPECIES

Numerous trials have been conducted with the reforestation species suitable for timber production.

In the framework of the reforestation programmes implemented in Côte d'Ivoire, it has been considered advisable to summarize the findings with regard to the species potentially of interest to silviculture and protection reforestation.

The following available results have been summarized for each species tested in monospecies trials:

- the biogeographical characteristics of its natural range (annual rainfall, duration of dry season, altitude);
- the chief properties of the wood (density, mechanical characteristics, impregnability, seasoning, ...) that determine its technological vocation;
- the major plant protection problems that could compromise successful plantations;
- the dendrometric parameters of the stands, describing initial growth and thinning thresholds for optimum growth. The silvicultural rules have been established for single-species, even-aged stands planted on non-marginal sites (bioclimatic and meso-ecological standpoints soil, topography, ...). The dendrometric parameter values (mean height, mean diameter, basal area, ...) are purely indicative and must be adjusted in relation to the growth conditions of each stand. The figures given for mean volume increment refer to standing timber; the products of thinning operations have not been taken into account, as their commercial exploitation is not yet assured. The question of the thinning products will be briefly dealt with in the paragraph entitled "volume of production";
- the best provenances to use, when known.

For some species, due to the scant data presently available, only provisional silvicultural rules have been given, which will require more precise specification as additional data become available from plantations now being harvested or to be established in future.

The species have been divided into four groups in relation to their behaviour on single-species plantations:

- Species with slow initial growth.

These are medium-rotation and long-rotation species that were formerly used for reforestation, many of which have been

abandoned due to their excessive silvicultural, phytopathological or economic disadvantages, such as:

- . Sipo (plant rearing problems and insufficient growth),
- . Mahogany (attacks by borers),
- . Niangon (insufficient growth),
- . Okoumé (insufficient growth and shape problems).
- Pilot species for industrial reforestation.

These are full sunlight species with fast initial growth and a medium or long rotation, and that grow satisfactorily on mechanized commercial plantations.

For these species (Fraké, Framiré, Samba, Cedrela), which at present account for the majority of planted areas, the silvicultural rules are well known. Yield tables make it possible to model the growth of Teak, Fraké, Cedrela and Framiré plantations.

- Species to be promoted for industrial reforestation.

These are full sunlight species with medium to fast initial growth and a medium rotation (Gmelina, Badi, Pines), that grow satisfactorily on mechanized plantations and whose introduction on concessions is foreseen to cover several hundred hectares.

Provisional silviculture rules have been drawn up based on experimental plantations currently being harvested.

- Species to be confirmed.

These are full sunlight species - whose behaviour has been successfully tested on trial plots and which are to be the object of supplementary experimentation: Padouk, Cordia, Pouo, Makoré....

1 - LONG-ROTATION SPECIES

1.1 - Teak (*Tectona grandis*)

Teak belongs to the Verbena family. It is a deciduous sun-loving species that prefers moist semi-deciduous forests. Its range is discontinuous, and comprises three major zones:

- the Indian peninsula,
- Myanmar, Laos and Thailand,
- the islands of Java and Muna (Indonesia).

In this area rainfall varies between 1 100 mm and 2 700 mm per year (in limited local areas it may reach 4 000 to 5 000 mm per year); Teak grows from sea-level to an altitude of 1 000 m.

In Côte d'Ivoire teak was introduced in 1926 in the forest zone (Banco forest) and in 1929 in the pre-forest zone (Bouaké region).

It starts flowering in May and continues until September, peaking in July. Fruit-setting follows in September, and is at its peak in December-January.

Reproduction begins very early: the first flowers appear between the age of 2 years and 8 years, depending on provenances. In selecting provenances, preference will be given especially to the late-blooming ones, as first bloom height and fork height are closely linked. The flowers are apical, and after the bloom stem has withered, the secondary lateral axes develop and sometimes give rise to forks.

The main criteria for selecting provenances or trees are vigour, forks (late flowering), striae, bumps and natural pruning.

Provenance trials in West Africa have not revealed any great differences in vigour, but have demonstrated the superiority, in qualitative terms, of certain East African and Asian provenances (SOUVANNAVONG, 1983).

As regards the tested provenances, those from West Africa flower and fork sooner than those from East Africa and Asia. The same provenance distribution also applies to natural pruning height. The choice of provenances is thus based essentially on plant shape criteria. The best tested provenances are: MTIBWA (Tanzania), BAN CHAM (Thailand), BAN PHA LAI (Thailand) and PAKSE (Laos).

The root system is of the taproot type, with lateral roots developing progressively as the tree ages.



Young Teak plantation; TENE station

The fruit (1 000/kg) contains 2 to 4 seeds, and its thick pericarp tends to induce dormancy. Soaking the fruits in water for 48 hours is recommended to reduce dormancy. A mature tree bears 2 to 4 kg of fruit. As the seeds are hard to extract, the fruits are used to obtain seedlings.

Teak has very good stump sprouting ability; two techniques can be used for vegetative propagation (SOUVANNAVONG, 1983):

- shield budding on stumps in March-April at the time when budding occurs at the beginning of the rainy season;
- plant cuttings (young 2 or 3 week-old terminal shoots);

The wood, which is yellow to brown in colour, is of medium density (density at 12 percent moisture content = 0.6 - 0.7), medium hardness (semi-hard), with low nervosity, low shrinkage, good durability, low impregnability, good to medium axial cohesiveness and medium transversal cohesiveness (DURAND, 1983).

Its calorific value of 5 000 cal/g makes it a good fuelwood. It is used for saw-logs, veneer-logs, indoor and outdoor woodwork and cabinet-making.

The chief phytopathological problems reported are:

- attacks of root-rot (*Fomes lignosus*, *Ganoderma* spp.), leading to destruction of the taproot and windrow in the evergreen zone;
- black spotting of the wood caused by scolidae and above all by bostrychidae (coleoptera),
- defoliation due to an orthoptera: *Zonocerus variegatus*,
- termite attacks, chiefly in the savannah zone.

SILVICULTURAL RULES

For this species there is a yield table applicable to all teak stands in Côte d'Ivoire (MAITRE, 1983; DUPUY, 1990).

The recommended planting density is 1 500 stems/ha.

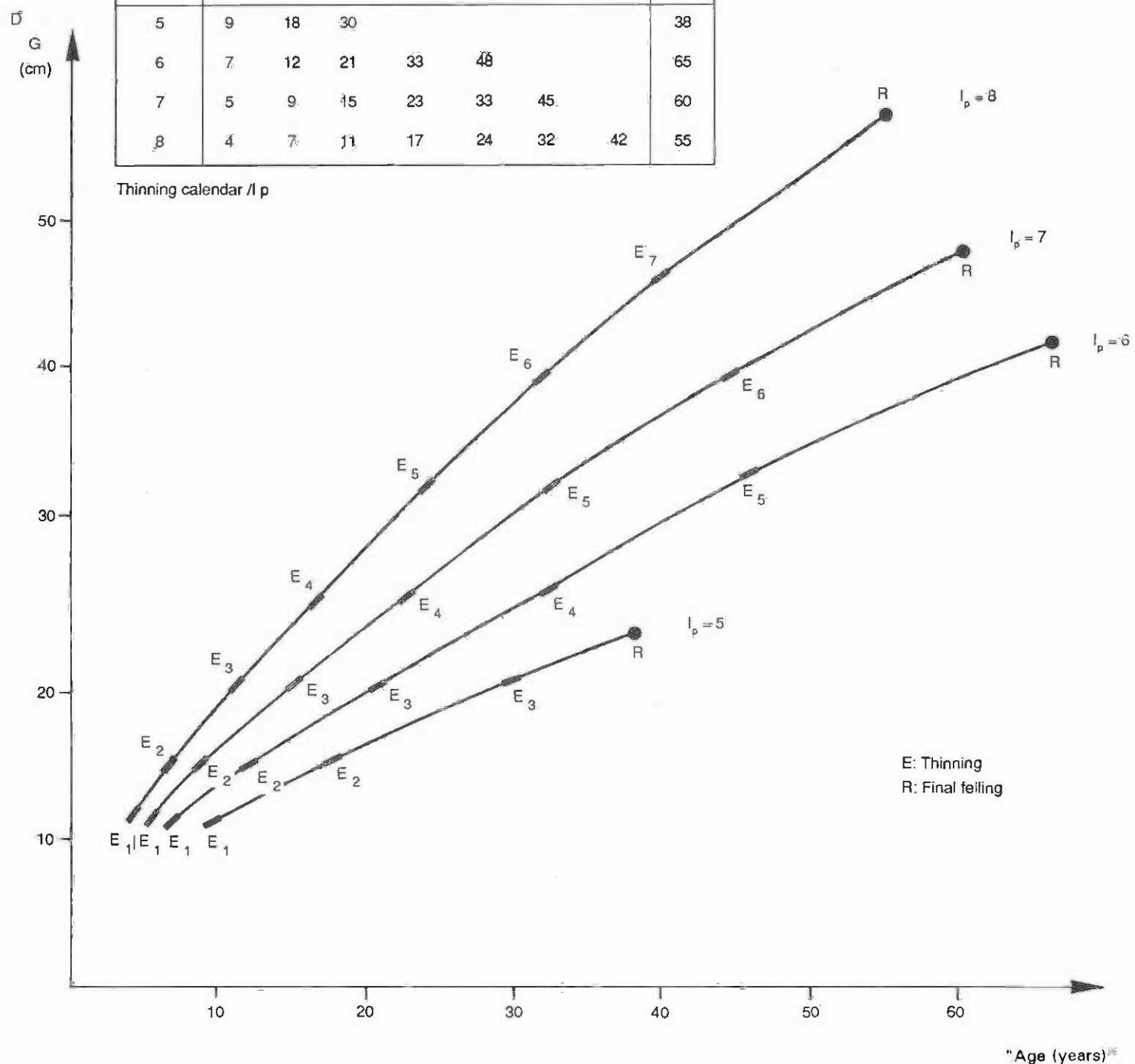
Teak has average initial growth-rate. Under favourable conditions, the mean total height is 10 m at the age of 4-5 years, and 14 m at 9-10 years.

On sites of fair and medium fertility, the rotation cycle is 50-60 years for an exploitable diameter of 45-50 centimetres.

The general criteria for thinning should be such that logging, while maintaining a high productivity level, does not cause excessive lateral exposure of the trunks to sunlight. If the lateral lighting increases too sharply, this will give rise to the appearance of epicormic branches detrimental to the quality of the future wood.

VARIATION IN MEAN DIAMETER (D_g) AS A FUNCTION OF AGE AND FERTILITY INDEX
AFTER APPLYING THE YIELD TABLE RECOMMENDATIONS (MAITRE 1983)

| I_p | E_1 | E_2 | E_3 | E_4 | E_5 | E_6 | E_7 | R |
|-------|-------|-------|-------|-------|-------|-------|-------|----|
| 5 | 9 | 18 | 30 | | | | | 38 |
| 6 | 7 | 12 | 21 | 33 | 48 | | | 65 |
| 7 | 5 | 9 | 15 | 23 | 33 | 45 | | 60 |
| 8 | 4 | 7 | 11 | 17 | 24 | 32 | 42 | 55 |



The imperative rules are the following (SOUVANNAVONG, 1983):

- a felling cycle of over 3 years in young stands and 5 years in old stands,
- a basal area felling rate of less than:
 - * 40% before the age of 12 years,
 - * 30% between 12 and 25 years;
 - * 25% after the age of 25 years.

If the forest manager wants to obtain high exploitable diameters, the thinning schedules are as follows:

THINNING SCHEDULES FOR DIFFERENT FERTILITY LEVELS

| Thinning operation | Fertility level | | | | |
|--------------------|-----------------|-------|-------|-------|-------|
| | 1 | 2 | 3 | 4 | 5 |
| 1 N ave (stems/ha) | 1 450 | 1 450 | 1 450 | 1 450 | 1 450 |
| Age (years) | 3 | 4 | 5 | 6 | 9 |
| Ave dg. (cm) | 10.5 | 11.0 | 11.0 | 10.7 | 10.9 |
| 2 N ave (stems/ha) | 750 | 750 | 750 | 750 | 750 |
| Age (years) | 6 | 8 | 10 | 13 | 20 |
| Ave dg. (cm) | 16.4 | 16.9 | 16.6 | 16.1 | 18.0 |
| 3 N ave (stems/ha) | 400 | 450 | 450 | 450 | 450 |
| Age (years) | 10 | 12 | 16 | 23 | 35 |
| Ave dg. (cm) | 24.0 | 22.7 | 22.7 | 22.7 | 22.7 |
| 4 N ave (stems/ha) | 250 | 300 | 300 | 300 | 300 |
| Age (years) | 15 | 19 | 24 | 35 | 55 |
| Ave dg. (cm) | 32.4 | 30.6 | 29.7 | 29.5 | 30.0 |
| 5 N ave (stems/ha) | 165 | 200 | 210 | 200 | |
| Age (years) | 20 | 26 | 32 | 47 | |
| Ave dg. (cm) | 40.6 | 38.7 | 36.8 | 37.2 | |
| 6 N ave (stems/ha) | 115 | 140 | 155 | | |
| Age (years) | 27 | 35 | 41 | | |
| Ave dg. (cm) | 49.9 | 47.5 | 45.7 | | |
| Clear felling: | | | | | |
| N ave (stems/ha) | 85 | 105 | 120 | 140 | 225 |
| Age (years) | 37 | 44 | 49 | 62 | 68 |
| Ave dg. (cm) | 59.9 | 55.3 | 50.2 | 45.2 | 35.1 |

(N ave: density before thinning. Dg: diameter of the tree with the average basal area).

The manager may also envisage the possibility of choosing lower harvesting ages. The last thinning operation may be eliminated and the final harvest (clear felling) carried out earlier.

Depending on the manager's objectives, the silviculture recommendations have the following features:

- a thinning schedule with from 3 to 6 thinnings depending upon fertility and exploitable diameter;
- a felling cycle of between 3 and 12 years depending on fertility and stand age;
- an exploitable age ranging from 35 to 68 years depending on fertility and exploitable diameter.

The productivity of Teak plantations is conditioned in the first place by the "fertility level" of the sites concerned. The productivity gradient is closely dependent on the rainfall regime. The highest production figures are recorded in the closed forest zones where the rainfall is highest and best distributed.

SILVICULTURE RECOMMENDATIONS AND PRODUCTIVITY DATA FOR TEAK

| Fertility | Number of thinnings | Exploitability | | | Mean increment | |
|-----------------------------|---------------------|----------------|---------|------------------------|----------------|---------------------------------------|
| | | Age (yrs) | Dg (cm) | V (m ³ /ha) | Final harvest | Total harvest (m ³ /ha/yr) |
| LARGE EXPLOITABLE DIAMETER | | | | | | |
| 1 | 6 | 37 | 60 | 363 | 9.8 | 15.8 |
| 2 | 6 | 44 | 55 | 360 | 8.2 | 12.8 |
| 3 | 6 | 51 | 50 | 315 | 6.2 | 9.7 |
| 4 | 5 | 62 | 45 | 276 | 4.5 | 6.9 |
| 5 | 4 | 68 | 35 | 229 | 3.4 | 4.8 |
| MEDIUM EXPLOITABLE DIAMETER | | | | | | |
| 1 | 5 | 35 | 55 | 401 | 11.5 | 16.1 |
| 2 | 5 | 40 | 50 | 372 | 9.3 | 13.2 |
| 3 | 4 | 45 | 45 | 309 | 6.9 | 10.0 |
| 4 | 4 | 56 | 40 | 290 | 5.2 | 7.1 |
| 5 | 3 | 55 | 30 | 205 | 3.7 | 5.0 |

(V: Volume of mainstem in m³/ha)

The productivity of Teak plantations varies between 5 m³/ha/year and 16 m³/ha/year.



Fuelwood-gathering on Teak plantations

In the closed forest zone, the mean increment in mainstem volume is between 10 and 16 m³/ha/year. This is in fact the zone where Teak grows best. In the pre-forest zone the stands have a medium rate of growth. Their mean volume increment is between 7 and 10 m³/ha/year. In the savannah zone, the rate of growth is low. The mean volume increment is between 5 and 7 m³/ha/year.

The silviculture recommendations for the various reforestation zones are thus based on a compromise between size, exploitable age and productivity.

ROTATION CRITERIA FOR TEAK REFORESTATION PLANTATIONS
IN RELATION TO FOREST ZONES

| Forest zone | Moist closed forest | Pre-forest area | Guinean savannah |
|--|---------------------|-----------------|------------------|
| Exploitable diameter(cm) | 45 to 60 | 40 to 45 | 30 to 40 |
| Exploitable age (years) | 35 to 50 | 45 to 60 | 55 to 70 |
| Mean increment (m ³ /ha/year) | 10 to 16 | 7 to 10 | 5 to 7 |

The final harvest constitutes approximately 70 percent of the total yield.

1.2 - Okoumé (Aucoumea klaineana)

The Okoumé's which is a member of the Burseraceae family, is a species native to the moist evergreen equatorial forest (Gabon, Congo, Equatorial Guinea).

In Okoumé's original range, rainfall varies from 1 500 to 3 500 mm/year, the dry season lasts 1 to 3 months and altitude ranges from 1 to 600 metres.

It is a sun-loving, gregarious and social species that colonizes gaps and clearings. In natural forest, it grows in clumps or scattered spinneys; free-standing trees are rare.

Under closely spaced conditions, single-species stands of Okoumé become ranked in tiers, separating into several storeys from the age of 10-15 years.

On plantations, individual trees subject to heavy competition develop a stunted crown; sudden exposure of the trunk to light (windrow, heavy thinning) gives rise to an explosive outgrowth of epicormic branches, frequently accompanied by a drooping crown.

In its area of origin, this species bears fruit in the rainy season (December-January), starting from the age of 10-15 years. The fruit (10 000 seeds/kg) is a drupe that ripens about three months after flowering. In Côte d'Ivoire, the Okoumé sets fruit at around 9-10 years of age. It has two fruiting periods, one in February-March and the other in August-September.

The roots of this species, which consist of a taproot in young plants, develop very rapidly into creeping roots with anastomotic formations. The Okoumé has a very good stump sprouting ability up to the age of 10-15 years. It can be propagated by cuttings and by bottle grafting.

Its soft, light wood ($D_{12} = 0.4/0.5$) dries easily, with low to medium shrinkage. Peeling for veneering, which is the chief use of this wood, can be carried out without difficulty after controlled seasoning. It is ideal for plywood, and is also used for indoor woodwork and furnishings.

In tree nurseries psyllid attacks are frequent, above all in the rainy season (preventive and curative treatments with Vamidothion).

Okoumé plantations, stands on former clearings and stands subject to very brutal thinning often suffer from attacks of black canker. This is a complex infection that combines a primary attack (bites) by scale carried by Sangounas ants (*Wassmania europunctata*, *Creamtogaster* spp., ...) with a secondary attack by fungi (*Botryodiplodia theobromae*). It is accompanied by dripping sap and the external proliferation of smut fungus which blacken the bole and branches.

SILVICULTURAL RULES

To reduce black canker problems, plantations on former clearings heavily infested with Sangounas ants are to be avoided in all cases. Preference for Okoumé should be on totally cleared primary or secondary forestland: planting immediately after clearing.

In consideration of tree shape, planting densities of the order of 1 100 stems/ha should be chosen to allow the selection of a sufficient number of well-formed trees to reach full maturity.

At the age of one year, the mean total height is approximately 0.75 m, at two years it is 1.5 m, at three years 3 m, and at ten years, 15 m.

The recommended thinning schedule involves vigorous thinning operations in the early years. It is in fact hard to salvage young Okoumé trees that have been poorly cultivated (in overcrowded stands or with uncontrolled regrowth): they are puny and misshapen, and are frequently infested by black canker when they are suddenly exposed to light by heavy thinning or spacing. The thinning schedule is as follows:

- 4-5 years : thinning-out to bring density down to 300-350 stems per hectare;
- 9-12 years : first thinning operation to reduce plantation density to 200-250 stems/ha. This involves spacing out the trees scheduled for full maturity (100 stems/ha) and thinning the rest of the stock, following two imperative rules with regard to the latter:
 - . preservation of the well-shaped, well-grown stems in the co-dominant storey that do not compete with the trees scheduled for full maturity;
 - . preservation of a girdle of dominated trees around the trees scheduled for full maturity, so as to protect the latter's trunks from excessive sunlight.

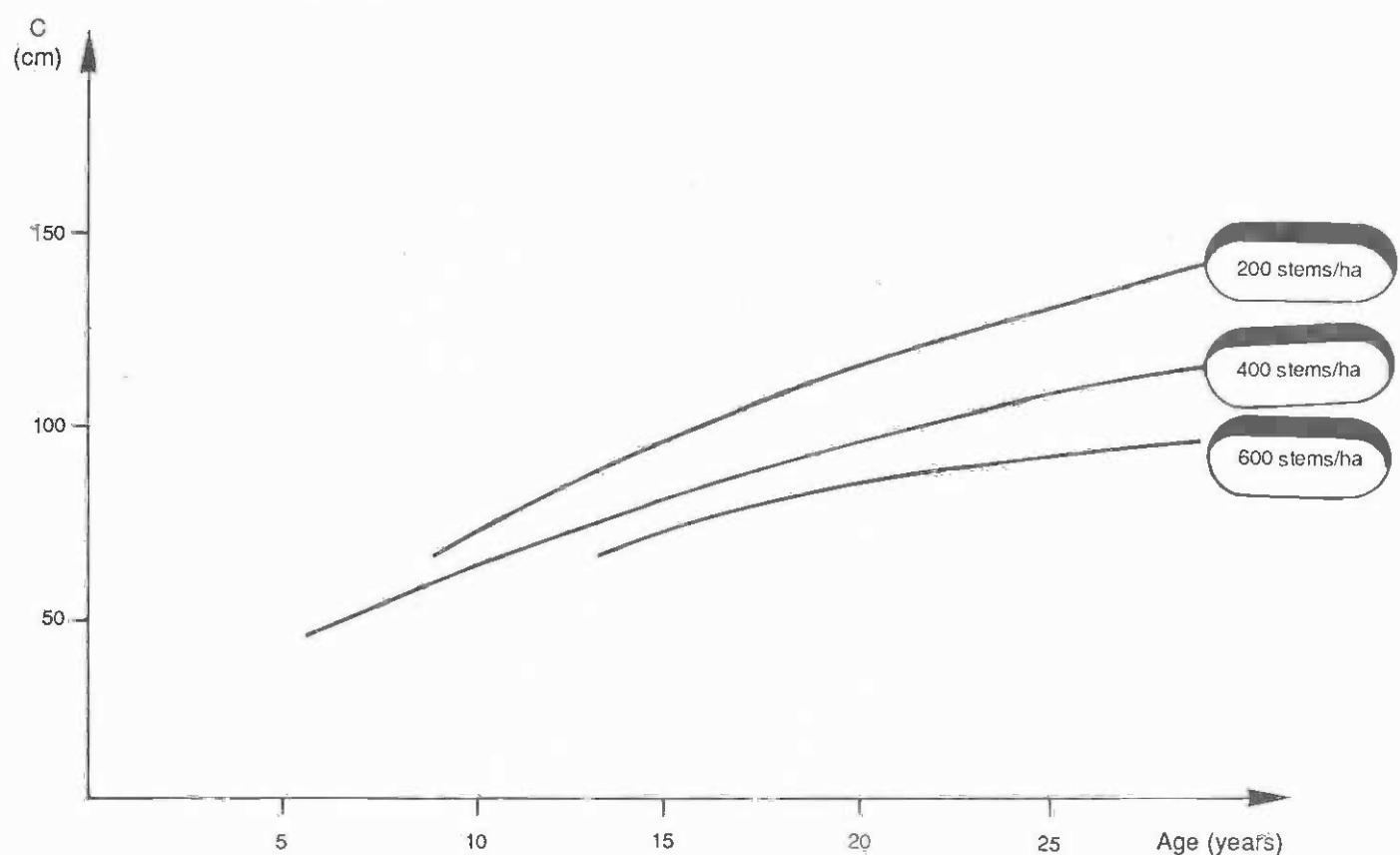
Before thinning, the mean total height is 13-15 metres, the mean circumference is 55-60 cm and the basal area 10 to 12 m²/ha.

- 14-16 years: a second thinning operation to reduce density to 150 stems/ha, about 100 of which are to be trees scheduled for maturity in the dominant storey. This thinning will be based essentially on tree shape, and care will be taken to limit competition between the trees scheduled for maturity and the rest of the stock.

Before thinning the mean total height will be 20-22 metres, the mean circumference 90-100 m and the basal area 16 to 18 m²/ha.

The maximum mean volume increment is attained around the age of 28-30 years, and is of the order of 14 m³/ha/year. A rotation cycle of 40 years is foreseen for an exploitable diameter of 60 centimetres.

VARIATION IN MEAN GIRTH AS A FUNCTION OF DENSITY AND AGE FOR OKOUME IN THE MOIST EVERGREEN FOREST ZONE



1.3 - Niangon (*Tarrietia utilis*)

The Niangon, which belongs to the Sterculiaceae family, is a moist evergreen forest species native to West Africa. Its range extends from Sierra Leone to Ghana, with mean annual rainfall over 1 800 mm/year and a dry season of less than three months.

It is a gregarious species, sun-loving but able to bear some degree of cover, although under these conditions its growth is decreased.

In natural stands, Niangon never grows very big: it is unusual to find individual trees with diameters exceeding 0.8 to 1 m.



Niangon growing free of cover, 14 years old (1976);
Yapo forest

The fruit is a samara. The tree sets fruit in December-January, and sometimes again in June-July. Heavy fruiting takes place once every two to four years.

The wood, of a pinkish-brown to reddish-brown hue, is light to semi-light ($D12 = 0.6-0.7$), of medium hardness (soft to semi-hard), and medium

nervosity. Its mechanical properties (transversal and axial cohesiveness) are in the medium range.

Seasoning must be gradual to avoid warping. The wood's natural durability is average and its impregnability is poor.

Its characteristics make it a desirable wood for cabinet-making, veneering, decoration, and indoor and outdoor woodwork.

This species is subject to attack by many insects, especially coleoptera (bud borers) and lepidoptera (bud and trunk borers, defoliators). The impact of these attacks is generally slight and in no way prejudices the future of the stands. Locally, in some elderly stands, there may be internal bole rot.

SILVICULTURAL RULES

Niangons are traditionally planted out at the age of 1 or 2 years, as tall bare-rooted saplings 1 to 2 m high. However, trials with bagged plants only a few months old have given satisfactory results, on the condition that adequate care is provided.

Niangon growth-rate is average: at 1 year the mean total height is 0.5 to 1 m, at 2 years it is 1.5 to 2 m, and at 3 and 4 years it is 3-3.5 and 4-4.5 m respectively.

Because of its gregarious temperament and certain shape problems, a planting density of 1 100-1 500 stems/ha is recommended.

Unlike many other species, the Niangon can stand crowding very well. At age 40, the average increment in the diameter of the largest 150 stems/ha is 1 cm/year, regardless of the density (SOUVANNAVONG, 1978).

The recommended schedule is as follows:

At 6-8 years, thinning-out to bring the density down to 700-800 stems/ha when the average height is 8-10 m.

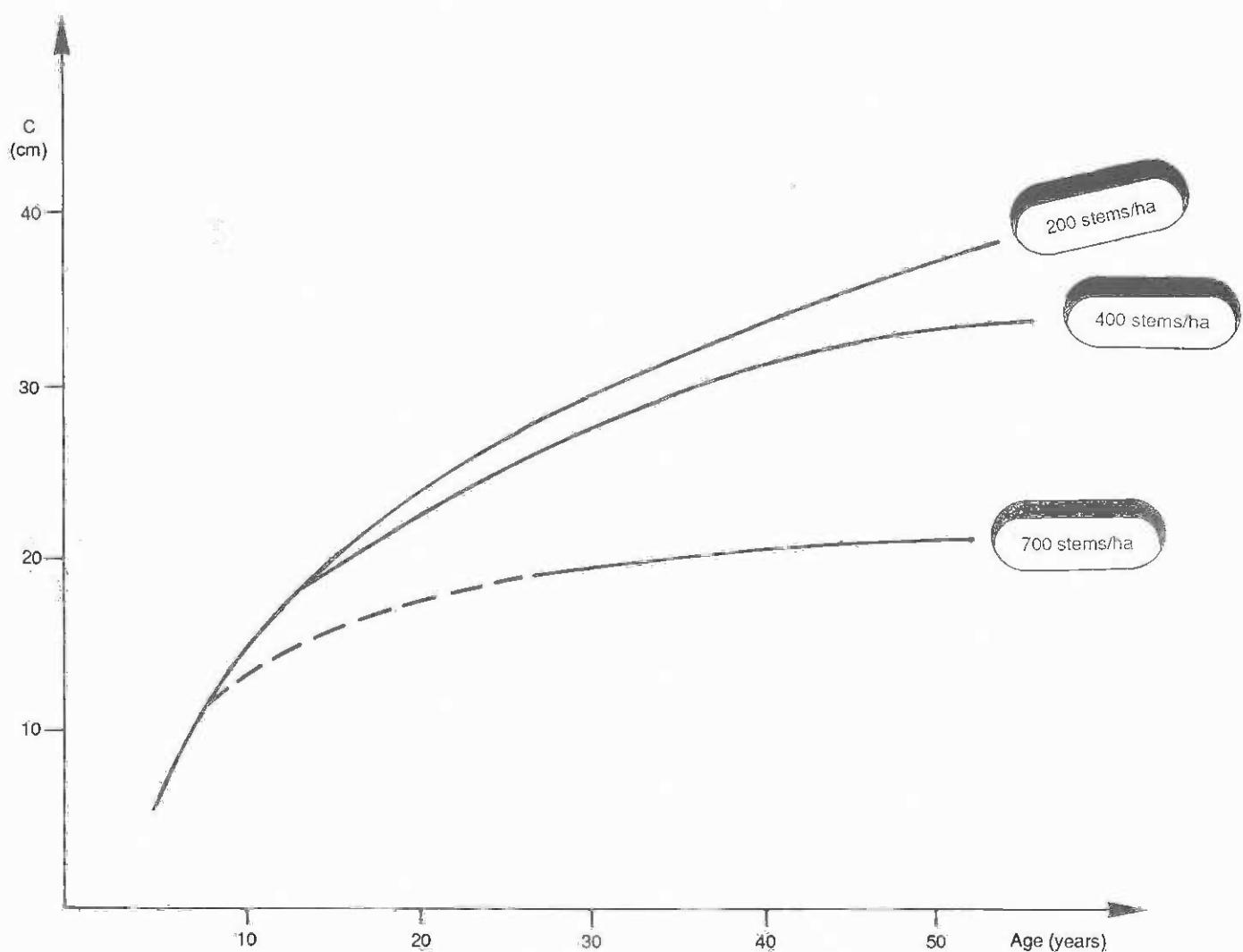
At 12-14 years, thinning to reduce density to 400-450 stems/ha. The mean diameter before thinning is 14-16 cm.

At 50 years, at this density, the basal area is 35 to 40 m²/ha, the mean diameter 35 to 40 cm and 150 stems/ha have reached the exploitable diameter of 50 cm. The total volume of merchantable volume (diameter > 7 cm) is then 550 to 600 m³ per hectare, 400 m³/ha of which consists of stems that have reached the mature exploitable diameter.

At around 18-20 years, a second thinning to lower density to its final level of 200 to 250 stems/ha. The mean diameter before thinning is 20 to 22 cm.

For an exploitable diameter of 50 cm, the harvesting age is 50 years.

VARIATION IN MEAN DIAMETER AS A FUNCTION OF AGE AND DENSITY FOR NIANGON



1.4 - Badi (*Nauclea diderrichii*)

The Badi or Bilinga belongs to the Rubiaceae family. It is an evergreen species native to moist evergreen forests and transitional to moist semi-deciduous forests. The Badi reaches a total height of 30 to 40 m and a diameter of 0.90 to 1.20 m, with a slender, straight, branchless, cylindrical bole rising to a height of 20 to 30 m.

This species is found from Sierra Leone to Cabinda and eastwards as far as Uganda. Rainfall varies in its range from 1 600 mm/year to 3 000 mm/year.

This sun-loving species has a broad spherical crown and thick foliage. It regenerates abundantly in gaps and openings. On plantations in the evergreen zone (Yapo and l'Abbé in Côte d'Ivoire) many naturally regenerated trees colonized the gaps and slope bottoms. On permanently hydromorphic soils it gives way to the Bahia (*Mitragyna ciliata*).



6 year-old Badi growing free of cover (1984); Yapo forest

The fruits are fleshy, fibrous cylindrical masses 3 to 4 cm in diameter and covered with polygonal honeycomb pits. Fruit-setting takes place in October-November. There are about 250 fruits/kg.

The wood is yellow and darkens slightly when exposed to light. It is semi-heavy ($D_{12} = 0.7$) and of medium hardness (semi-hard); its shrinkage and nervosity are average. Its mechanical properties, durability and impregnability are good. Thanks to its good mechanical properties and good natural durability (which can be enhanced by a preservative treatment) it is sought after as timber for outdoor uses (harbour works, railway sleepers), building (carpentry, floors, facings, indoor and outdoor woodwork), for slicing and for cabinet-making. On young plantations, infestation with bud-boring caterpillars (*Orygmophora mediofoveata*) is frequent, without however seriously affecting the growth of the stands.

SILVICULTURAL RULES

The seeds must be sown early, 6 to 8 months before planting out, as the seedlings' growth is often irregular. Because of the very small size of the seeds, they must be sown in seed beds. The seedlings are pricked out about a month after germination began. This species is very easy to propagate by cuttings.

The initial recommended plant density is 1 100 stems per hectare.

This is a full sunlight species with average growth. At 1 year the total mean height is 1.2 to 1.7 m, at 2 years it is 2.5 to 3.0 m, and at 4 years it is 6 to 7 m.

The young saplings are often multi-stemmed, and the secondary stems must be eliminated in the early years by pruning.

The silvicultural rules of thumb are as follows:

- A first thinning at the age of about 5 years reduces density to 400/500 stems/ha. Before thinning, the mean height is 11 to 13 m, the mean diameter is around 10 cm and the basal area 6 to 8 m²/ha.
- The second thinning at the age of about 9 years reduces density to 200/250 stems/ha. Before thinning, the mean height is 16 to 18 m, the mean diameter is 16 to 18 cm and the land area is 9 to 10 m²/ha.
- The third thinning is done when the trees are about 15 years old and the basal area approximately 12 m²/ha. One stem out of three is removed. The mean diameter before thinning is about 25 cm.

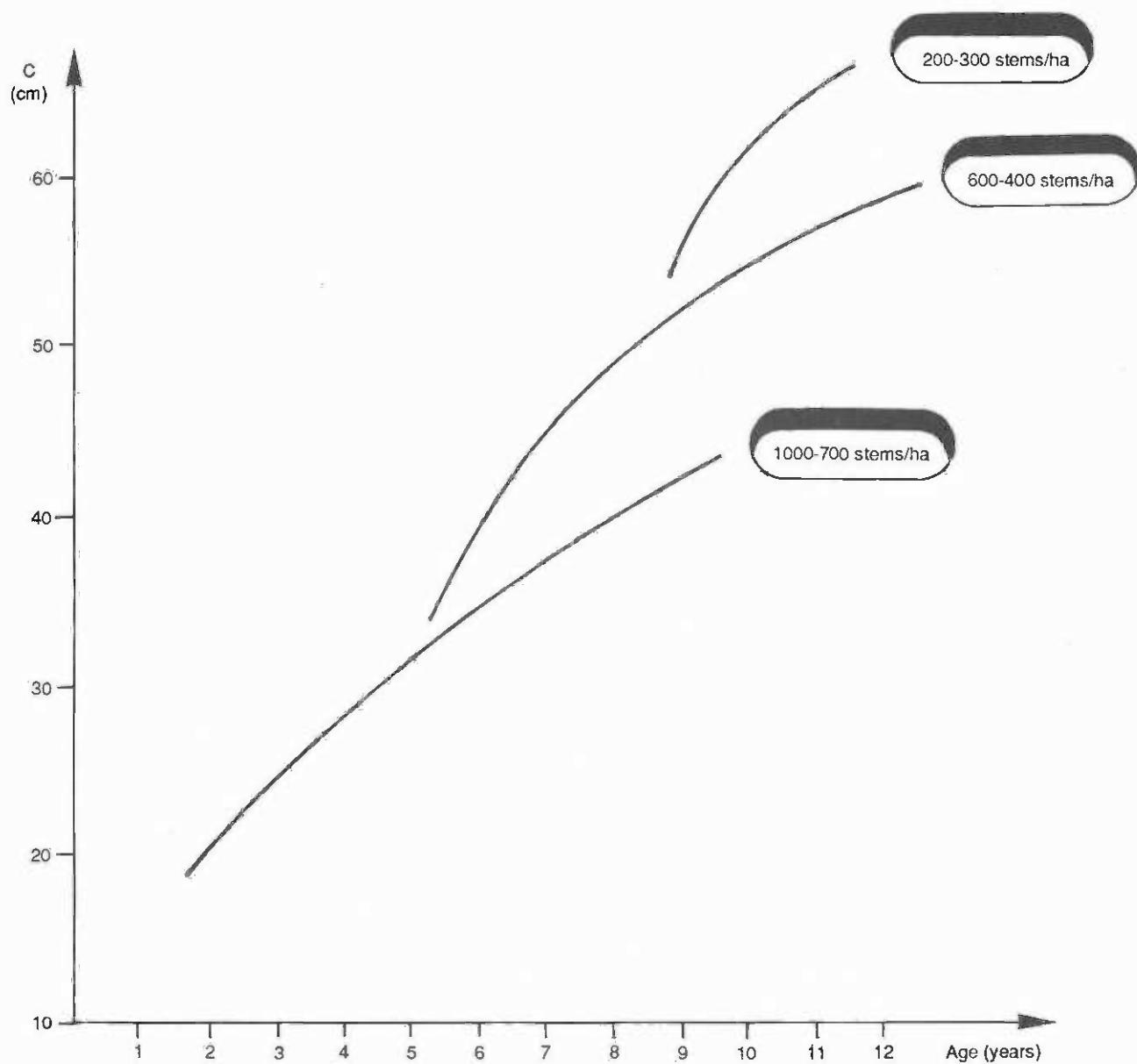
The rotation cycle ranges from 30 to 40 years for an exploitable diameter of 50 cm.

1.5 - Mahogany

Several different species belonging to the *Khaya* genus (Meliaceae family) are grouped together under the name "Mahogany":

- * *Khaya ivorensis* (Bassam mahogany), a moist evergreen forest species;

VARIATION IN MEAN GIRTH AS A FUNCTION OF AGE AND DENSITY
IN THE MOIST EVERGREEN FOREST ZONE FOR BADI



- *Khaya anthotheca* (white mahogany), a transitional moist evergreen forest/moist semi-deciduous forest species;
- *Khaya grandifoliola* (broadleaved mahogany), a semi-deciduous forest and Sudanese gallery-forest species;
- *Khaya senegalensis* (bastard mahogany), a Sudano-Guinean and Guinean species.

The Mahoganies have a very extensive range. The bastard mahogany is found from Senegal to Cameroon, Central Africa and Uganda. The ranges of the other Mahoganies correspond roughly to the moist semi-deciduous and evergreen forest formations of West and Central Africa.

The fruits are globulous woody capsules borne upright on top of the tree's crown. Their diameter varies from one species to another: 4-7 cm in the case of *Khaya ivorensis* and 6-10 cm in that of *Khaya anthotheca* and *grandifoliola*. The dehiscent fruits split into 4-5 superior valves joined together at the base.

The winged seeds are of medium size (4 to 5 cm long and 2 to 3 cm wide). The main flowering season extends from August to December and the corresponding fruit-setting runs from January to April. The trees may fruit twice a year, with the second fruiting occurring in July-September.

The bastard mahogany, which is a savannah species, is a medium-sized tree 15 to 20 m in height, frequently with a sinuous bole. The other Mahoganies are tall trees that reach a height of 35-45 m, with conical crowns and foliage growing in tufts. The bassam mahogany generally has a straight trunk, whilst that of the white mahogany may be winding and has massive buttresses.



10 year-old stand of Mahogany; Yapo forest

The wood, which ranges in hue from pink to crimson, is soft (bassam mahogany) to semi-hard (broadleaved mahogany), semi-heavy (D12 = 0.5 for bassam mahogany, 0.6 for white mahogany, 0.7 for broadleaved mahogany). Its mechanical properties are low (bassam mahogany) to medium (broadleaved mahogany and white mahogany).

Durability is medium to good, with low impregnability. The wood is easy to season and to work. Its technological characteristics make it a highly desirable wood for cabinet-making, slicing, veneering (peeling), furnishings, decoration and joinery.

SILVICULTURAL RULES FOR BASSAM MAHOGANY

The fruits are sometimes infested by microlepidoptera caterpillars that destroy the seeds.

The seeds are sown in seed-beds and the seedlings are pricked out in nursery beds for subsequent planting when they reach the age of 1 or 2 years, as saplings 1.2 to 1.5 m high.

Bagged plants a few months' old are another possibility.

The chief constraint to growing Mahogany is the destruction of the terminal shoots by the larvae of the microlepidopters *Hypsipyla robusta* and, to a lesser extent, *Gyroptera robertsii*, commonly known as "mahogany borers".

The destruction of the terminal bud causes the lateral buds to sprout into growth, with consequent forking.

The time when these attacks occur varies from one stand to another. As a general rule, they appear between the ages of 1 and 3 years. The infestation spreads very rapidly, and generally affects all trees aged 3-4 years. However, in these infested stands a small number of well-shaped, fast-growing trees (6-8 m high at 4 years) can be observed. The infestation heavily affects the trees' growth up to the age of 10-15 years, after which their impact on growth tends to decrease.

However, the case of the N'Zida plot (Côte d'Ivoire, 1952), which suffered no attacks worthy of mention, is worth noting.

As an indication, the following values have been recorded on some experimental plots:

| Health status | Silvicultural parameters | Age (years) | | | | | | | |
|----------------|-----------------------------|-------------|-----|---|-----|-----|----|----------|----|
| | | 1 | 2 | 3 | 4 | 5 | 10 | 15 | 19 |
| Healthy plots | Height (m) Diameter (cm) | | | | 8 | 10 | | 24 30 | 42 |
| Infested plots | Height (m) Diameter (cm) | 1 | 2.2 | 3 | 3.5 | 4.5 | 10 | 15 | 28 |

Stands of pure Mahogany with no cover, of both high and low stem density, are attacked by borers at a very early age, often even before the saplings are one year old.

Two solutions can be envisaged for the establishment of Mahogany plantations:

- Plantations sheltered by Leucaena leucocephala at a density of 700 stems/ha

In the year before planting, the Leucaena is sown in rows. In the planting year, the Leucaena is cut back before the Mahogany is planted out. Until the saplings exceed the Leucaena's height, the latter is regularly cut back or well thinned out so as to keep the cover light.

The Mahogany trees are attacked when they emerge from the Leucaena cover (age 4/5 years); their mean height is 4/5 m. Leucaena maintenance makes it possible to keep adventitious vegetation under effective control.

The final density will be 70-80 stems/ha with a rotation cycle of approximately 40 years (exploitable diameter 60 cm). The average strong wood volume increment is 6-8 m³/ha/year.

- Mixed plantations

Grown in association with species whose initial growth is slow such as Niangon, Okoumé or Badi, a certain number of Mahogany stalks, in spite of parasite attacks, grow sufficiently well to ensure that they stay in the dominant storey and develop a buttlog length of about 10 metres.

The success of this type of mixed plantation is the result of a compromise between:

- on the one hand, the relatively slow growth of the borer-infested Mahogany trees;
- and on the other, the association with initially slow-growing species.

The silvicultural regime applied is to grow Mahogany with other trees, the aim being to obtain some well-shaped Mahogany trees in the midst of a stand where the other species predominates (see the paragraph on mixed stands).

There is no method of fighting mahogany borers that is suitable for application on an industrial scale. Chemical treatments (Methidathion) are only feasible in nurseries.

Behaviour trials with various provenances of bassam mahogany have not revealed any interprovenance differences with regard to susceptibility to borer attacks.

At the present state of knowledge, the only feasible solutions for Mahogany plantations are those described above, but with no real certainty of success.

1.6 - Sipo (*Entandrophragma utile*)

The Sipo, which belongs to the Meliaceae family, is a gregarious, half-shade, slow-growing species native to moist semi-deciduous forests.

In its natural range, annual rainfall varies between 1 400 mm and 2 500 mm per year. The Sipo is found essentially in Côte d'Ivoire, Ghana, Nigeria, Cameroon, the Central African Republic and Congo.

The fruit is a capsule 18 to 28 cm long and 5 to 7 cm wide, with 5 thick valves and 5 or 6 seeds per compartment. The Sipo sets fruit once a year in February-March, and the fruit is always abundant.

The wood, of a pinkish-brown colour, is semi-heavy ($D_{12} = 0.6$), fairly soft and shrinkage is average. Its mechanical properties range from poor to average. Its natural durability is average; it is hard to impregnate and easy to season. Sipo wood is much sought-after for indoor and outdoor woodwork, cabinet-making, slicing and peeling.

The chief problem with Sipo plantations is, on some plots, the withering of the terminal bud, which stops the growth of the main stem and is accompanied by lateral branching and the formation of a broad flat crown.

SILVICULTURAL RULES

In natural forest, the mean increment in diameter remains constant up to the age of 200 years at about 0.5 cm/year. The large-diameter natural forest trees that are traditionally exploited for timber are often 300 years old or more. In the case of trees with a diameter of 60 cm, the percentage of sapwood ranges from 20 percent to 35 percent, with an average of 28 percent.

The Sipo is a species that requires a certain amount of cover when young.

The seeds are sown directly into pots because of the fragility of the root system, which is essentially of the taproot type. Particular care is needed in handling the plants. Germination takes from 15 days to 1 month.

The seedlings are bedded out between 6 weeks and 2 months after sowing. It is imperative that bedding-out be done before the seedlings' taproot has had time to develop a crook. Treatment with auxins (AIB) improves root development.

The plants subsequently remain in the nursery beds for 1 or 2 years, depending upon when and if they attain the dimensions required for planting-out, namely:

- height between 80 cm and 1 m;
- collar diameter between 2.5 cm and 3.5 cm,
- annual height increment at 1 year between 50 and 60 cm.

The ideal sapling for planting purposes is a 1-year-old rosette with a good root system. When trimming the roots, a length of 30 cm should be left on the taproot and 15 cm on the lateral roots.

Stumping must be avoided, as the taproot system cannot grow back easily. The slow initial growth rules out the use of small-sized bagged plants in favour of carefully selected larger saplings grown in nurseries. Every care must be taken when rearing the plants to make sure they do not develop crooks.

The initial growth-rate on plantations is slow: at 10 years, the mean height increment is 0.8 to 1 m/year and the mean diameter increment for 100 stems to be grown to maturity is 1 to 1.2 cm/year. Amongst these stems, about 30 stems/ha have a diameter increment of 2 to 2.5 cm/year.

In old stands a decrease in the growth-rate can be noted. At 30 years, the mean diameter increment drops to only 0.5 cm/year with a mean height increment of 0.5 m/year. The Sipo is definitely a slow-growing species.

Sipo plantations involve considerable problems. This slow-growing species requires from the second year onwards a progressively increasing exposure to light to stimulate initial growth (GOUDET - WENCELius, 1974).

As in the case of Mahogany, planting under cover of Leucaena sown in rows a year before the year in which the Sipo saplings are planted ensures a good recovery rate and the satisfactory initial growth of this half-shade species whilst also keeping regenerative growth under control. The Leucaena plants should be cut back for the first time before the second rainy season and subsequently at regular intervals until the Sipo crowns break free of the regrowth.

On plantations, Sipo trees grow best in the moist evergreen forest zone (Abbé, Anguédédou, Irobo: Côte d'Ivoire) than in the semi-deciduous closed forest zone (Oumé, Gregbeu: Côte d'Ivoire).

1.7 - Ilomba (*Pycnanthus angolensis*)

The Ilomba belongs to the Myristicaceae family. It is found in moist forests from West Africa to Uganda and Tanzania.

This tree is mainly to be found in scattered fashion in the secondary formations of evergreen and semi-deciduous forests. The boundaries of its natural range correspond to a minimum annual rainfall of 1 300 mm and a dry season of less than 6 months.

The oblong fruit is a drupe that opens into two fleshy valves. It contains a black seed covered with a pink laciniated aril. Flowering takes place in September-November and fruiting in January-February.

The white-coloured wood is light (D12, 0.50), very soft, of medium nervosity and shrinkage. Its natural durability is low, but it is easy to impregnate. Its mechanical properties are medium and it is easily machined. During seasoning the wood sometimes warps.

This soft, easily worked and straight grained wood is used for veneer-peeling, panels, furniture frames, box-making and minor joinery.

The young plant very rapidly grows a large taproot whose development must be checked in the nursery. Care must be taken to avoid cutting the taproot if it is large, because its destruction greatly reduces the plant's rate of growth. The use of stumped plants must be avoided, in favour of seedlings in large bags.

SILVICULTURAL RULES

The Ilomba is a sun-loving species with a medium rate of initial growth. It reaches the height of 0.5 m at one year and 3-4 m at 4 years. At the age of 10 years the average height is 12-15 m, and reaches 20-25 m at age twenty.

The natural pruning of this species is inadequate and is accompanied by the formation of large verticillate scar ridges. Early artificial pruning is therefore to be recommended.

The recommended planting density is 1 100 stems/ha. The first thinning should be carried out when the trees are about 7 years old to reduce the density to 300-350 stems/ha. Before thinning, the mean diameter is about 15 cm.

Toward the age of 12 years a second thinning reduces density to 150-200 stems/ha. The mean pre-thinning diameter is around 20 cm. When the trees are aged about 20 a third and last thinning reduces density to 70-90 stems/ha. The mean pre-thinning diameter is 30 cm.

On good evergreen forest sites, the exploitable diameter of 50 cm is reached around the age of 30 years and that of 60 cm toward 45 years. At age 15, the mean volume increment is 15 m³/ha/year. At age 30, it is 10 m³/ha/year (DUPUY, 1983).

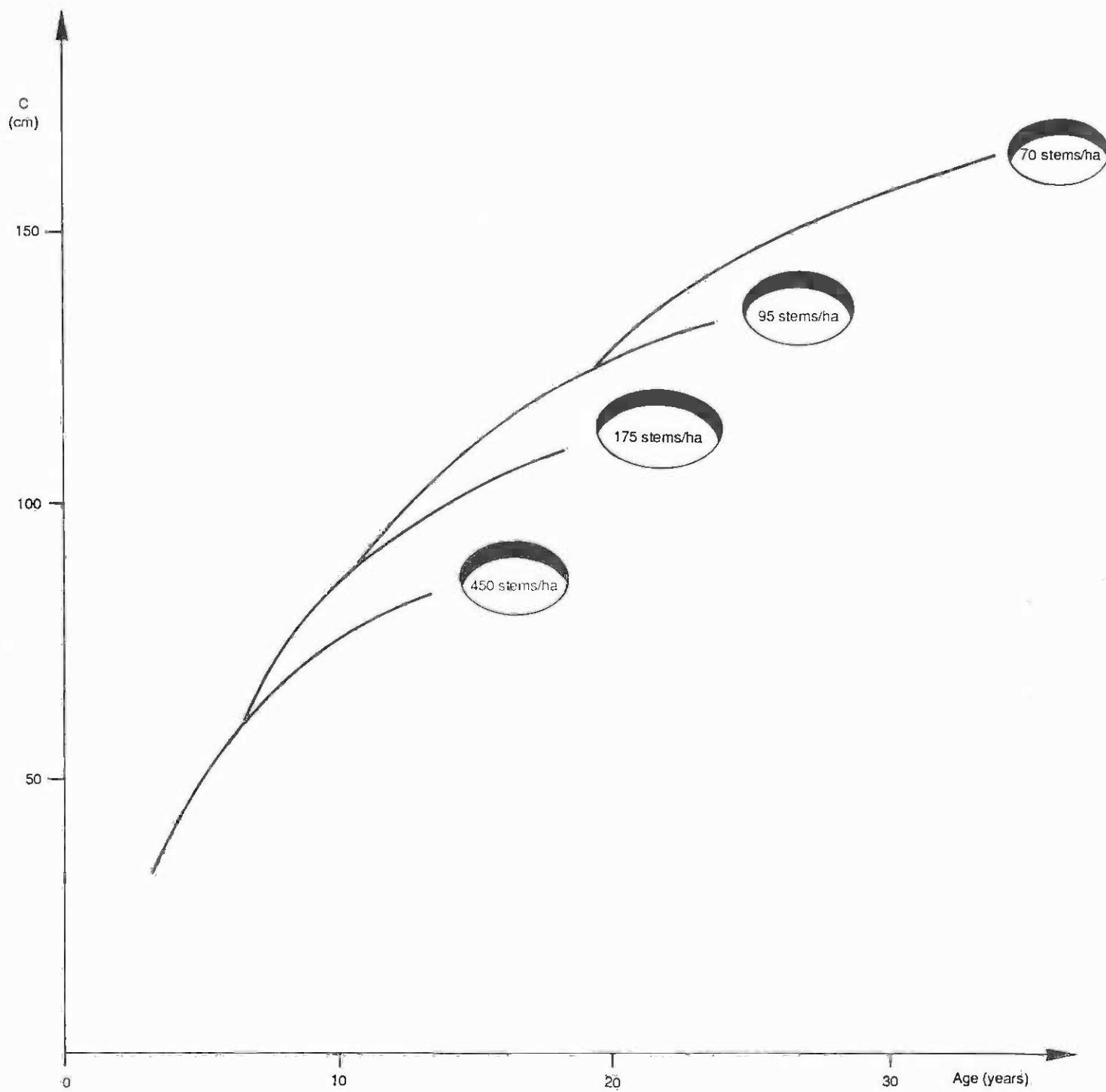
1.8 - Azobé (*Lophira alata*)

The Azobé, a member of the Ochnaceae family, is an evergreen species native to the flatland moist evergreen forests (Guinea, Liberia, Côte d'Ivoire, Ghana, Cameroon, Equatorial Guinea, ...). Its range corresponds to an annual rainfall exceeding 2 000 mm/year and a dry season lasting less than 3 months. Under the less favourable ecological conditions of the semi-deciduous forests, it is to be found in the valleys and along the major watercourses (Sangha, Oubangui, ...) where it may form almost pure stands.

The fruit is an achene with two pink wings. The trees flower from November to January and bear fruit from January to March. The root system of the young plants is mixed (taproot/creeping roots).

The Azobé is a sun-loving, gregarious, medium growth-rate species that grows in secondary forests. Like the Okoumé, this gregarious species establishes itself in cleared forest. It has been used since 1926 for enrichment and reforestation operations for the production of fuelwood and building timber in Côte d'Ivoire.

VARIATION IN GIRTH AS A FUNCTION OF AGE AND DENSITY FOR FRAMIRE UNDER AVERAGE FERTILITY CONDITIONS





9 year-old Azobés; Yapo forest

The brownish-red to purplish-brown wood is very heavy ($D_{12} = 0.95 - 1.1$), very hard, with heavy shrinkage during seasoning and good mechanical properties. It is hard to cut to shape and hard to impregnate, but its natural durability is remarkable.

Its properties make it an excellent utility wood (fuelwood, stakes, posts...) and an excellent timberwood for hydraulic uses (sluice gates, harbour works, ...), railway sleepers, mining works, etc.

Traces of gall midge attacks have been observed on the leaves.

SILVICULTURAL RULES

The mean height increment is 1-1.5 m up to the age of 15. At 6 years the mean height is 6-8 m, and 12 years, 16-20 m.

On single-species plantations, the mean diameter increment is 1-1.5 cm/year at age 10.

In natural forest, the mean diameter increment ranges from 0.2 cm/year to 1 cm/year. For an exploitable diameter of 70 m, the estimated age of the natural forest trees is about 90 years.

At 6-8 years, with a density of 1 300 stems/ha, the mean diameter is 8-10 cm, and the mean increment in diameter is 1-1.2 cm.

At 13 years, with a density of 400 stems/ha, the mean diameter is 13-15 cm, with a mean increment of the order of 1.2 cm/year.

At 15 years, with a density of 800 stems/ha, 150 stems/ha have a diameter exceeding 15 cm.

At 24 years, with a density of 360 stems/ha, the mean diameter is 17 cm and 100 stems/ha have a diameter exceeding 20 cm.

The recommended plantation density is 1 100 stems/ha with a first thinning around 6-8 years to reduce density to 500-600 stems/ha. The thinning products can be sold as fuelwood. For an exploitable diameter of 60 cm, the rotation cycle is around 50 years.

1.9 - Makoré (*Thieghemella heckelii*)

The Makoré is a member of the Sapotaceae family. It is one of the largest moist evergreen forest species, and can attain a diameter of 3 m and a height of 50 m.

The Makoré flowers in February-March and its fruits ripen from August to October.

The fruits are ovoid and large: 8 cm long and 7 cm in diameter. They contain two or three large oily seeds. These seeds do not keep well. They must be sown as soon as the fruits fall to the ground, either in nursery beds or by direct sowing. The seeds germinate very easily and the seedlings grow very rapidly in the nursery. Given the large size of the seeds (3 cm x 5 cm) and the rapid growth of the taproot, the plants must be grown in large-sized bags.



Plot of 9-year-old Makoré trees: Yapo forest.

The wood is brownish-pink, of medium density (0.7), and semi-hard. Its nervosity and shrinkage are medium, and it is of good durability. Makoré wood is much appreciated for veneering, outdoor joinery and cabinet-making.

SILVICULTURAL RULES

The Makoré is a sun-loving species that must be planted in full sunlight. The use of a cover plant such as Pueraria may be envisaged to control adventitious vegetation.

At the age of 1 year, the mean height is around 0.5/1 m; at 3 years it is 3 m. and at 7 years it reaches 10 m.

The older plantations were planted under cover. This in fact slows their growth. At 10 years, the mean diameter is 10-12 cm. At 15 years, it is 15-17 cm and at age 25, 25 cm.

For plantations with no cover, the mean diameter at 10 years is 15-18 cm.

The recommended planting density is 1 100 stems/ha (3 m x 3 m), and the first thinning at around 10 years.

For an exploitable diameter of 60 cm the rotation cycle is some 60-80 years.

2. - MEDIUM-ROTATION SPECIES

2.1 - Framiré (*Terminalia ivorensis*)

The Framiré belongs to the Combretaceae family. Its range extends continuously from Guinea to West Cameroon.

It is a transitional moist evergreen forest/moist semi-deciduous forest species. Its range, thanks to forest clearances, tends to expand into the moist evergreen forest zone. The boundaries of this sun-loving deciduous species correspond to a rainfall of less than 1 300 mm/year and a dry season exceeding 4-5 months. It grows up to an altitude of 1 200 m (Cameroon).

The fruit is an elliptical samara measuring 6 to 7 cm in length and 2 cm in width. Flowering begins in April after the new leaves have begun to appear, and lasts until June. The interval between the opening of the leaf buds and flowering is 3-4 weeks. The flowers are fertilized by insects (lepidoptera and diptera). Fruiting, which begins in December, is abundant from January to March.

In the case of natural forest trees, the wood is light (D12 = 0.5), soft, with low shrinkage and medium nervosity. Its transversal cohesiveness is poor and its axial cohesiveness is average. Both natural durability and impregnability are average. The wood is easily seasoned.

The chief uses of this wood are building (indoor and outdoor woodwork, timberwork), the panelling industry (plywoods and coreboards) and cabinet-making.

The Framiré starts bearing fruit at 5-6 years. One kilo of seeds contains approximately 5 000 winged seeds or 10 000 de-winged seeds. To arouse the seeds from their original dormant state (which is probably due to the integument), the seeds should be soaked in cold water for 2 days.

For planting purposes, the use of bagged plants is preferable to that of stumped plants. Cutting the seedling's root system, which is basically of the taproot type, prior to planting will in fact alter its subsequent growth by favouring the development of creeping roots. Moreover, stumped plants grow at a slower rate than bagged plants.

The seeds are frequently attacked by two Curculionidae (*Nanophyes* spp. and *Auletobius kuntzeni*) which can considerably reduce the germination rate.

On saplings, the leaves and young shoots are subject to attack by numerous species (Coleoptera, Lepidoptera, Orthoptera) which can lead to withering of the crown.

On older plantations the following have been observed:

- defoliation by Notodontidae caterpillars (defoliating caterpillars);
- nibbling of the trunk by Coleoptera (Cerambycidae, Bostrichidae) and Lepidoptera (Cossidae, Megalopygidae);
- symptoms of root-rot (*Armillaria*) have also been occasionally reported on some trees.

If no thinnings are carried out the surplus-dominated trees, after a phase of arrested growth lasting several years, gradually die off through a wasting process characterized by a drooping top followed by the withering of the crown and by secondary attacks by insects (scolytids and cerambycidae) and pathogenic fungi.

Detailed study of this wasting process has revealed abnormalities in the cycle of mineral and organic (nitrogen) elements and also alterations in the nutritional balance in the withering trees on plantations. Incidentally, when the decomposition of Framiré roots in the soil was studied in a controlled environment, it was found that the latter have a markedly depressive effect on the growth and nitrogen uptake of young plants (MALLET, 1979).

Lastly, the Framiré happens to be very sensitive to water supply stress. On marginal sites with an unbalanced water supply or after a running fire has passed, withering phenomena can also be observed in standing trees.

These findings show that this sudden withering is linked to the frequently combined action of:

- unfavourable environmental factors (site, water deficiency, fires ...)
- stress from intense competition
- disturbed nutritional balance.



Base of a 25-year-old Framiré; Yapo forest

SILVICULTURAL RULES

The recommended planting density is 700 stems/ha.

The Framiré is a species with average initial growth: at 1 year the mean height is 2/2.5 m, at 2 years it is 5/6 m, at 3 years it is 9/10 m and at 4 years it reaches 12/14 m.

Analysis of height increments reveals that at 15 years the greater part of such growth has already been achieved, and the final harvest stand must already be established. The recommended thinning schedule for plantations grown without cover is as follows:

First thinning:

Should start as soon as the dominant height reaches 11 m; one stem out of two should be removed.

Second thinning:

Reduces the density to 175 stems/ha; before thinning, the mean diameter is 20 cm and the basal area 11 m²/ha.

Third thinning:

Brings the density down to 70 stems/ha; before thinning, the mean diameter is 40 cm and the basal area 12 m²/ha.

A provisional yield table is available for Framiré (DUPUY et al., 1989). There are four site classes. The last thinning is optional, depending upon the target diameter.

| Site classes | 1 | 2 | 3 | 4 |
|---------------------------|----------|----------|----------|----------|
| Exploitable diameter (cm) | 45 50 | 44 48 | 43 46 | 42 45 |
| Number of thinnings | 3 4 | 3 4 | 3 4 | 3 4 |
| Exploitable age (years) | 22 27 | 27 32 | 32 40 | 37 60 |

Two targets have been retained with regard to exploitable diameter: 40 and 45 cm. The following tables indicate the characteristics of the corresponding stands.

HARVEST CHARACTERISTICS AT THINNINGS AND FINAL FELLING

| Target exploitable diameter 40-45 cm | Site classes | | | |
|--|--------------|------|-------|------|
| | 1 | 2 | 3 | 4 |
| <u>First thinning</u> | | | | |
| Age (years) | 3 | 4 | 5 | 6 |
| Number of stems/ha harvested | 361 | 361 | 361 | 361 |
| Harvest volume (m ³ /ha) | (25) | (25) | (25) | (25) |
| <u>Second thinning</u> | | | | |
| Age (years) | 6 | 7 | 8 | 9 |
| Number of stems/ha harvest | 175 | 175 | 175 | 175 |
| Harvest volume (m ³ /ha) | 36 | 44 | 51 | 58 |
| Mean diameter | 17 | 19 | 20 | 21 |
| <u>Third thinning</u> | | | | |
| Age (years) | 11 | 12 | 13 | 15 |
| Number of stems/ha harvested | 85 | 85 | 80 | 80 |
| Harvest volume (m ³ /ha) | 47 | 47 | 45 | 51 |
| Mean diameter (cm) | 26 | 26 | 26 | 27 |
| <u>Final harvest</u> | | | | |
| Age (years) | 22 | 27 | 32 | 37 |
| Number of stems/ha harvested | 90 | 90 | 95 | 95 |
| Harvest volume (m ³ /ha) | 228 | 220 | 214 | 204 |
| Mean diameter (cm) | 45 | 44 | 43 | 42 |
| Total volume produced (m ³ /ha) | 336 | 336 | 335 | 338 |
| Mean increment (m ³ /ha/year) | 15.3 | 12.4 | 10.55 | 9.1 |

HARVEST CHARACTERISTICS AT THINNINGS AND FINAL FELLING

| Target exploitable diameter 45-50 cm | Site classes | | | |
|--|--------------|------|------|------|
| | 1 | 2 | 3 | 4 |
| <u>First thinning</u> | | | | |
| Age (years) | 3 | 4 | 5 | 6 |
| Number of stems/ha harvested | 361 | 361 | 361 | 361 |
| Harvest volume (m ³ /ha) | (25) | (25) | (25) | (25) |
| <u>Second thinning</u> | | | | |
| Age (years) | 6 | 7 | 8 | 9 |
| Number of stems/ha harvested | 175 | 175 | 175 | 175 |
| Harvest volume (m ³ /ha) | 36 | 44 | 51 | 58 |
| Mean diameter (cm) | 17 | 19 | 20 | 21 |
| <u>Third thinning</u> | | | | |
| Age (years) | 11 | 12 | 13 | 15 |
| Number of stems/ha harvested | 80 | 80 | 75 | 75 |
| Harvest volume (m ³ /ha) | 44 | 44 | 42 | 48 |
| Mean diameter (cm) | 26 | 26 | 26 | 27 |
| <u>Fourth thinning</u> | | | | |
| Age (years) | 17 | 20 | 24 | 27 |
| Number of stems/ha harvested | 30 | 25 | 25 | 25 |
| Harvest volume (m ³ /ha) | 37 | 31 | 31 | 33 |
| Mean diameter (cm) | 34 | 34 | 34 | 34 |
| <u>Final harvest</u> | | | | |
| Age (years) | 27 | 32 | 40 | 50 |
| Number of stems/ha harvested | 65 | 70 | 75 | 75 |
| Harvest volume (m ³ /ha) | 214 | 204 | 200 | 188 |
| Mean diameter (cm) | 50 | 48 | 44 | 45 |
| Total volume produced (m ³ /ha) | 356 | 349 | 350 | 352 |
| Mean increment (m ³ /ha/year) | 13.2 | 10.9 | 8.8 | 7.0 |

For an exploitable diameter of 40-45 cm, three thinnings are necessary and the exploitable age is approximately 30 years.

For an exploitable diameter of 45-50 cm, four thinnings are necessary and the exploitable age is approximately 40 years.

The mean increment in strong wood volume ranges from 7 to 15 m³/ha/year.

2.2 - Fraké (*Terminalia superba*)

The Fraké, which belongs to the Combretaceae family, is a deciduous sun-loving species native to the moist semi-deciduous forest. In its natural range, the annual rainfall is 1 000 mm/year to 1 800 mm/year; very locally it may be as high as 2 500 or even 3 000 mm/year (Cameroon, Gabon). The duration of the dry season is 3 to 5 months. The Fraké is found at altitudes between 150 and 600 m.

The leaves are shed in November-February; most trees have grown new leaves before the end of the dry season.

The dates of refoliation and flowering are closely correlated: flowering, which lasts for 2 to 5 weeks, takes place either as the new leaves are appearing or immediately afterwards. "The process of defoliation-refoliation gives rise to the appearance of flowers, doubtlessly as a result of some stimuli such as, for example, the auxins synthesised as budding occurs" (BOUILLET 1984).

The duration of fruiting is variable: from 6 to 9 months. The fruits, which are winged samaras, develop during the rainy season and reach maturity at the beginning of the following dry season. The trees that bear the most flowers are often 25 years old or more. There are approximately 10 000 wingless seeds per kg.

This is a species that can be easily propagated by grafts and cuttings. The root system is basically of the taproot type in young plants, but rapidly develops into a creeping root system with numerous secondary roots.

In the natural forest trees, the white-coloured wood is soft to semi-hard, light ($D_{12} = 0.5 - 0.6$), with low nervosity and low shrinkage. It is used for indoor and outdoor joinery, veneer-peeling, slicing, plywood and interior decorating.

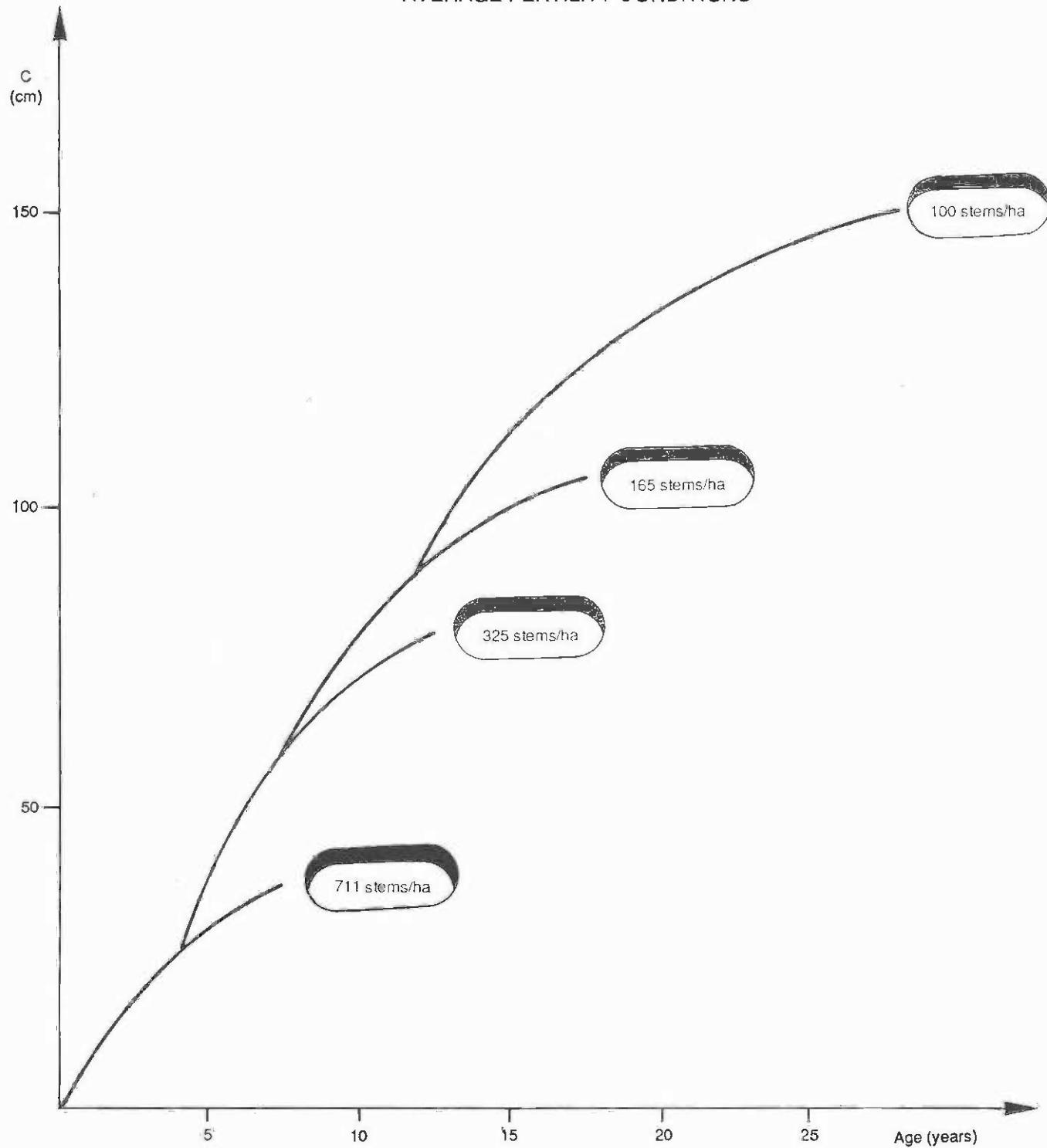
Its mechanical properties are medium to poor: its transversal cohesiveness is poor and its axial cohesiveness is medium. Its natural durability is poor. Seasoning and impregnation are easy.

The density of plantation wood is less than that of natural forest wood.

As regards natural pruning, which is often imperfect, the pruned height at a given age and for a given total height varies according to the provenance. At age 12, with the same total height of 22 m, the pruned height varies from 10 to 15 m depending upon the provenance.

Fraké trees also show interprovenance variability with regard to early shedding of leaves, early shedding being negatively correlated with vigour.

VARIATION IN MEAN GIRTH AS A FUNCTION OF AGE AND DENSITY FOR FRAKE UNDER AVERAGE FERTILITY CONDITIONS



The best provenances are Gregbeu (Côte d'Ivoire), Abofour and Amentia (Ghana), and M'Balmayo (Cameroon). Introduction trials with Limba provenances native to the Southern hemisphere proved disappointing.

The chief phytopathology problems encountered are:

- internal black spotting caused by *Doliopygus* spp.
- infestation by defoliating caterpillars (*Lasiocampides*, *Lymantriides* and *Saturnides*) and grasshoppers (*Zonocerus variegatus*) which destroy the leaves or the terminal shoots.
- internal pockets of black rot due to injuries or defective natural pruning. In particular, the presence of arboreal ants' nests at the level of the verticils can be a contributing factor.
- infestation by cossidae (*Eulophonotus* spp.) at the level of the verticils and pruning stumps.

SILVICULTURAL RULES

A yield table is available for the Fraké (DUPUY et al. 1987).

The recommended planting density is 711 stems/ha. Fraké is a fast-growing deciduous species: the mean total height increment at age 4 is 2.5 m/year, and 2 m/year at age 10.

On sites of average fertility, the rotation cycle is 20-25 years for an exploitable diameter of 45-50 cm.

The recommended thinning schedule is based on three operations:

First thinning: When the dominant height reaches 10 m, and one stem out of two is removed.

Second thinning: When the dominant height reaches 15 m and the basal area 10 m²/ha. Before thinning, the mean diameter is approximately 20 cm. The thinning rate is one stem out of two.

Third thinning: When the dominant height reaches 20 m and the basal area 10-11 m²/ha. Before thinning, the mean diameter is 28 cm. Approximately one tree out of three is thinned.

The thinning schedule depends on site fertility. Five site classes have been envisaged:

| Site class | 5 | 4 | 3 | 2 | 1 |
|--|-----|------|--------|------|-----------|
| Fertility | Bad | Poor | Medium | Good | Very Good |
| <u>First thinning</u> | | | | | |
| N ave (stems/ha) | 711 | 711 | 711 | 711 | 711 |
| N _e (stems/ha) | 361 | 361 | 386 | 401 | 411 |
| Age (years) | 7 | 6 | 5 | 4 | 3 |
| <u>Second thinning</u> | | | | | |
| N ave (stems/ha) | 350 | 350 | 325 | 310 | 300 |
| N _e (stems/ha) | 165 | 175 | 160 | 150 | 150 |
| Age (years) | 10 | 9 | 8 | 7 | 6 |
| <u>Third thinning</u> | | | | | |
| N ave (stems/ha) | 185 | 175 | 165 | 160 | 150 |
| N _e (stems/ha) | 55 | 60 | 65 | 65 | 60 |
| Age (years) | 16 | 14 | 12 | 11 | 9 |
| <u>Harvest</u> | | | | | |
| N (stems/ha) | 130 | 115 | 100 | 95 | 90 |
| Age (years) | 25 | 24 | 23 | 20 | 18 |
| Mean diameter (cm) | 35 | 40 | 45 | 47 | |
| Merchantable volume (diameter > 7cm) standing at cycle end (m ³ /ha) | 165 | 197 | 226 | 233 | 246 |
| Total production at cycle end (m ³ /ha) | 241 | 286 | 331 | 346 | 348 |
| Mean increment at cycle end (m ³ /ha/year) | 9.6 | 11.9 | 14.4 | 17.3 | 19.3 |

N ave = Number of stems/ha before thinning

N_e = Number of stems/ha harvested during thinning

The suggested provisional yield table is characterized by a series of early and energetic thinnings. The forest manager intervenes as soon as possible to try to prevent the development of a state of competition that would be detrimental to the individual growth of the trees scheduled to reach maturity.

The thinning rates are, incidentally, dimensioned so as to reduce the number of operations without compromising the future of the stands in question. As a general rule, the younger the stand and the better its site, the higher the thinning rate will be.



Fraké after first thinning; Mopri forest

The object is to ensure that the thinnings are carried out in the dynamic phase of the stand's establishment, this being the period during which the trees respond most successfully and rapidly to changes in environmental conditions.

The stand is thus brought to its final density at an early age and can thus enjoy a maturing period of about ten years before the final harvest.

The option of a more staggered thinning schedule which could allow intermediate harvests of medium-sized products has not been pursued. This would in fact, result in a longer rotation cycle; on the other hand the marketing prospects for thinning products are very uncertain.

The felling cycle for thinning is in fact very short: intervals of 3-4 years on fertile sites, and up to 6 years on a bad site. The choice of rotation cycle length is determined in relation to exploitable diameter, which ranges from 35 cm on the least fertile sites to 50 cm on the best sites. Consequently, the length of the recommended rotation cycle never exceeds 25 years, even in the case of stands with poor rates of growth.

Under average conditions, the final harvest represents around 70 percent of the total production. This final harvest amounts to

200-250 m³/ha m³/ha (mainstem volume), with a bole volume of approximately 170-230 m³/ha. This corresponds to a cycle-end mean increment of 8-13 m³/ha/year (standing volume of the main stem).

2.3 - Samba (*Triplochiton scleroxylon*)

The Samba belongs to the Sterculiaceae family. It is a deciduous species native to semi-deciduous closed moist forests. Clearing is affording this species the opportunity to take hold in the moist evergreen forest zone as well.

In its natural range, the annual rainfall varies between 1 100 mm and 1 800 mm per year and the dry season lasts from 3 to 5 months.

Flowering starts in November and fruit-setting follows in February-March. It is very irregular; moreover, the fruits are very often parasitized by:

- fungi (*Mycosyrinx nonveillieri*) that cause lethal malformations in the floral organs and fruits,
- or weevils (*Apion* spp.) that attack the fruits.

Furthermore, when the seeds are harvested care must be taken to avoid drying them too suddenly; the drying process must be very gradual, otherwise the seeds' germinative ability decreases sharply. There are approximately 5 000 wingless seeds to the kilo. To make up for the Samba's irregular fructification, reforestation operators rely on large-scale vegetative propagation by herbaceous cuttings (DELAUNAY 1978).

The implementation of this technique is based on a regularly cut-back wood supply area that provides the leafy herbaceous shoots which will be planted under frames (see nursery techniques).

The root system consists of a taproot, frequently forked, with a few secondary roots.

The wood is yellowish-white in colour, low in density (D 12 = 0.4) and in hardness, shrinkage and nervosity; it is easy to season and to impregnate. Its physical properties make it a good wood for sawing, slicing and peeling. Its mechanical properties (low axial and transversal cohesiveness) and low durability restrict its use to furniture, indoor woodwork and the panelling industry.

The logs often show spots and discolorations due to the Samba bark-beetle (*Trachyostus ghanaensis*). In addition, the Samba is also subject to cossidae attacks (*Eulophonotus* spp.), which can involve a large number of trees. Luckily, this is generally limited to the buttwood, up to a height of 2-3 metres.

Attacks by Notodontid caterpillars (*Anaphe venata*) known in Nigeria as a major defoliation agent, have also been recorded.



17-year-old Samba trees, Mopri forest

SILVICULTURAL RULES

The Samba is a species with fast diameter growth. The mean increment ranges from 1 cm/year to 3 cm/year, depending on the age and type of stand. The Samba is a sun-loving species that must be planted without cover to express its full potential.

The recommended planting density is 700 stems/ha.

In relation to the planting method options (undergrowth and no cover), two separate yield tables have been drawn up (DUPUY et al. 1990).

No cover method

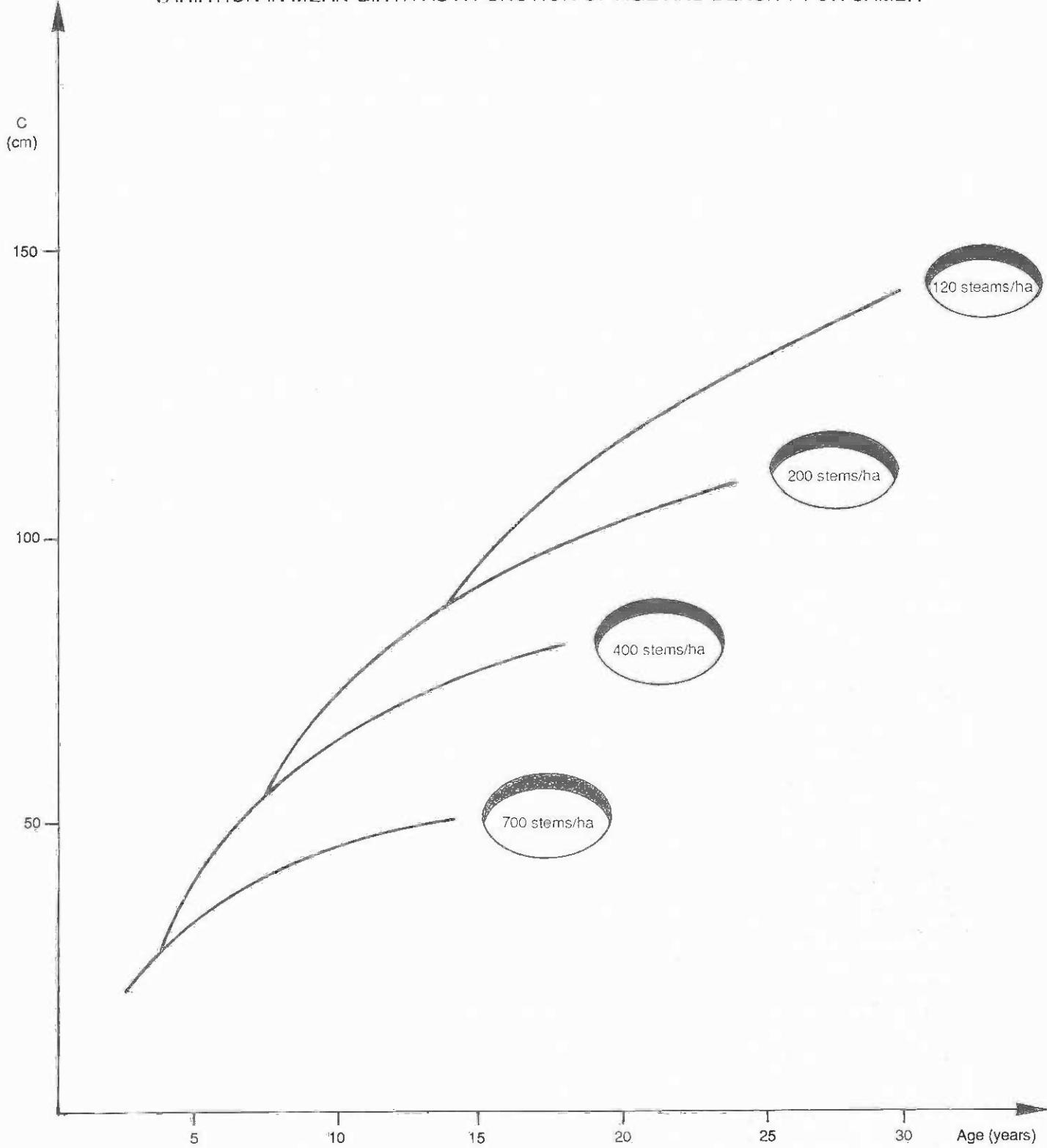
The exploitable diameter ranges from 35 cm to 60 cm, depending upon site fertility. The proposed silvicultural options have been proportioned so as to avoid excessively long rotation cycles. The foreseen exploitable diameter varies in relation to fertility.

Thinning is heavy and carried out early on in the cycle so as to bring the stands to their final density as soon as possible.

The exploitable ages range from 18 to 40 years.

The mean volume increment is between 5 and 18 m³/ha/year.

VARIATION IN MEAN GIRTH AS A FUNCTION OF AGE AND DENSITY FOR SAMBA



SILVICULTURE RECOMMENDATIONS AND PRODUCTIVITY DATA
FOR SAMBA PLANTED WITH NO COVER

| Site classes | Number of thinnings | Harvestability | | | Mean increment | | |
|--------------|---------------------|----------------|---------|------------------------|----------------|---------------------------------------|--|
| | | Age (years) | Dg (cm) | V (m ³ /ha) | Final harvest | Total harvest (m ³ /ha/yr) | |
| 1 | 4 | 18 | 60 | 209 | 17.8 | 11.6 | |
| 2 | 3 | 24 | 50 | 263 | 14.3 | 10.9 | |
| 3 | 3 | 30 | 45 | 237 | 10.4 | 7.9 | |
| 4 | 3 | 35 | 40 | 184 | 7.7 | 5.2 | |
| 5 | 3 | 40 | 35 | 138 | 5.5 | 3.4 | |

It is useful to take into account the influence of thinning on the volumes harvested. For this purpose, four cuts can be envisaged.

The results are given for the five site classes taken into consideration for this yield table.

| Site class | 5 | 4 | 3 | 2 | 1 |
|--|-----|------|--------|------|---------|
| Fertility | Bad | Poor | Medium | Good | V. Good |
| <u>First thinning</u> | | | | | |
| N ave (stems/ha) | 711 | 711 | 711 | 711 | 711 |
| N e (stems/ha) | 361 | 361 | 386 | 401 | 411 |
| Age (years) | 7 | 6 | 5 | 4 | 3 |
| <u>Second thinning</u> | | | | | |
| N ave (stems/ha) | 350 | 350 | 325 | 310 | 300 |
| N e (stems/ha) | 165 | 175 | 160 | 150 | 150 |
| Age (years) | 10 | 9 | 8 | 7 | 6 |
| <u>Third thinning</u> | | | | | |
| N ave (stems/ha) | 185 | 175 | 165 | 160 | 150 |
| N e (stems/ha) | 55 | 60 | 65 | 65 | 60 |
| Age (years) | 16 | 14 | 12 | 11 | 9 |
| <u>Harvest</u> | | | | | |
| N (stems/ha) | 130 | 115 | 100 | 95 | 90 |
| Age (years) | 25 | 24 | 23 | 20 | 18 |
| Mean diameter (cm) | 35 | 40 | 45 | 47 | 49 |
| Standing volume of the main stem at cycle end (m ³ /ha) | 165 | 197 | 226 | 233 | 246 |
| Total production at cycle end (m ³ /ha) | 241 | 286 | 331 | 346 | 348 |
| Mean increment at cycle end (m ³ /ha/year) | 9.6 | 11.9 | 14.4 | 17.3 | 19.3 |

The suggested provisional yield table is characterized by a series of early and energetic thinnings. The forest manager intervenes as soon as possible to try to prevent the development of a state of competition that would be detrimental to the individual growth of the trees scheduled to reach maturity.

The thinning rates are, incidentally, dimensioned so as to reduce the number of operations without compromising the future of the stands in question. As a general rule, the younger the stand and the better its site, the higher the thinning rate will be.

The object is to ensure that the thinnings are carried out in the dynamic phase of the stand's establishment, this being the period during which the trees respond most successfully and rapidly to changes in environmental conditions.

The stand is thus brought to its final density at an early age and can thus enjoy a maturing period of about ten years before the final harvest.

A more staggered thinning schedule which could allow intermediate harvests of medium-sized products has not been considered. It would in fact, result in a longer rotation cycle; on the other hand, the marketing prospects for thinning products are very uncertain.

The felling cycle foreseen for the thinnings is in fact short. It foresees intervals of 3-4 years on fertile sites, and up to 6 years on a bad site. The choice of rotation cycle length is determined in relation to exploitable diameter. This diameter ranges from 35 cm on the least fertile sites to 50 cm on the best sites. Consequently, the length of the recommended rotation cycle never exceeds 25 years, even in the case of stands with poor rates of growth.

Under average conditions, the final harvest represents areound 70 percent of the total production. This final harvest amounts to 200-250 m³/ha (mainstem volume), with a bole volume of approximately 170-220 m³/ha. This corresponds to a cycle-end mean increment of 8-13 m³/ha/year (standing volume of the main stem).

Undergrowth method

To obtain an exploitable diameter of 40 cm, it takes between 20 and 30 years under conditions of good to medium fertility.

The mean timber volume increment is thus between 5 and 11 m³/ha/year, depending upon density and fertility (class 2 to 3).

The maximum productivity recorded on a class 1 site with a density of 150 stems/ha and an exploitable diameter of 50 cm is 14.7 m³/ha/year at age 30.

Depending on fertility and plantation density, the following silvicultural recommendations can be made:

EXPLOITABLE AGES AND DIAMETERS FOR SAMBA PLANTATION SITE CLASSES:
UNDERBRUSH METHOD

| Site classes | Age (years) | Density (stems/ha) | Exploitable diam. (cm) | Mean volume increment (m ³ /ha/year) |
|--------------|-------------|--------------------|------------------------|---|
| 1 | 30 | 150 | 50.3 | 14.7 |
| | 27 | 75 | 59.8 | 11.7 |
| 2 | 37 | 150 | 44.9 | 9.4 |
| | 29 | 75 | 50.4 | 7.7 |
| 3 | 35 | 150 | 35.4 | 6.0 |
| | 29 | 75 | 40.0 | 4.7 |
| 4 | 33 | 100 | 30.0 | 3.0 |

The influence of density is considerable. It must be noted that plantations of this type, where the trees have been planted far apart, are not thinned at all.

EFFECT OF DENSITY ON DIAMETER INCREMENT
SITE CLASS 2

| | | | | |
|--------------------|------|------|------|------|
| Age (years) | 20 | 23 | 29 | 32 |
| Density (stems/ha) | 75 | 100 | 150 | 200 |
| Diameter (cm) | 39.7 | 39.8 | 40.7 | 40.2 |

Under good conditions of fertility, the exploitable diameter of 40 cm will be reached at an age ranging from 20 to 32 years for densities ranging from 75 to 200 stems/ha.

2.4 - Cedrela odorata

The *Cedrela odorata* is a member of the Meliaceae family native to tropical America and found from Mexico to Argentina. Its natural range is in moist semi-deciduous and evergreen forest zones with an annual rainfall of 1 200-2 500 mm/year and a dry season of 2 to 4 months.

It fruits in the dry season (February-March). There are approximately 50 000 seeds to the kg.

The fragrant wood is red, soft and light. Its traditional uses are joinery and cabinet-making. Under plantation conditions, its density ranges from 0.35 to 0.50. The technological characteristics of the plantation-grown wood are satisfactory.

This species was first introduced into tropical Africa early in this century (1920 in Ghana, 1929 in Nigeria). In Côte d'Ivoire, the first plantations were established around 1945 (Soubré). In 1964-65, plots were established at Mopri and Sangoué for behaviour trials.

Due particularly to the extensiveness of *Cedrela*'s natural range, a very high degree of genetic variability was observed in the provenance trials.

Certain provenances tested in Côte d'Ivoire gave very poor results in terms of vigour and shape: Missiones (Argentina). As regards vigour, the best provenances are Chiquibil (Honduras) and Ste Marie (Jamaica) which, at the age of 8 years, had a mean height increment of 2.5 m/year and a mean diameter increment of 3 cm/year. These two provenances have a good natural pruning aptitude, although the Chiquibil had a high rate of forked trees.

The best provenances for shape are not the most vigourous. With regard to conformation, silviculture and genetic improvement are heavily interdependent. Various introductions confirm the superiority of specific provenances from Belize and Costa Rica.

The Ghanaian provenances from seed orchards do not fulfil the hopes to which they had given rise. Empirically speaking, the antagonism between vigour and shape is also to be found in the recommended silvicultural practices. It will often be necessary to give preference to well-shaped codominant trees by eliminating vigourous dominants lacking commercial value.

In its original range, a certain number of foliage attacks have been observed as well as attacks of rootrot, although borers (*Hypsipyla grandella*) are the chief problem.

No borer attacks have been reported in Côte d'Ivoire. However, certain insects (*Platipodidae*, *Bostrychidae*) may cause considerable damage to *Cedrela* trees. Very localized areas of rootrot (*Phellinus noxius*, *Armillariella spp.*, *Rigidoporus lignosus*) have been observed.

SILVICULTURAL RULES

The results of the trials make it clear, considering the shape problems encountered, that the highest possible planting densities should be adopted: the minimum density envisaged is 1 100 stems/ha (MAITRE, 1979).

For planting purposes, both stumped plants and bagged plants are equally suitable.

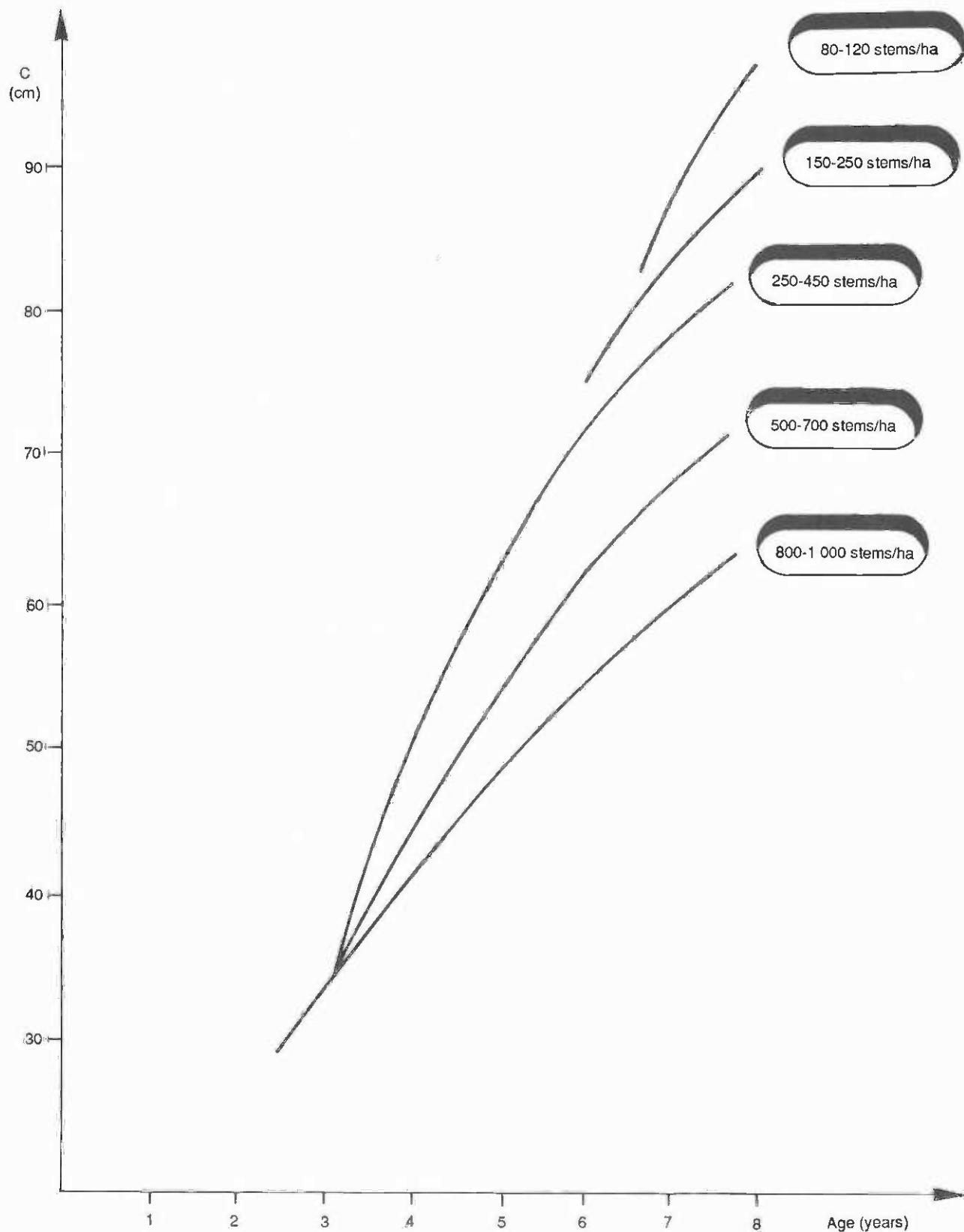
A yield table is available for *Cedrela odorata* (DUPUY *et al.* 1988) which foresees four different site classes.

The recommended thinning schedule is as follows:

First thinning: This thinning is carried out as soon as the dominant height reaches 9.5 m. One stem out of two is thinned.

Second thinning: This thinning takes place when the dominant height reaches 15 m. Before thinning, the mean diameter is 19 cm and the basal area is 19 m²/ha. One stem out of two is thinned.

VARIATION IN MEAN GIRTH AS A FUNCTION OF DENSITY AND AGE FOR CEDRELA ODORATA



Third thinning: This thinning is carried out when the dominant height reaches 22 m. Before thinning, the mean diameter is 30 cm and the basal area 19 m²/ha. About 40 percent of the standing stems are thinned.

Fourth thinning: This thinning begins at a basal area of 21 m²/ha. Before thinning, the mean diameter is approximately 40 cm. One stem out of three is thinned.

| | Site classes | | | |
|---------------------------------------|--------------|-------|-------|-------|
| | 1 | 2 | 3 | 4 |
| <u>First thinning</u> | | | | |
| Age (years) | 3 | 4 | 5 | 7 |
| Density (stems/ha) : | | | | |
| . Before thinning | 1 100 | 1 100 | 1 100 | 1 100 |
| . Extracted | 550 | 550 | 550 | 550 |
| Volume extracted (m ³ /ha) | 32 | 41 | 40 | 41 |
| <u>Second thinning</u> | | | | |
| Age (years) | 5 | 6 | 8 | 12 |
| Density (stems/ha) : | | | | |
| . Before thinning | 550 | 550 | 550 | 550 |
| . Extracted | 275 | 275 | 275 | 250 |
| Volume extracted (m ³ /ha) | 54 | 54 | 53 | 49 |
| Mean diameter of trees extracted (cm) | 15 | 15 | 14 | 15 |
| <u>Third thinning</u> | | | | |
| Age (years) | 8 | 10 | 14 | 21 |
| Density (stems/ha) : | | | | |
| . Before thinning | 275 | 275 | 275 | 300 |
| . Extracted | 125 | 115 | 100 | 100 |
| Volume extracted (m ³ /ha) | 60 | 54 | 6 | 43 |
| Mean diameter of trees extracted (cm) | 24 | 24 | 23 | 22 |
| <u>Fourth thinning</u> | | | | |
| Age (years) | 13 | 16 | 22 | |
| Density (stems/ha) : | | | | |
| . Before thinning | 150 | 160 | 175 | |
| . Extracted | 55 | 55 | 50 | |
| Volume extracted (m ³ /ha) | 53 | 49 | 40 | |
| Mean diameter of trees extracted (cm) | 35 | 33 | 31 | |
| <u>Final harvest</u> | | | | |
| Age (years) | 25 | 28 | 32 | 30 |
| Density (stems/ha) | 95 | 105 | 125 | 200 |
| Volume (m ³ /ha) | 263 | 241 | 217 | 193 |
| Mean diameter (cm) | 61 | 55 | 48 | 36 |



Spacing trial with 15-year-old *Cedrela odorata*; Sangoué forest

Cedrela odorata is a species in which vigour and shape show great variability. The thinning operations must comply with spacing criteria and at the same time every care must be taken to eliminate poorly shaped and impaired trees in the dominant storey: the selective aspect of thinnings is fundamentally important. In order to maximize the individual growth increments of the final harvest trees it is necessary to intervene at an early stage, because in the juvenile growth phase *Cedrela*'s great thinning response capability allows intensive but few thinnings.

The mean increment in main stem volume ranges from 11 to 19 m³/ha/year, depending upon fertility. Anticipated exploitable diameters range from 40 to 60 m.

3 - FAST-GROWING SPECIES FOR TIMBER PROMOTION

3.1 - Pines

The introductory trials with Central American pines resulted in the selection of two species:

- *Pinus caribaea* var. *hondurensis*
- *Pinus oocarpa*

In its natural range, *Pinus caribaea* var. *hondurensis* is a species that grows in low lands and coastal valleys where stands on one part of the watershed are isolated from the others by different plant formations. Between 600 and 800 m high it is found mixed with *Pinus oocarpa*. The latter species generally grows at altitudes above 600 m, where it constitutes the next vegetation level after the low-altitude formations where *Pinus caribaea* is usually found.

Pinus Caribaea var. *hondurensis*, the range of which is between latitudes 12° and 18° North, grows from sea-level to an altitude of 800 m.

In this range, the annual rainfall varies between 1 200 mm/year inland to 4 200 mm/year on the Atlantic seaboard. The dry season ranges from 0 to 6 months.

The differences between provenances are considerable. The selection criteria employed are vigour, straightness, forking, size and angle of branches.

The best provenances tested in the moist evergreen forest zone proved to be those from Nicaragua (Alamicamba, Karawalata, Santa Clara), Guatemala (Poptun) and Honduras (Limones, Guanaja). The selection of provenances suited to the evergreen forest zone will be channelled towards low altitude areas (< 700 m) with an annual rainfall exceeding 1 800 mm/year (Diabaté 1980).

Pinus oocarpa, whose range lies between 12° and 27° North, grows at altitudes of 400-1 800 m. This species may also be found locally at altitudes of up to 2 450 m (Guatemala) or as low as 200 m (Mexico and Guatemala).

In this range, the annual rainfall varies between 700 and 2 500 mm/year and the dry season ranges from 2 to 6 months; consequently, there is also a high degree of interprovenance variability in this species.

In the moist evergreen forest zone, the best provenances are those from Nicaragua (Yucul, Camelias, Rafael) and Belize (Mt Pine Ridge). Selection will be oriented towards provenances from low altitude areas (< 900 m) in which annual rainfall exceeds 1 500 mm/year.

In lowland Côte d'Ivoire, the first fruit-bearing by *Pinus caribaea* var. *hondurensis* was observed at the age of 10 years. This species can be propagated by grafting (cleft and approach grafts) and by cuttings.

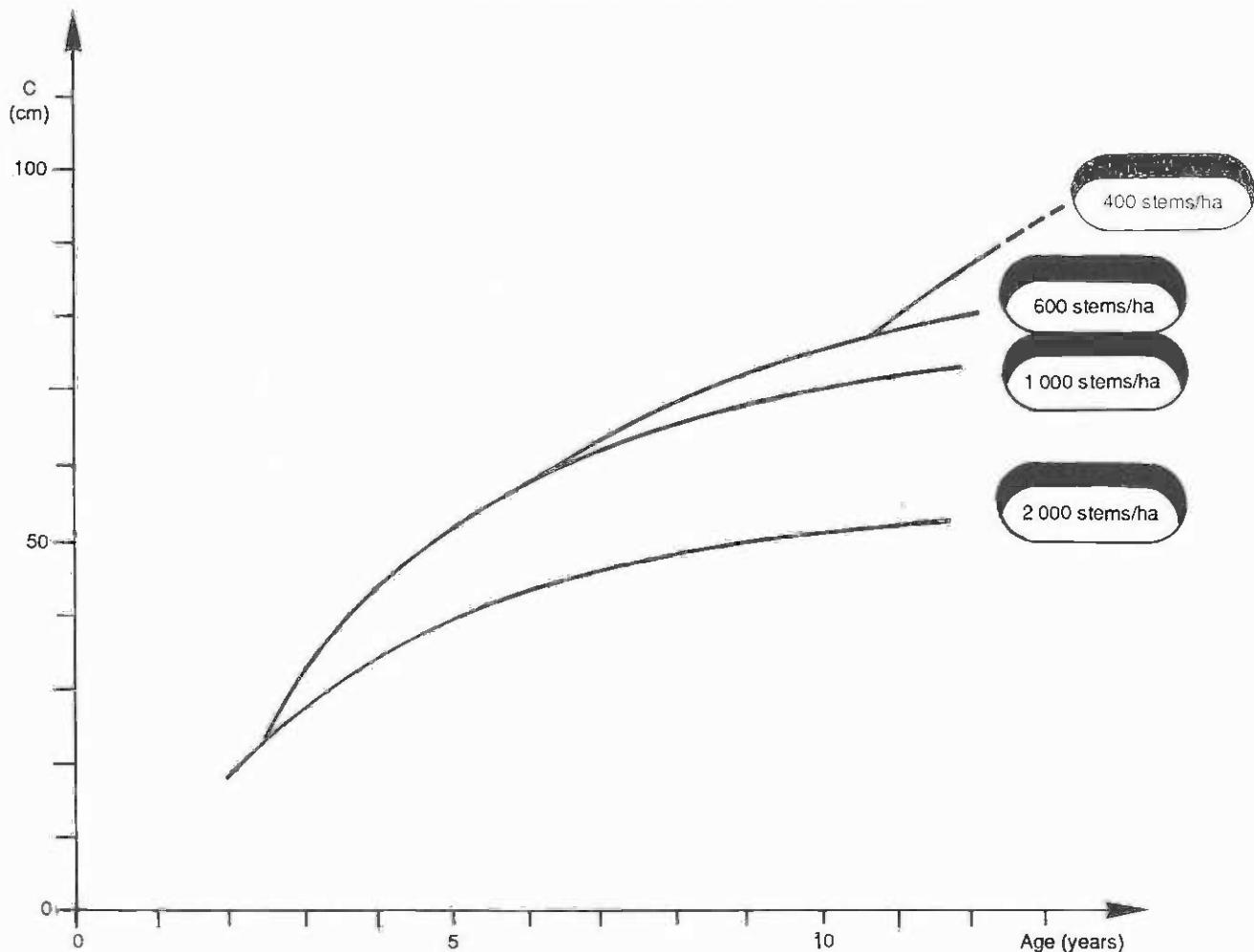
The wood is light (*Pinus caribaea*: D 12 = 0.4-0.5) to semi-heavy (*Pinus oocarpa*: D 12 = 0.5-0.6), with low to medium shrinkage. Its mechanical properties are medium to low.

SILVICULTURAL RULES

As regards the best provenances tested in the moist evergreen forest zone, at the age of 4 years the initial height increment of *Pinus caribaea* (1.8 to 2.3 m/year) was greater than that of *Pinus oocarpa* (1.2 to 1.5 m/year).

In the lowland moist evergreen forest zone, *Pinus caribaea* var. *hondurensis* has a medium initial growth rate. The average height is from 0.8 to 1 m at 1 year, 3-4 m at 2 years and 7-9 m at four years.

VARIATION IN GIRTH AS A FUNCTION OF DENSITY IN THE MOIST EVERGREEN FOREST ZONE FOR *PINUS CARIBAEA*





22-year-old Caribbean pines;
Yapo forest

The recommended planting density is 1 100-1 500 stems/ha.

In the moist evergreen forest zone, the proposed provisional thinning schedules is as follows:

- When the mean height is 7 to 9 m and the mean diameter 10 to 12 cm, the plants should be thinned out to bring the density down to 800-900 stems/ha. The age of the stand is then 3-4 years.
- When the mean height is 14 to 16 m and the mean diameter 18 to 20 cm, the first proper thinning reduces density to 500-600 stems/ha. The age of the stand is then 7 to 9 years.
- When the mean height is 17 to 19 m and the mean diameter 23 to 25 cm, a second thinning reduces density to 350-400 stems/ha. The age of the stand is then 10 to 12 years.
- At the age of about 15 years, the third thinning brings the stand's density down to about 200 stems/ha. The particulars of any further thinnings still remain to be specified.

At the age of 8-10 years, with a density of 600 stems/ha, the mean standing main stem volume increment is around 25 m³/ha/year.

For an exploitable diameter of 60 cm the rotation cycle is approximately 30 years.

In the pre-forest zone, preference will be given to low-altitude provenances of *Pinus oocarpa*.

At age 10, with a density of 645 stems/ha, the mean diameter is 18 cm and the mean total height 17 m.

At age 15, with a density of 420 stems/ha, the mean diameter is 23 cm and the mean total height is 22 m. The mean main stem volume increment is 11 m³/ha/year (Outtara 1982).

3.2 - Gmelina arborea

Gmelina arborea is a member of the verbenaceae family. It is a species of Asian origin whose natural range is in India (latitude 28° North to 5° South, longitude 70° to 95° East). It ranges from Pakistan to Bangladesh, Burma, Sri Lanka, Thailand, Laos, Kampuchea, Viet Nam and the southern provinces of China. It is also found in Malaysia and in the Philippines, where it appears to be sub-spontaneous. It has also been introduced into many countries in the moist tropical zone of Africa, where it has been growing for several decades.

In its original area, it is found from sea-level up to an altitude of 1 500 m. The annual rainfall varies from 700 mm/year (dry deciduous forest) to 4 500 mm/year (moist deciduous forest). The minimum temperatures range from -1°C to 16°C and maxima from 38°C to 48°C.

Such an extensive range implies differentiation into numerous ecotypes. Two varieties have been identified in India: var. *glaucescens* and var. *canescens*.

In its natural state, the *Gmelina* is a not very gregarious species extending from moist evergreen forest areas to dry forest areas. In the latter, it often grows in shrub-like form. It cannot tolerate hydromorphic soils or soils that are flooded for long periods.

This deciduous species is leafless in the dry season. In its natural range, it flowers at the end of the dry season and bears fruit approximately two months later. There are in fact considerable inter- and even intra-individual differences in flowering and fructification periods.

In Côte d'Ivoire, fructification extends from December to June. The fruit is a fleshy drupe whose kernel contains from one to five seeds, most frequently two. There are approximately 800 fruits per kilo.

On plantations, the trees begin to bear fruit at the age of 3-4 years. Each tree produces about 5-6 kg of fruit, equivalent to approximately 0.5 kg of depulped fruit per tree.

In cultivated stands, the mean lifespan of the trees ranges from about ten years on the poorest sites to around fifty on the best sites. *Gmelinas* have very good stump sprouting ability and can easily be grown from cuttings (unlignified shoots).

The seeds germinate from one to two weeks after sowing, with no preliminary treatment required. However, soaking the seeds for twenty-four hours regularizes sprouting times. For planting-out, both bagged and/or stumped plants can be used with equally good results.

The best provenances are selected on the basis of the following criteria: cylindrical, straightboles, quality and height of natural pruning, forking height, multiple stems.

In the moist evergreen forest zone, the best tested provenances are:

- Tamilnadu (India), which proved very vigorous but branchy;
- Bamoro (Côte d'Ivoire) and Kundrukutu (India), which did well in terms of straightand, cylindricalcole and vigour, with average self-pruning qualities.

In the moist semi-deciduous forest zone, the best tested provenances are: Baramura (India), Shikaribari (India) and Bamoro (Côte d'Ivoire), which combine good vigour with good to average shape characteristics.

With regard to shape problems, the first observations from provenance trials conducted in Côte d'Ivoire show that:

- the multiple stem trait frequently present in Gmelina is independent of provenance and seems instead to be linked to site (type of plantation, soil, ...);
- defective pruning (presence of stubs) is worse when branchiness is also present;
- cylindrical trees are straight, vertical and well-pruned;
- a straightbole, the presence of stubs and knot size are site-independent traits.

SILVICULTURAL RULES

The Gmelina, which is very frequently introduced in experimental short-rotation reforestation programmes, is a fast-growing species.

In the moist forest zones, the mean man total height is 1.5 m at 1 year and (2.5 m at 2 years. Introduced in the pre-forest zone, the Gmelina has proved to be a promising reforestation species. With a density of 250-350 stems/ha, at the age of 11 years the following mean increments are obtained:

| Geographical area | Mean increment in: | | |
|-------------------|--------------------|--------------------|----------------------------------|
| | height (m/year) | diameter (cm/year) | volume (m ³ /ha/year) |
| Evergreen | 2.5/3 | | |
| Semi-deciduous | 2.2/2.7 | | |
| Pre-forest | 1.5/2 | 2.5/3 1.5/2 | 20/25 15/20 |

In the moist evergreen forest zone, with 1 100 stems/ha and not thinned, *Gmelina* has a mean diameter of 20 cm (DHP) at the age of 8-10 years with a mean strong wood increment of 30-40 m³/ha/year on experimental plots.

At this density, competition appears very early on. By the age of 3-4 years, with timber production as the goal, thinning to bring the density down to 600-700 stems is necessary. At 5 years, the mean diameter is around 13-15 cm.

Frequent problems with natural shape (straightbole, forking, multiple stems) and pruning lead us to recommend planting densities of the order of 1 100 stems/ha which ensures a quickly closed cover favourable to natural pruning and a sufficiently large stock for a good selection of trees at the time of thinning (CABARET, 1988).

Silvicultural studies indicate the following silvicultural imperatives:

- a high planting density (1 100 stems/ha);
- a schedule of heavy and early thinnings;
- an exploitable age and diameter that vary in relation to fertility.

The thinning schedule depends on site fertility. The exploitable diameter increases with fertility.

The proposed silvicultural rules are:

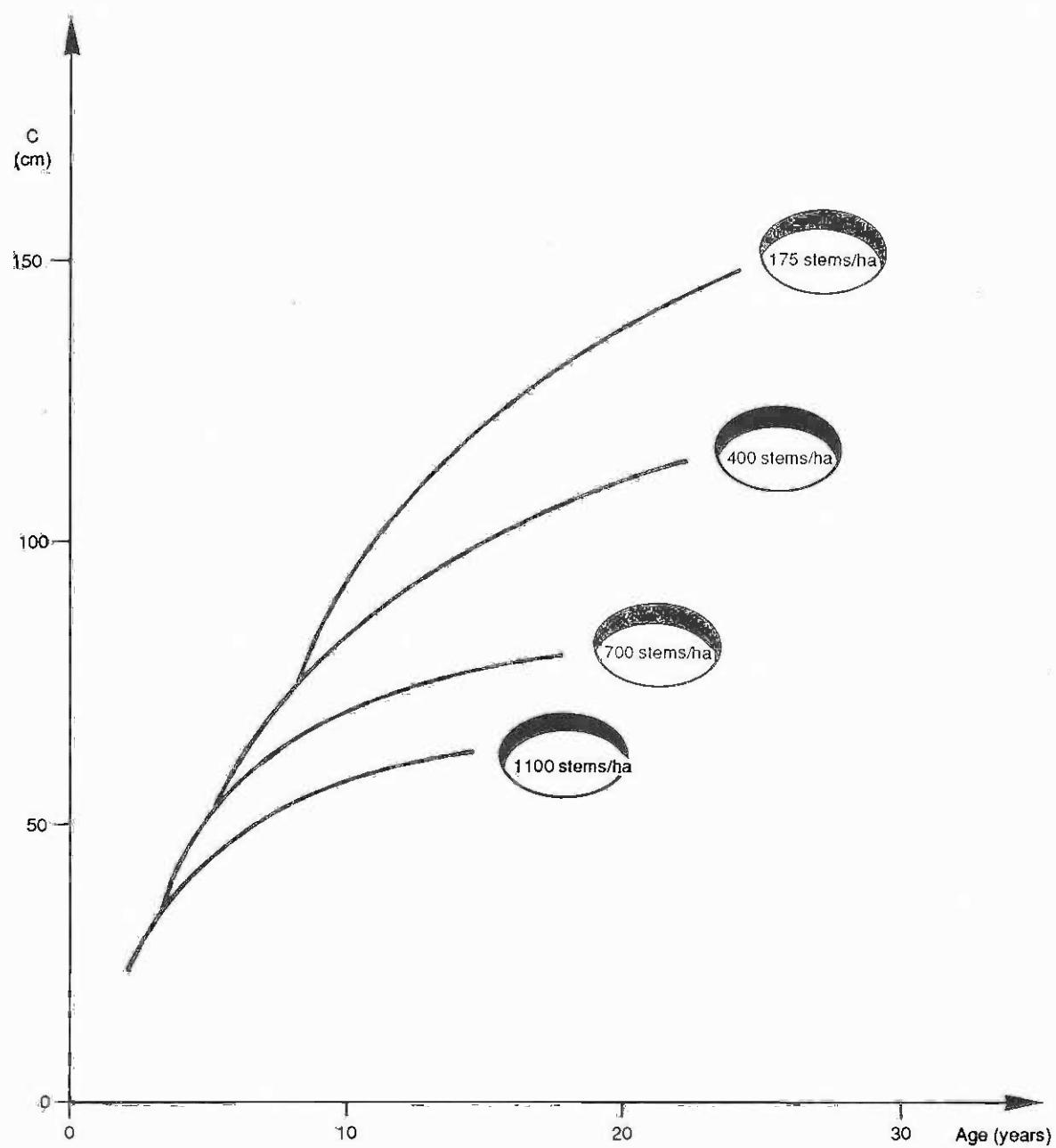
- a thinning schedule of 3 thinnings;
- an interval of 3 to 12 years between thinnings, depending upon site fertility and stand age;
- an exploitable diameter ranging from 35 to 60 cm, depending upon site fertility;
- an exploitable age of 23 to 55 years, depending upon site fertility and exploitable diameter.

| Thinning operation | Fertility level | | | | |
|--------------------|-----------------|-------|----------|-------|-------|
| | 1 | 2 | 3 | 4 | 5 |
| N ave (stems/ha) | 1 111 | 1 111 | 1 111 | 1 111 | 1 111 |
| 1 Age (years) | 3 | 4 | 5 | 6 | 10 |
| Ho | | over | 9 metres | | |
| N ave (stems/ha) | 400 | 400 | 400 | 400 | 500 |
| 2 Age (years) | 6 | 7 | 9 | 13 | 17 |
| Dg. (cm) | 23.8 | 23.5 | 22.8 | 22.2 | 18.8 |
| N ave (stems/ha) | 200 | 200 | 200 | 200 | 250 |
| 3 Age (years) | 9 | 11 | 15 | 24 | 35 |
| Dg. (cm) | 34.3 | 33.9 | 32.9 | 32.2 | 26.9 |
| Final harvest | | | | | |
| N (stems/ha) | 115 | 115 | 115 | 115 | 150 |
| Age (years) | 23 | 27 | 30 | 40 | 55 |
| Dg. (cm) | 60.2 | 57.2 | 50.1 | 45.0 | 35.3 |

N ave : Mean density before thinning

Dg : Mean diameter

VARIATION IN GIRTH AS A FUNCTION OF AGE AND DENSITY FOR GMELINA ARBOREA



The productivity of the plantations depends primarily on the fertility of the trial sites.

Five site classes have been identified.

| Site classes | Harvestability | | | Mean increment (m ³ /ha/yr) | |
|--------------|----------------|---------|------------------------|--|---------------|
| | Age (years) | Dg (cm) | V (m ³ /ha) | Final harvest | Total harvest |
| 1 | 23 | 60.2 | 350 | 15.2 | 20.3 |
| 2 | 27 | 57.2 | 314 | 11.6 | 16.2 |
| 3 | 30 | 50.1 | 236 | 7.8 | 11.8 |
| 4 | 40 | 45.0 | 187 | 4.7 | 7.7 |
| 5 | 55 | 35.2 | 144 | 2.6 | 4.3 |

The productivity of *Gmelina arborea* plantations ranges from 4 to 20 m³/ha/year (main stem volume).

The productivity gradient, expressed by fertility, is closely dependent on the rainfall regime.

The best productivity data is recorded in moist forest areas where the rainfall is highest and most evenly distributed.

| Forest zone | Moist forest | Pre-forest area | Guinean savannah |
|--|--------------|-----------------|------------------|
| Exploitable diameter (cm) | 45 to 60 | 30 to 35 | 25 to 35 |
| Exploitable age (years) | 15 to 25 | 25 to 45 | 30 to 55 |
| Mean increment (m ³ /ha/year) | 11 to 20 | 5 to 13 | 4 to 9 |

In closed forest areas the mean volume increment ranges from 11 to 20 m³/ha/year and the exploitable diameter from 45 to 60 cm.

In the pre-forest zone the mean volume increment ranges from 5 to 13 m³/ha/year and the exploitable diameter ranges from 30 to 45 cm.

In savannah areas the mean volume increment ranges from 4 to 9 m³/ha/year. The exploitable diameter ranges from 25 to 35 cm.

The final harvest constitutes 60 to 75 percent of the total harvest.



Young Gmelina plantation

In the light of the available data, the following silviculture rules can be recommended for the closed forest zone:

- At the age of about 3-4 years, the first thinning reduces density to 400 stems/ha. Before thinning, the trees in the stand have a mean diameter of 10 cm, a mean height of 10 m and basal area of 9 m²/ha.
- At the age of about 5-7 years, the second thinning reduces density to 200 stems/ha. Before thinning, the mean diameter is 20 cm, the mean height 15 m and the basal area 13 m²/ha.
- At about 8-10 years, the third thinning reduces density to 125 stems/ha. The mean diameter is 30 cm, the mean height 20m and the basal area 15 m²/ha.

For an exploitable diameter of 45 cm, the rotation cycle is 15-20 years. The mean volume increment is from 10 to 15 m³/ha/year.

In the pre-forest zone, the growth rate of *Gmelina arborea* is still attractively high. For mature stands on fertile sites the following figures are obtained:

| Age (years) | Density (stems/ha) | Girth at 1. 30 m (cm) | g (m ² /ha) |
|----------------|-----------------------|--------------------------|---------------------------|
| 16 | 296 | 98.4 | 23.4 |
| 16 | 520 | 79.5 | 26.6 |
| 26 | 292 | 110.0 | 28.9 |
| 26 | 516 | 84.4 | 29.7 |

4 - SPECIES TO BE CONFIRMED

4.1 - Padouk (Pterocarpus soyauxii)

The Padouk, which belongs to the Papilionaceae family, is a native of Equatorial Africa, where it is found from Nigeria to Zaire. It is a moist evergreen forest species that seldom exceeds a diameter of 1 m.

Its wood is bright red in colour and is semi-heavy ($D_{12} = 0.65 - 0.85$) and hard. It darkens when exposed to light. It is used for indoor and outdoor woodwork, cabinet-making and veneering.

The Padouk was successfully introduced in the moist evergreen forest zone of Côte d'Ivoire in 1960.

The Padouk is susceptible to "platypes" attacks on the bole.

SILVICULTURAL RULES

This is a fast-growing species: at 1 year the mean height is 1.5 to 2 m, at 2 years it is 4 to 5 m and at 6 years it reaches 15 to 18 m (ADOU KOUABLAN 1981).

At the age of 6 years, the mean height increment is around 2.2 m/year with a mean diameter increment of 2.5 cm/year.

When planted at a density of 625 stems/ha with no thinnings (fuelwood, energy-oriented plantation), the mean increment in main stem volume is 30 m³/ha/year at age 15 with a mean diameter of 25 to 30 cm.

At age 17, in the case of a plantation thinned down to 400 stems/ha, the mean increment in the diameter of the 150 largest trees is 2.5 cm/year.

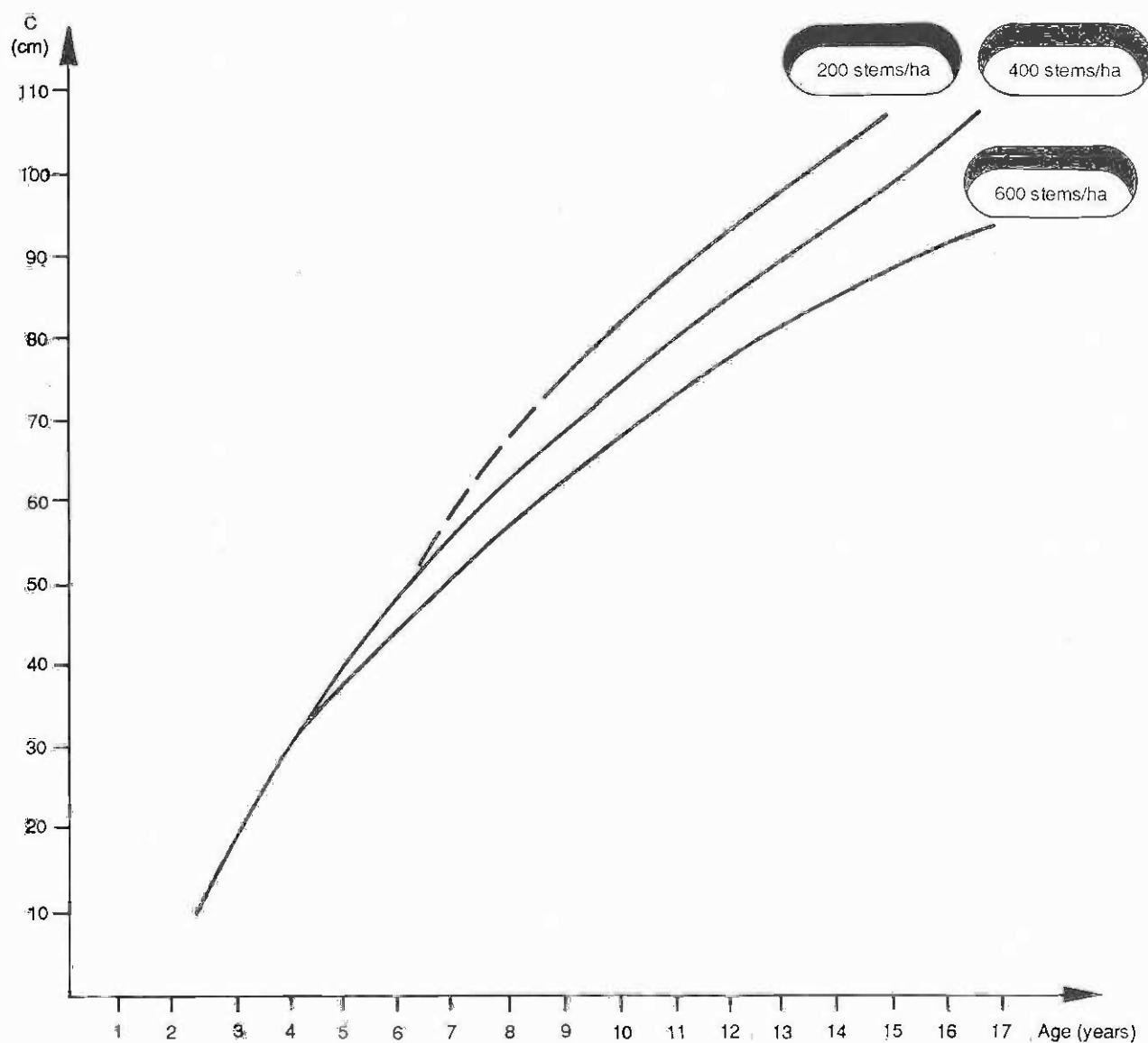
However, in 15-year-old trees with a diameter of 35 cm the percentage of sapwood is 60 percent.

The first provisional silvicultural recommendations are as follows:

- the planting density is 700 stems/ha.
- when the mean height is 9 to 11 m, the mean diameter is 10 to 12 cm and the basal area 6 to 8 m²/ha, the first thinning is carried out to reduce density to 300-350 stems/ha. The stand's age is 4 to 5 years.
- when the mean height is 13 to 15 m, the mean diameter is 15 to 17 cm and the basal area 6 to 8 m²/ha, a second thinning reduces density to 125-150 stems/ha. The stand's age is 6 to 8 years.

With an exploitable diameter of 50 to 60 cm, the rotation cycle is from 30 to 40 years. The mean increment in main stem volume is of the order of 15 m³/ha/year at age 15.

VARIATION IN GIRTH AS A FUNCTION OF AGE AND DENSITY IN PADOUK
IN THE MOIST EVERGREEN FOREST ZONE



4.2 Cordia alliodora

This deciduous sun-loving species native to Latin America belongs to the Boraginaceae family. It is a medium-sized, buttressed tree that can reach a diameter of 1 m and a height of 30 m.

Cordia alliodora has a very extensive range from latitudes 25° North (Southern Mexico) to 25° South (Northern Argentina).

In this area, the annual rainfall ranges from 1 000 to 5 000 mm per year. *Cordia* is a low-altitude species (< 500 m) which can locally reach an altitude of 2 000 m (Columbia). The duration of the rainy season ranges from 0 to 5 months.

The extensiveness of its natural range (which is, moreover, discontinuous) gives rise to a high degree of genetic variability. The provenance trials conducted in Côte d'Ivoire revealed very high interprovenance variability: at the age of 4-5 years the mean total height ranged from 7 to 17 m according to provenance amongst those tested at Sangoué.

The best introduced provenance is "Finca la Fortuna" (Honduras). At age 4-5 years, its mean dendometrical characteristics are:

| Density | Total height | Girth at 1.30 m | Pruned height | Fork height | Basal area |
|--------------|--------------|-----------------|---------------|-------------|-----------------------|
| 711 stems/ha | 17 m | 56 cm | 11 m | 11 m | 18 m ² /ha |

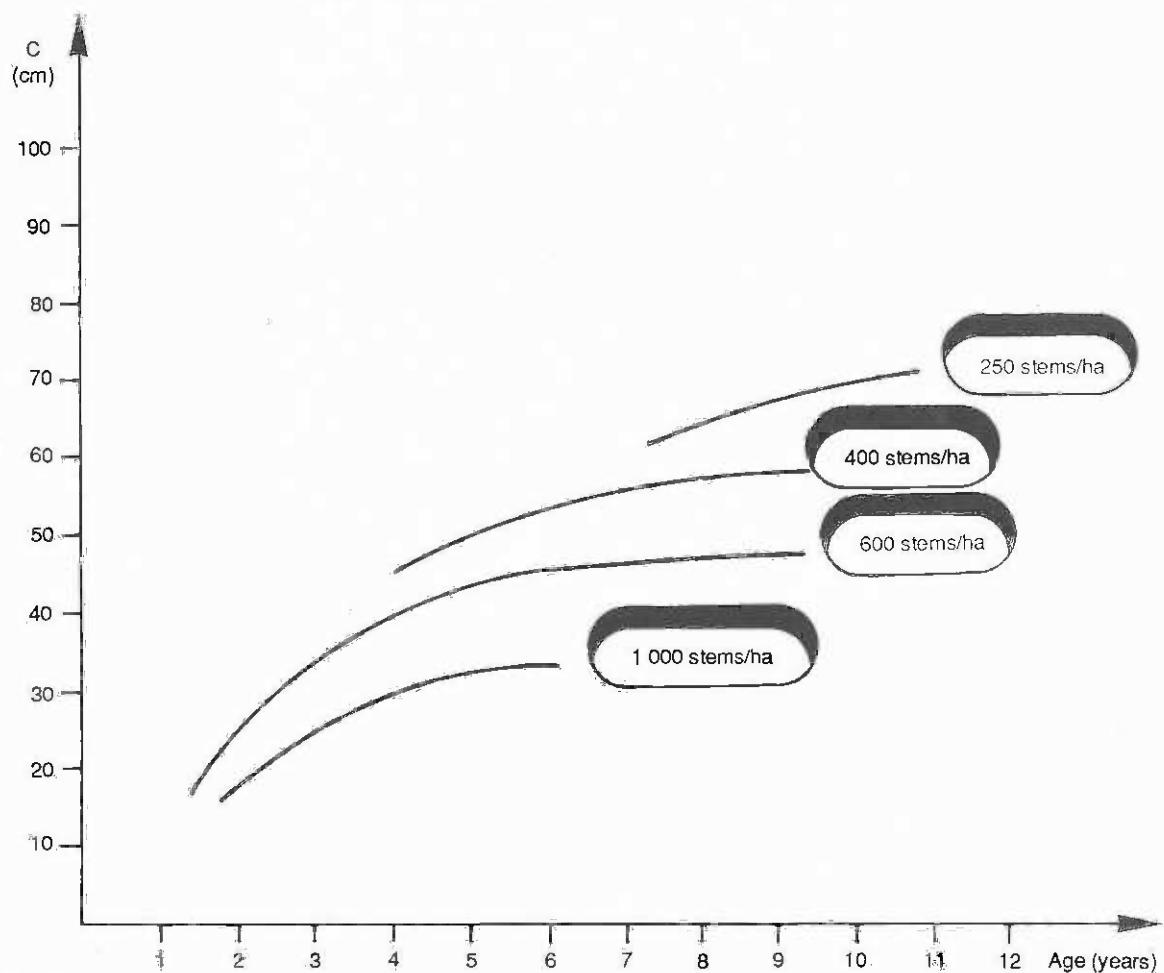
The bent stem characteristic reported in certain stands appears to be provenance-linked.

In reforestation, the best results have been reported in the evergreen zone with annual rainfall exceeding 1 600 mm/year.

In Côte d'Ivoire flowering begins at 4-5 years, in December-February; the tree fruits at the beginning of the rainy season (June to August).

The wood is light to very light ($D_{12} = 0.4 - 0.5$), soft, of low nervosity with low to medium mechanical properties. Its durability and impregnability are medium. The wood sometimes fluffs when sawn. It is easy to season and machine. Its principal uses are indoor woodwork, cabinet-making and veneer-peeling.

VARIATION IN MEAN GIRTH AS A FUNCTION OF AGE AND DENSITY FOR CORDIA





15-year-old plantation of *Cordia alliodora* Sangoué forest

SILVICULTURAL RULES

The effect of site conditions on the success or failure of *Cordia alliodora* introductions is considerable.

Cordia is sensitive to water supply imbalances of climatic, topographic and/or edaphic origin. In particular, its introduction should not be attempted on the following types of sites:

- Lowland or upslope areas with highly porous soils (sandy texture), where periodic rainfall deficits are amplified by the topographic and edaphic conditions;
- Down slope areas on compact, imporous soils (clayey texture) that are likely to be waterlogged for lengthy periods, especially in moist evergreen forest.

The best growth is observed on soils of balanced texture, of colluvial origin, that have a regular water supply without any marked temporary deficits or excesses. These sites are often located on the lower slopes.

Cordia has a high rate of initial growth: at the age of 5 years its mean total height is from 12 to 15 m, and at 10 years it reaches 25 m (MAITRE, 1979).

The provisional silvicultural rules proposed for this species are:

- planting density: 700 stems/ha.
- at the age of 4 years, the first thinning reduces density to 500 stems/ha. Before thinning, the mean girth is around 40 cm.
- at the age of 8 years, a second thinning reduces density to 250 stems/ha. Before thinning, the mean girth is around 55 cm.
- one or two supplementary thinnings are to be established to bring the stand to its final density.

The rotation cycle is around 30 years to provide an exploitable diameter of 50 cm.

4.3. - Cleistopholis glauca

Cleistopholis glauca (Sobu) is a member of the Annonaceae family. It is a moist secondary forest species found from Cameroon to Angola.

In natural forest it reaches a total height of 35-40 m with a diameter of 80-100 cm.

The white-coloured wood is light and very soft, with considerable shrinkage during seasoning. The suitability of this species for timber remains to be confirmed.

The first plantations established in Zaire showed fast initial growth. At the age of 17 years, with a density of 800 stems/ha, the mean increment in main stem volume is around 35 m³/ha/year.

This species was first successfully introduced in Côte d'Ivoire in 1966 in the evergreen forest zone, using seeds from Gabon.

SILVICULTURAL RULES

Cleistopholis glauca is a sunloving, fast-growing species. However, unlike many experimentally cultivated species, its mean height increment does not reach its maximum level until the age of 10-12 years.

- at 2 years the mean height increment is 1.5 m/year,
- at 4 years it is between 2 and 2.5 m/year,
- at 8 years it is between 2.5 and 3 m/year,
- at 12 years it reaches 3.2 m/year.



18-year-old *Cleistopholis glauca*; Yapo forest

At the age of 2 years the mean height is 2.5-3 m; at 4 years it is 8-10 m and at 6 years it is 16-18 m (PESME 1982).

The provisional silvicultural rules are as follows:

- The recommended planting density is 400-500 stems/ha.
- When the mean height is about 3 m, at the age of around 2-3 years, the trees should be thinned out to 200 stems/ha.
- Around the age of 5-6 years, when the mean height is 15-17m, the mean diameter about 20 cm and the basal area is 8-10 m²/ha, thinning reduces the density to 80 stems/year.

At age 13, with a density of 60 stems/ha, the mean increment in mainstem volume is 14 m³/ha/year. For an exploitable diameter of 60 cm the rotation cycle is 15-20 years.

Planted out with a density of 700 stems/ha with no thinnings, the mean increment in main stem volume is 40-45 m³/ha/year at 10-12 years on experimental plantations. The mean diameter is around 30 cm.

4.4 - *Maesopsis eminii*

The *Maesopsis* belongs to the Rhamnaceae family. This closed forest species appears to have two ecotypes with different growth patterns:

- The first, described by Aubréville, is native to West Africa (it is found from Liberia to Cameroon). It is a tree of second-rank size that reaches a maximum height of 15-20 meters and a maximum diameter of 25-30 cm, and is of no interest from the reforestation standpoint.

- The second is native to Equatorial Africa (where its range extends from Gabon to Angola, Kenya, Tanzania ...). It is a medium-sized tree that reaches a height of 30-35 m and a diameter of 100-120 cm.

This equatorial species ranges from latitudes 8° North to 2° South, with annual rainfall from 1 500 to 3 000 mm/year and a dry season lasting less than 4 months. It grows at altitudes below 700 m.

The wood is light ($D_{12} = 0.4$), of a coppery-brown colour, soft, not very durable but easily impregnated. It can be used for indoor carpentry, boxes, and possibly also for veneer-peeling.

This species, which has been successfully planted in lower Côte d'Ivoire since 1966 using seeds from Uganda, is used for reforestation purposes, particularly in Zaire. There are about 750 seeds to the kilogram.

Infestations of trunk borers, above all at the level of pruning scars, have been observed.



19-year-old *Maesopsis eminii*; Anguededou forest

SILVICULTURAL RULES

This is a fast-growing no-cover species; in Zaire the mean height at the age of 5 years is 17 m with a mean diameter of 14 cm.

In Côte d'Ivoire the initial growth is fast; the mean increment in total height is 2.5-3 m/year. At 1 year the mean total height is 2 m; at 2 years it is 4 m; at 3 years it ranges from 7 to 8 m; and at 5 years it is 11-13 m (PESME, 1982).

The first provisional silvicultural rules are as follows:

- the planting density should be around 500 stems/ha;
- at about the age of 3 years, when the mean height reaches 7-8 m, the mean girth is 25-30 cm and the basal area 3-4 m²/ha, the first thinning reduces the density to 250-300 stems/ha;
- at around 6 years, when the mean height is 11-13 m, the mean girth 65-75 cm and the basal area 10-12 m²/ha, the second thinning reduces the density to 100-125 stems/ha.

At the age of 13 years, the mean diameter increment is 2.3 cm/year with a density of 130 stems/ha.

For an exploitable diameter of 50 cm, the rotation cycle is about 25 years.

4.5 - *Funtumia elastica*

The Funtumias (Apocynaceae family) are small to medium-sized trees. They are divided into two species: *F. africana* and *F. elastica* (Pouo), which do not differ greatly from the morphological standpoint. These are species native to the evergreen forest and transitional semi-deciduous forest. They are sun-lovers that colonize clearings and gaps. They can also grow with a certain amount of cover above them. The Pouo's range is very extensive. They are found from West Africa to Central Africa.

The economic importance of the Pouo (*Funtunia elastica*), which used to be tapped for rubber, was abruptly reduced to the second rank with the development of Hevea plantations. However, for the last two decades this species has been used on a massive scale for matchwood.

The wood is light (D 12 = 0.5), very soft, of low to medium nervosity. Natural seasoning is easy to effect, with low to medium shrinkage. This wood is easy to saw, to peel for veneer and to plane, and holds very well when glued or nailed. However, its natural durability is low.

It bears fruit very early. Fruit-setting is at its maximum in December-January. The fruits are elongated pods grouped in pairs. The seeds are small and very numerous. They are dark-brown, elongated in shape, with a crest of long silky hairs at the top.



9-year-old Pouo; Yapo forest

The Pouo is susceptible to attacks by leaf-eating caterpillars that can be controlled by applications of "Decis".⁵

SILVICULTURAL RULES

The recommended planting density is 1 100 stems/ha. The Pouo is a species with a medium rate of growth. At one year, the mean height is from 0.5 to 0.8 m. The young trees' shape is often defective and requires pruning to shape the buttwood. At the age of 6 years, the mean height is about 8 metres.

Without thinning, the Pouo attains a mean diameter of 10 cm towards the age of 6-10 years. At densities of 300 stems/ha, the mean diameter at age 25 is 20 cm. The hundred largest stems per hectare have a mean diameter of 27 cm, with a mean increment of about 1 cm/year (K. KOFFI 1989).

At this age, the mean volume increment is 6 m³/ha/year. Under average conditions, one may reasonably count on a mean diameter increment of 1.5 cm/year up to the age of 15 years, and of 1 cm/year after that. The exploitable diameter of 45 cm should be reached by the age of 35-40 years.

⁵

Registered trademark.

4.6 - Araucarias

In the tropics, two species of the genus Araucaria are of interest for timberwood production in the moist savannah zone.

These are:

- *Araucaria cunninghamii* (Hoop Pine), a tree native to Queensland (Australia) and Papua New Guinea, at latitudes between 8 and 30° South. It grows from sea-level to an altitude of 2 400 m, with annual rainfall of 1 000 to 1 500 mm, the wettest months being from January to April. The average temperature of the hottest month is between 20° and 26° C, and that of the coldest month between 9 and 16° C, with the possibility of below-freezing temperatures in the uplands in the Southern part of the area. The climates involved can thus range from moist tropical in the North to subtropical in the South. This species flourishes on deep fertile soils, well-drained but with good water retention properties of metamorphic basalt or granite origin.
- *Araucaria hunsteinii* (Klinki Pine), which has a more restricted range in Papua New Guinea, between 5 and 10° S, at altitudes of 600 to 1 500 m. The climate is tropical, with annual rainfall ranging from 1 600 to 1 800, a moderate dry season (no month with $R > 75$ mm) and average temperatures ranging from 27° to 32° C (maxima) and from 18° to 19° C (minima). The soils are heavy-textured, fairly alkaline silty-clay soils with moderate drainage, from somewhat weathered lacustrian or alluvial deposits of sands and conglomerates.

Araucarias have been successfully introduced in the humid savanna of the Niari valley, in the Congo and in Côte d'Ivoire. On the other hand, in the coastal savanna area near Pointe Noire and those of the Chaillu forest (Ngouha II region) in the Congo, the soils are too poor for successful growth and Araucaria does poorly and is susceptible to plant disease.

The wood of these two Araucarias is whitish. Dry density ranges from 0.52 for the *cunninghamii* to 0.45 for the *hunsteinii*. Compared to other equally resinous woods, it has low shrinkage and good bending and axial compressive strength. On the other hand, its radial and tangential compressive strength is low, as is its durability. These Araucarias can thus be used for saw-wood, indoor uses, veneering and plywoods. The long fibres, also suit *Auricaria* for paper manufacturing purposes.

SILVICULTURAL RULES

The development of Araucaria plantations outside their natural range is hindered first of all by seed preservation and transportation problems. For example, the germination rate of the seeds of *Araucaria hunsteinii* decreases by 10 percent each week during the first month, and is nil after eight weeks' storage at room temperature. However, seeds stored in sealed bags at 3 or 4° C retain a germination rate of 50 percent after 18 months. Cold-storage long-distance transport is thus essential.

To overcome this difficulty, propagation by cuttings has been experimentally studied in the Congo, but it is tricky and does not seem suitable for large-scale use.

In the nursery, the seeds are sown on a well-shaded seedbed, at low seed densities to allow for 4 months of growth. After pricking out, the plants are kept in the nursery for 8 months; the saplings planted out at the age of one year are between 20 and 60 cm high.

The planting densities range from 1 600 to 1 100 plants per hectare, i.e. spacing of 2.5×2.5 m to 3×3 m. The initial growth-rate is fairly slow and the plants require assiduous care for the first 3 years.

The plantations are still too young to provide any silvicultural models, but the following results, obtained in the Congo with trees aged 10 1/2 years, should be noted:

| | Araucaria cunninghamii | Araucaria hunsteinii |
|------------------------|---------------------------|-------------------------|
| Ht (m) | 15.3 | 14.8 |
| C 1.50 (cm) | 52 | 49 |
| G (m ² /ha) | 22 | 15.8 |
| V (m ³ /ha) | 168 | 118 |

Plantations established on good soil, in the Niari Valley, show satisfactory growth. Some problems have arisen with parasites on dominated trees in particularly dry years, but they recover with a return to normal weather.

5 - PRODUCTIVITY CHARACTERISTICS

5.1 - The principal species

5.1.1 - Yield volume

Volume tables are available for the principal species currently used for reforestation purposes. The diameters are expressed in metres and the volumes in cubic metres.

These tables refer to main stem volume, corresponding to a cross-section diameter of 7 cm.

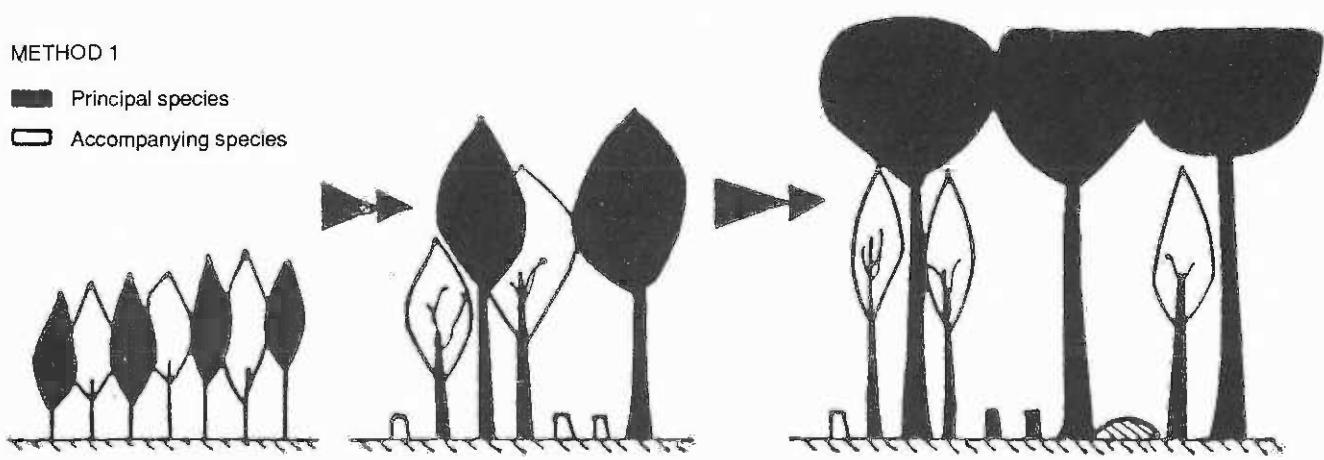
| Species | Volume tables Main stem volume | Validity limits (Diameter) |
|--|--|-------------------------------|
| <i>Tectona grandis</i> (Teak) | $V = 0.0456 - 1.2356 D + 11.8011 D^2$ | 10 - 50 cm |
| <i>Terrietia utilis</i> (Niangon) | $V = 0.023 - 1.136 D + 14.526 D^2$ | 10 - 50 cm |
| <i>Nauclea diderrichii</i> (Badi) | $V = 0.235 + 1.902 D + 4.316 D^2$ | 10 - 40 cm |
| <i>Khaya ivorensis</i> (Mahogany) | $V = 0.466 + 2.794 D + 5.964 D^2$ | 10 - 85 cm |
| <i>Terminalia ivorensis</i> (Framiré) | $V = -0.0382 + 8.093 D^2$ $V = -0.04156 + 14.5062 D^2$ | 10 - 25 cm 25 - 70 cm |
| <i>Terminalia superba</i> (Fraké) | $V = 0.024 - 1.126 D + 13.521 D^2$ | 10 - 55 cm |
| <i>Triplochiton scleroxylon</i> (Samba) | $V = 0.090 - 1.908 D + 13.521 D^2$ | 10 - 40 cm |
| <i>Cedrela odorata</i> (Cedrela) | $V = 0.0364 + 7.353 D^2$ | 10 - 60 cm |
| <i>Pinus caribea</i> (Pine) | $V = 0.028 - 0.946 D + 10.503 D^2$ | 10 - 45 cm |
| <i>Pinus oocarpa</i> (Pine) | $V = 0.017 - 0.609 D + 8.158 D^2$ | 10 - 45 cm |
| <i>Gmelina arborea</i> (Gmelina) | $V = 0.009 - 0.651 D + 9.447 D^2$ $V = 0.185 + 8.909 D^2$ | 10 - 30 cm 30 - 60 cm |

The volume yield is in relation to the characteristics of the stand at the end of the rotation cycle.

STRATIFICATION AND MIX METHODS

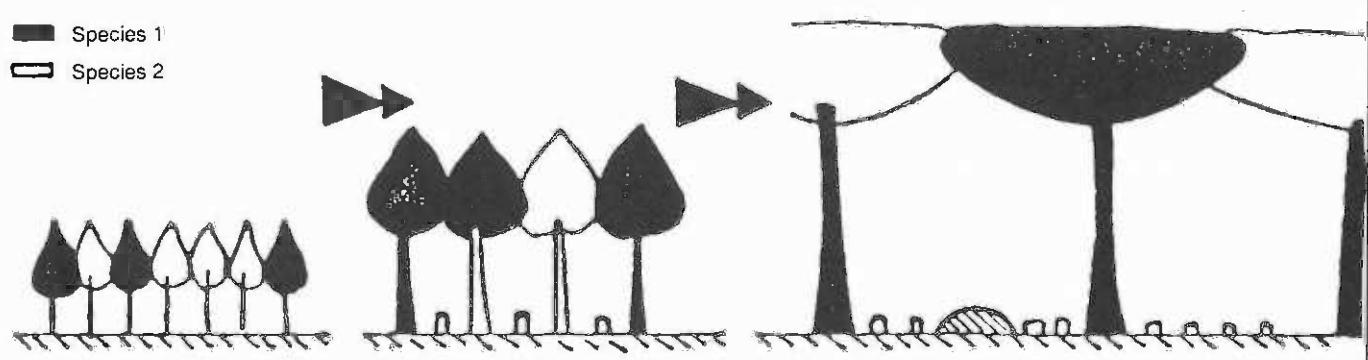
METHOD 1

- Principal species
- Accompanying species



METHOD 2

- Species 1
- Species 2



5.1.2 - Characteristics of the principal species at end of rotation

For economic reasons the forest manager may consider reducing the length of the rotation cycle. As an indication, the rotation and the main stem volume at harvest have been calculated for different exploitable diameters.

| Reforestation species | Rotation (in years) in relation to the exploitable diameter | | | Standing main stem volume in relation to the exploitable diameter (HWV in m ³ /ha) | | | Mean increment (m ³ /ha/year) of stand | |
|--|---|----------|----------|---|------------|------------|---|----|
| | 40 cm | 50 cm | 60 cm | 40 cm | 50 cm | 60 cm | | |
| <i>Tectona grandis</i> (Teak) | 25 45 | 35 65 | 50 85 | 220 250 | 320 360 | 350 400 | 5 | 10 |
| <i>Aucoumea Klaineana</i> (Okoumé) | 25 30 | 30 35 | 35 45 | 300 350 | 350 400 | 400 450 | 9 | 14 |
| <i>Tarrietia utilis</i> (Niangon) | 35 45 | 45 55 | - - | 300 400 | 400 500 | - - | 6 | 11 |
| <i>Nauclea diderichii</i> (Badi) | 20 25 | 25 35 | 35 45 | 150 200 | 300 350 | 350 400 | 9 | 14 |
| <i>Terminalia ivorensis</i> (Framiré) | 20 30 | 30 40 | 35 45 | 180 220 | 200 250 | 225 275 | 7 | 11 |
| <i>Terminalia superba</i> (Fraké) | 15 20 | 20 25 | 25 35 | 130 220 | 225 275 | 275 325 | 8 | 14 |
| <i>Triplochiton scleroxylon</i> (Samba) | 16 22 | 22 30 | 30 40 | 200 250 | 250 300 | 300 350 | 8 | 14 |
| <i>Cedrela odorata</i> (Cedrela) | 12 17 | 17 25 | 25 30 | 180 220 | 200 250 | 250 300 | 10 | 13 |
| <i>Gmelina arborea</i> (Gmelina) | 15 20 | 20 25 | - - | 225 275 | 275 325 | - - | 11 | 19 |

The upper figure indicates the minimum rotation for standing main stem volume and its mean increment.

The lower figure indicates the maximum values for the same parameters.

The variations in mean volume increment at a given age should be noted: they reveal the effect of site conditions and stand treatments on stand growth. In particular, this effect could be quantified indirectly by analysing the yield tables. The values mentioned above are indicative and only provide orders of magnitude.

Moreover, the choice of exploitable diameter affects the timber volume (cut at 30 cm) available when the stand reaches the mean dimensions established by the forest manager.

In the case of Framiré, the following values are obtained:

- for the available timber volume in relation to exploitable diameter;
- for the ratio of timber volume (TV) to main stem volume, as the volume indicated in volume tables is in fact very often the main stem volume (MS).

| Exploitable diameter | 40 cm | 50 cm | 60 cm |
|--|---------|---------|---------|
| Timber volume (TV) m ³ /ha | 100/140 | 210/250 | 300/340 |
| TV/MS (as percent) | 70 | 85 | 95 |

With reference to Mahogany, these values become:

| Exploitable diameter | 40 cm | 50 cm | 60 cm |
|--|---------|---------|---------|
| Timber volume (TV) m ³ /ha | 100/110 | 170/190 | 270/300 |
| TV/MS (as percent) | 76 | 88 | 96 |

The provisional estimates of the influence of exploitable diameter (exp. diam.) on the timber volume logged per hectare in the final harvest (clear felling) are as follows:

| | Exp. diam. | Framiré | Fraké | Samba | Mahogany | Okoumé |
|--|----------------|------------|--------------|-------------|------------|------------|
| Timber/volume in m ³ /ha | 50 cm 60 cm | 230 320 | 230 320 | 230 310 | 190 270 | 320 400 |
| Mean increment in timber volume (m ³ /ha/year) | 50 cm 60 cm | 8.5 9.1 | 10.6 10.8 | 9.4 10.3 | 5.7 6.7 | 10 10 |

These values are of course merely indicative, but they make it possible to show the effect of an economic option (exploitable diameter) on dendrometric parameters such as the timber volume available at the time of harvest.

5.2 - Thinning products

With regard to thinning products, except in the case of species with dense wood of good durability (Teak, Badi) which can be used for fuelwood and construction (building poles), the chief potential uses for most of the species are as posts and small diameter saw-wood. The minimum all-over diameter required for saw-wood is approximately 25 cm.

The chief problems encountered in sawing trials on thinned timbers are:

- low diameter of the wood;
- a high percentage of sapwood;
- a high rate of young wood with very heterogeneous physical and mechanical properties;
- low density;
- the presence of defects: black spots, internal growth strains, frequent knots.

Some of these drawbacks can be attenuated by using selected and improved plant stock, by adequate silvicultural practices (seedling selection, prunings), and the use of sawing equipment and techniques suited to this type of wood.

The technological trials on plantation wood (DURAND 1985) show that the technological characteristics of plantation-grown wood more or less 15 years old are slightly inferior to those of natural forest-grown wood.

| | Natural forest/Plantation (N.F.) (P) | | | | | | Plantation | | | | |
|--------------------------------|---|------|------------------|------|------------------|------|------------|-----------------|-----------------|---------|------|
| | Framiré N.F. P. | | Fraké N.F. P. | | Samba N.F. P. | | Cedrela | Pinus carib. | Pinus oocar. | Gmelina | Teak |
| Density | 0.51 | 0.42 | 0.57 | 0.40 | 0.40 | 0.36 | 0.30 | 0.45 | 0.53 | 0.48 | 0.65 |
| Volumetric shrinkage (%) | | | 12.9 | 11.5 | 9.8 | 9.7 | 11.3 | 11.7 | 12.5 | 9.2 | 8.1 |
| Nervosity (%) | 0.36 | 0.37 | 0.47 | 0.43 | 0.37 | 0.36 | 0.32 | 0.40 | 0.41 | 0.44 | 0.35 |

$$V_s - V_o$$

$$\text{Volumetric shrinkage} = \frac{V_s - V_o}{V_o} \times 100\%$$

where V_o : Anhydrous volume

V_s : Volume of a sample passing from the anhydrous to the saturated state.

Nervosity: Volumetric shrinkage/moisture content of the wood at saturation point

With regard to the mean dimensions of thinning products, the following figures are indicative (DUPUY 1988) :

N: Number of stems/ha harvested in thinning operation

D: Mean diameter, in cm, of the stands prior to thinning. The mean diameter of the stems harvested in the thinning operation is slightly less than that of the stand prior to thinning.

V: Mean main stem volume (in m³/ha) of the thinning harvest. The figure for this volume is given only when the thinning products are big enough to be used for construction wood or timber.

| Species | Thinning-out or 1st thinning | | | 2nd thinning | | | 3rd thinning | | |
|--|---------------------------------|------|----|--------------|----|----|--------------|----|-----|
| | N | D | V | N | D | V | N | D | V |
| Aucoumea klaineana (Okoumé) | 600 | - | - | 150 | 17 | - | 80 | 29 | 70 |
| Tarrietia utilis (Niangon) | 250 | - | - | 350 | 15 | - | 175 | 21 | - |
| Terminalia superba (Fraké) | 380 | (10) | 20 | 160 | 18 | 40 | 65 | 26 | 45 |
| Terminalia ivorensis (Framiré) | 360 | (10) | 25 | 175 | 18 | 40 | 80 | 25 | 45 |
| Triplochiton scleroxylon (Samba) | 300 | - | - | 175 | 12 | - | 90 | 21 | 40 |
| Cedrela odorata (Cedrela) | 600 | - | 40 | 275 | 15 | 50 | 120 | 23 | 55 |
| Pinus (Pine) | 500 | 9 | - | 300 | 12 | - | 200 | 23 | 100 |

In the case of Teak, in relation to the thinning products' dimensions and conformation, the following uses can be envisaged (DURAND, 1984) :

| | | | | | |
|-----------|---------|------------|------------|------------|---|
| Diameter: | < 10 cm | 10 - 14 cm | 15 - 21 cm | 25 - 35 cm | > 35 cm |
| Length: | < 3 m | 3 - 4 cm | 8 - 18 m | > 3 m | > 3 m |
| Use: | stakes | poles | posts | saw-wood | saw-wood, cabinet- making, slicing |

The term "saw-wood" comprises products such as planks, boards, rafters and battens.

For this species, the products obtainable from the various thinnings are thus as follows (MAITRE H.F., 1983) :

| Thinning (no.) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|--|----|----|----|----|----|----|----|
| Mean diameter (in cm) | 11 | 15 | 21 | 25 | 30 | 38 | 43 |
| Main stem wood volume (m ³ /ha) | 25 | 36 | 35 | 39 | 39 | 44 | 36 |
| Fuelwood | * | * | * | * | * | * | * |
| Construction wood | * | * | * | * | * | * | * |
| Timber | * | * | * | * | * | * | * |

* = possibility of use

5.3 - Rotation periods

At the time when trees are planted, the desire to harvest a crop is already present.

Production reforestation corresponds to the intention to obtain given categories of wood products at maturity.

It is important to foresee different exploitable ages in relation to the objectives established by the forestry plan.

The optimization of the logging age depends upon technical, silvicultural and financial criteria.

In the present context, the aim of intensive reforestation projects is the quick implementation of successive harvest that will make it possible to relieve the pressure on natural forests, with a view to rationalizing their exploitation and ensuring their continued existence through adequate planning.

Exploitable age is considered here from the standpoint of optimizing the relationship between timber volumes/silviculture and profitability (DUPUY, 1987).

5.3.1 - Ratio of exploitable diameter to usable volume

In the early stages, it is important to seek to exploit the greatest possible amount of the timber capital produced. The stem volume is generally considered equivalent to main stem volume. When timber is the objective, it is generally prudent to limit the small-end section to a diameter of 25 cm.

It is thus possible to evaluate the volume of usable timber by means of the small-end section volume/main stem volume ratio.

| Small-end cut volume | Diameter at 1.30 m (in cm) | | | | | |
|----------------------|----------------------------|-----|-----|-----|-----|-----|
| Main stem volume | 35 | 40 | 45 | 50 | 55 | 60 |
| <u>25 cm cut</u> | | | | | | |
| Fraké | 82% | 89% | 92% | 92% | 93% | 93% |
| Gmelina | 64% | 80% | 91% | 93% | 94% | 95% |
| Cedrela | 74% | 79% | 83% | 87% | 90% | 94% |
| <u>30 cm cut</u> | | | | | | |
| Fraké | 64% | 76% | 83% | 88% | 91% | 93% |
| Gmelina | 41% | 61% | 75% | 84% | 90% | 90% |
| Cedrela | 61% | 67% | 72% | 76% | 79% | 82% |

With a 25 cm small-end cut, it is necessary to avoid setting exploitable diameters of less than 40 - 45 cm so as to ensure that at least 80 percent of the stem volume will be usable.

5.3.2 - Ratio of exploitable diameter to number of thinnings

The silvicultural rules have in any case been formulated so as to limit inter-tree competition by thinning while maintaining a steady pace of individual growth.



Commercial Teak thinning products

Regular thinning is therefore indispensable. The number of thinnings depends on the exploitable diameter.

| Species | Exploitable diameter | Number of thinnings |
|----------------------------|----------------------|---------------------|
| Teak | 30 cm | 3 |
| | 40 cm | 4 |
| | 45 cm | 5 |
| | 50 cm | 6 |
| Fraké, Framiré Samba | 40 cm | 2 |
| | 50 cm | 3 |
| | 60 cm | 4 |
| Cedrela | 40 cm | 3 |
| | 50 cm | 4 |
| | 60 cm | 5 |

To obtain an exploitable diameter of 50 cm, one must plan.

- 6 thinnings for Teak,
- 4 thinnings for Cedrela,
- 3 thinnings for Fraké, Framiré and Samba.

If the exploitable diameter is to be 60 cm one extra thinning should be planned to reduce inter-tree competition.

5.3.3 - Ratio of exploitable diameter to average exploitable age

For correctly managed stands and average site fertility the average time required to reach exploitable diameters can be calculated.

| Species | Exploitable diameter | Length of cycle |
|---------|----------------------|-----------------|
| Teak | 40 cm | 35 years |
| | 45 cm | 45 years |
| | 50 cm | 55 years |
| Fraké | 40 cm | 16 years |
| | 45 cm | 20 years |
| | 50 cm | 25 years |
| | 60 cm | 35 years |
| Framiré | 40 cm | 20 years |
| | 45 cm | 25 years |
| | 50 cm | 35 years |
| | 60 cm | 45 years |

5.3.4 - Exploitable diameter and profitability

Without knowing the selling price for plantation wood it is difficult to make accurate estimates. By way of indication, if a value of 10 percent is ascribed to the internal return rate for an exploitable diameter of 50 cm for Fraké, the following is obtained:

| Exploitable diameter | Rate of return |
|----------------------|----------------|
| 40 cm | 4% |
| 50 cm | 10% |
| 60 cm | 8% |

In the case of Teak, if the value of 10 percent is ascribed to the internal rate of return for a diameter of 45 cm, the result is:

| Exploitable diameter | Rate of return |
|----------------------|----------------|
| 40 cm | 4 % |
| 45 cm | 10 % |
| 50 cm | 8.5 % |

5.3.5 - Rotation recommendations

In the case of species with medium-length rotation cycles (Fraké, Framiré, Samba, Gmelina, Cedrela):

- The exploitable diameter must be at least 40 cm to limit commercial losses on the stem volume produced;
- An exploitable diameter in excess of 50 cm, would require an extra thinning.
- Over 50 cm in exploitable diameter, the required additional rotation time does not give rise to any additional profit.

For Teak, an exploitable diameter of 45 cm is the best compromise between profit and yield.

Insofar as the goal is to enhance the return on timber and avoid the very large diameters that would protract the rotation cycle for no additional financial benefit, it is reasonable to adopt an exploitable diameter of 45 - 50 cm for medium-rotation species and of 40 - 45 cm for Teak, on fertile sites. On sites with poor fertility it is necessary to adopt smaller exploitable diameters so as to avoid excessively protracting the cycle and allow the rapid conversion of these rather unproductive stands.

| Species | Fertility | Exploitable diameter | Exploitable age |
|--|-----------|----------------------|-----------------|
| Teak | Excellent | 50 cm | 45 years |
| | Medium | 45 cm | 50 years |
| | Poor | 40 cm | 65 years |
| Fraké | Excellent | 50 cm | 18 years |
| | Medium | 45 cm | 22 years |
| | Poor | 40 cm | 25 years |
| | Bad | 35 cm | 25 years |
| Framiré Cedrela Samba Gmelina | Good | 45-50 cm | 25-30 years |
| | Good | 45-50 cm | 18-22 years |
| | Good | 45-50 cm | 25-30 years |
| | Good | 45-50 cm | 15-20 years |

The choice of exploitable age is subject to the following constraints:

- Technical: to obtain, in a given time, the largest possible quantity of wood suitable for timber;
- Financial: for timber one must seek to achieve an optimum rate of return;
- Silvicultural: to avoid too many thinnings in mature stands, so as to preserve the stand and simplify management.

In the present state of the art, the following exploitable ages can be foreseen for properly-managed stands of medium fertility:

| Species | Exploitable diameter | Exploitable |
|---------|----------------------|-------------|
| Gmelina | 50 cm | 15-20 years |
| Fraké | 50 cm | 20-25 years |
| Cedrela | 50 cm | 20-25 years |
| Framiré | 50 cm | 30-35 years |
| Samba | 50 cm | 30-35 years |
| Teak | 45 cm | 50-60 years |

6 - MIXED STANDS

The idea of associating species, most often two, on plantations is an old one. The object was to attempt to solve, or at least simplify the silvicultural (pruning, shape ...) and plant protection (borers, psyllids, ...) problems inherent in single species plantations.

Ever since the first line enrichment and forest underplanting operations, silviculturalists have attempted associations of Niangon, Mahogany, Sipo, Makoré, Framiré, Okoumé, etc. Recently, with the development of wholly exposed plantations, different associations have been attempted with Teak, Framiré, Mahogany, Fraké, Cedrela, Samba, Gmelina, etc.

These trials suggest two modes of association in relation to the silvicultural characteristics of the species to be associated in mixed stands.

6.1 - Ways of associating two species in mixed stands

6.1.1 - Creation of a two-storey stand

The object is to create a two-storey stand consisting of a principal species to be given priority in silvicultural operations and an accompanying species whose role is primarily silvicultural. This two-tiered structure, determined by the intrinsic characteristics of the species concerned, changes in relation to the silvicultural treatments applied.

Depending upon the silvicultural characteristics of the principal species, the characteristics of the accompanying species may differ considerably:

- If the principal species is sun-loving and has a fast initial growth-rate, the accompanying species forms:

- either a permanent or temporary sub-storey playing a training role (stem formation, pruning)
- or an accompanying stand to fill in which will then be harvested during the first thinnings (cover formation).

The role of the associated species is in reality often a mixed one: training and filling-in.

| Principal species | + | Accompanying species |
|-------------------|---|--|
| Samba | + | Teak (training role) |
| Sipo | + | Niangon (accompanying role) |
| Mahogany | + | Niangon (mixed role: training/filling) |

- If the principal species

- either cannot be planted in mono-species stands for plant protection reasons (Mahoganies)
- or has a slow initial growth rate (Sipo),

the role of the accompanying species is in this case to take the place of the natural regrowth during the first years following planting, as a formation whose growth is controlled by the silviculturalist.

Throughout the first phase of stand growth, the accompanying species is dominant and the principal species is dominated.

The importance of the accompanying species gradually and progressively decreases to the advantage of the principal species, of which only the best individuals are preserved, however, during the thinning operations: the final stand is a two-storey single-tree mixture of the two species.

6.1.2 - Creation of a single-storey stand

The object is to create a synergy between two species whose silvicultural importance is identical.

The aim of this type of association is thus to obtain, at the end of the rotation cycle, a single-storey formation where two species grow together in clumps, or in a single-tree mixture where both reach the exploitable diameter simultaneously.

Under these conditions, the two species must have similar growth patterns and silvicultural rules, in particular with regard to the following parameters:

- planting density
- manner and intensiveness of thinning out and thinning operations (stand age, number of stems to be removed, basal area, operation limit)

- number of operations
- length of rotation cycle

| Species 1 | + | Species 2 |
|-----------|---|-----------|
| Framiré | + | Fraké |
| Fraké | + | Samba |
| ... | | |

When a species of economic interest is vulnerable to adverse weather conditions, disease or other factors (for example Framiré), the forester engages in mix planting (such as Framiré + Fraké) to reduce the risk of failure by combining:

- a target or main species (Framiré),
- a secondary species (Fraké).

Thus, if the main species fails to grow satisfactorily, the mix can be converted into a single-species stand of the secondary species. This option is only used, of course, as a last resort.

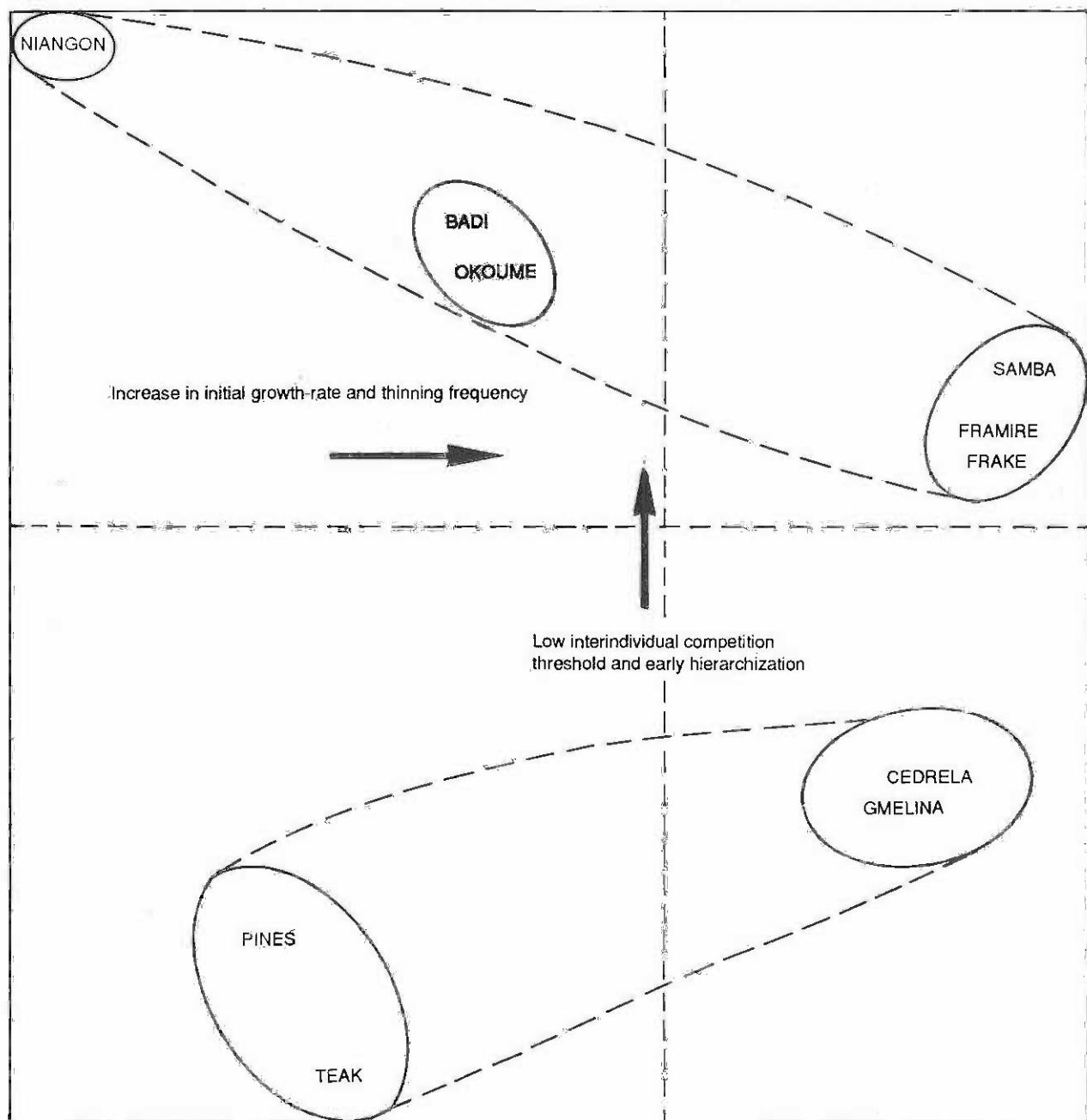
6.2 - Comparative growth and compatibility of mixed species

It appears that the compatibility of two mixed species is linked to temperament. The two associated species must be able to tolerate each other. In particular, if their initial growth is different, the species with the slowest growth must tolerate being dominated.



Teak/Fraké mix (aged 3 years); TENE forest

SILVICULTURAL AFFINITIES OF REFORESTATION SPECIES



At the present time, the species used for reforestation purposes are sun-loving; when they are dominated by others their growth is greatly slowed down. Keeping them in this state can, in the end, lead to their elimination. However, some of these species can tolerate a certain amount of cover. Two types of species stand out this regard:

| | |
|--|---|
| Exclusively dominant species: | Framiré, Fraké Samba, Gmelina, Cedrela, Pines, Okoumé |
| Species that can tolerate a certain amount of cover: | Niangon, Teak, Mahogany, Sipo |

In associating two species with the object of creating a two-storey, principal species/accompanying species stand (mode 1) it is possible to associate:

- as the accompanying species, those that can tolerate a certain amount of cover;
- as the principal partner, a species with faster growth than the accompanying species, as the principal species remains dominant.

In this case, the silvicultural operations will be performed for the benefit of the dominant species. The role of the accompanying species remains subordinate at all times to that of the principal species.

The association of two species in a single-tree mixture must meet the following criteria:

- their growth patterns must be similar, in order to check the appearance of a dominant/dominated state;
- their social behaviour (competition thresholds) and thinning regime (number and intensiveness) must be compatible;
- silvicultural treatment must be the same for both species.

A silvicultural affinities trial (A.C.P.) to classify the various species reveals a very marked partition of the species in the main storey.

It is based on the following criteria:

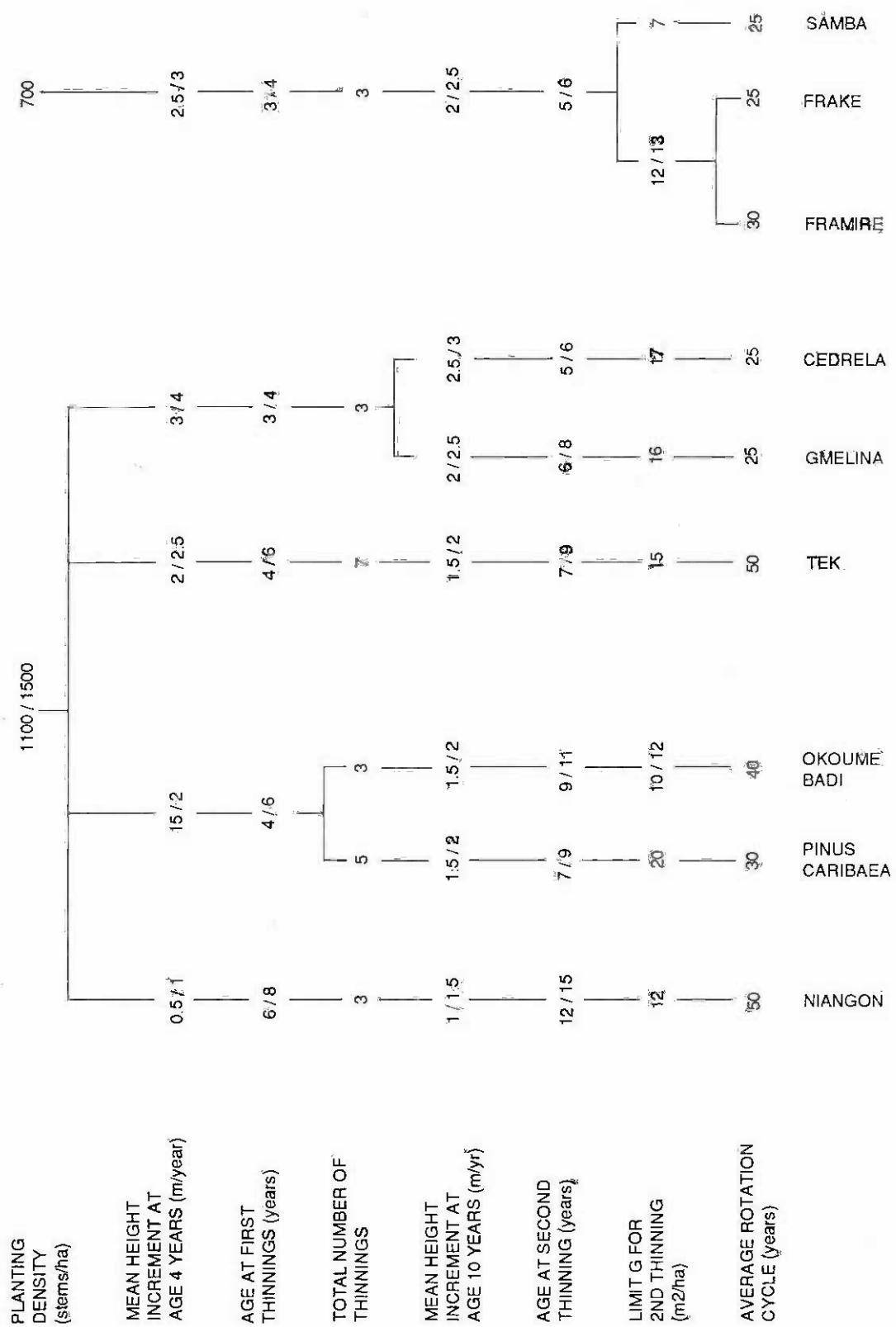
- mean height increment (between the ages of 1 and 10 years), which determines the stands' future stratification;
- social behaviour, which is quantified by the basal area thresholds above which individuals begin to compete;
- planting density, the value of which can favorably influence the conformation of the harvested stems by fostering pruning, straightness etc.;
- the thinning schedule, defined so as to ensure optimum stand growth.

There is a very marked partition of the species in the main storey.

Analysis of the characteristics of the principal axes makes it possible, after interpretation, to distinguish:

SILVICULTURAL CONSTRAINTS ON MIXED STAND MANAGEMENT

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- * The social species that rapidly become ranked into several tiers when interindividual competition appears. Dominant subjects emerge in the stand with the appearance of a codominant tier and a dominated tier. The latter two tiers consist of slow-growing individuals who are sooner or later eliminated by their competitors.

In this group two separate entities stand out:

- species with slow to medium initial growth (1 to 2m/year) with a long rotation cycle (> 35 years) and late thinning: Okoumé, Badi and Niangon;
- species with rapid initial growth (2 to 3 m/year), medium-length rotation (25 to 30 years), and early thinning: Framiré, Fraké, Samba.

The silvicultural procedures for the species in this first group are characterized by few thinnings (3) occurring at medium to low (< 15 m²/ha) basal area thresholds which can be considered as competition indicators.

- * Species which tolerate heavy competition without the rapid appearance of dominant subjects and distinct vertical ranking.

In this group the following two sub-groups can be distinguished:

- species with a medium rotation cycle, fast initial growth and a few heavy thinnings (3): Cedrela and Gmelina;
- species with medium and long rotation cycles characterized by repeated thinnings (5 to 7) of medium intensity: Teak and Pine.

The silvicultural procedures for the species in this second subgroup are characterized in particular by thinning operations carried out at high basal area thresholds (> 15 m²/ha).

Classification into these four sub-groups can more clearly show certain mixed-species affinities.

The species in the above groups show similarities in their specific and social behaviour which, however, are not sufficient to conclude that they can always be grown in a single-tree mixture. For example, Teak has a faster initial growth rate than Pines and would quickly rise above them, which would consequently alter their further growth.

As regards the special case of Mahogany, silviculturalists have had recourse to mixed planting to try to solve the problems of terminal bud destruction by borers. These terminal bud attacks do in fact considerably decrease initial growth and cause certain shape problems (especially forking).

It appears that when planted in association with species with slow initial growth (Niangon, Okoumé, Badi), some Mahogany trees, in spite of attacks, grow sufficiently well to stay in the dominant storey and develop well-shaped buttwood that reaches a length of around ten metres. The success of this type of mix, which is the result of a compromise between:

- on the one hand, the medium to slow initial growth rate of Mahogany. (When not attacked, it is around 2 m/year in height, but is in fact reduced by about half by the borer attacks);

and on the other, its association with slow-growing species (1m/year) which in the end, through selective thinnings, makes it possible to obtain a single-tier stand of the long-rotation species (Badi, Okoumé, Niangon) with a few dozen Mahogany trees mixed among them. The final mix depends on the growth and/or shape characteristics of the Mahogany trees. If the latter prove too disappointing, the final stand will be converted into a single-species, one consisting exclusively of the long-rotation species associated with the Mahogany in the original mix.

6.3 - Silvicultural constraints on the creation of mixed stands

The characteristic behaviour of each species gives rise to a set of silvicultural constraints applying to mixed stands.

If the reforestation manager decides to plant a mix of two species, he must ensure that these species:

- have identical ecological requirements;
- are species with similar planting densities;
- have compatible growth and silvicultural characteristics.

| | Fraké | Framiré | Samba | Cedrela | Gmelina | Teak | Pine | Badi | Okoumé |
|---------|-------|---------|-------|---------|---------|------|------|------|--------|
| Fraké | | | | | | | | | |
| Framiré | +/0 | | | | | | | | |
| Samba | +/0 | +/0 | | | | | | | |
| Cedrela | | | | | | | | | |
| Gmelina | 0 | 0 | +/0 | +/0 | | | | | |
| Teak | 0 | 0 | 0 | 0 | +/0 | | | | |
| Pine | | | | | | | | | |
| Badi | | | | | | | | | |
| Okoumé | | | | | | | | +/0 | |
| Niangon | | | | | | | | 0 | 0 |

- + : The two species can be grown together in a single-tree mixture without favouring one over the other.
- 0 : The principal species must be chosen prior to planting or, at latest, at the time of the first thinning-out operation so as to definitively establish the stand's vocation at an early stage. As a rule, the principal species is the one with the most rapid initial growth.
- : Association to be avoided.



Niangon/Badi mix (aged 3 years); Yapo forest

The principal mixes that can at present be recommended are the following:

Principal species/accompanying species mixture

Framiré/Teak:

Fraké/Teak

Samba/Teak

Cedrela/Teak

Gmelina/Teak

Teak is the accompanying species: it can tolerate a certain amount of cover in this role. Its growth, relatively slower than that of the main species considered here, relegates it to the dominated storey. These mixes, which are suitable for use essentially in the moist semi-deciduous forest zone, may evolve in the pre-forest zone towards a single-tree mixture as the growth of the so-called principal species slows sooner than Teak, which can thus catch up with them.

Mahogany/Niangon:

This mix, suitable for use in the moist evergreen forest zone, evolves as time passes. Certain Mahogany trees, dominated when young, may in spite of borer attacks catch up with the Niangons and rise above them as the stand grows older. The stand evolves towards a single-tree mixture of a few Mahoganies in a stand predominantly composed of Niangons.

Single-tree mix

Framiré/Fraké:

This mix, suitable only for the moist evergreen forest/semi-deciduous closed forest transitional zone, must be treated so as to favour the Framiré by late thinning.

Fraké/Samba: This mix, suitable for the moist semideciduous forest zone only, may be made to favour the Sambas by early thinning.

Framiré/Samba: This mix, which has not yet been tested, could be used in the moist evergreen forest/moist semideciduous forest zone. Late thinning should favour the Framiré.

Badi/Mahogany: This mix, already successfully used in Central Africa, should be managed so as to favour the Mahoganies when they are growing well; otherwise, the Mahoganies are to be eliminated.

Cedrela/Gmelina: This mix, which can be used throughout the closed forest zone, must be managed so as not to penalize the Gmelinas, whose initial growth-rate is slower than that of the Cedrelas: late thinning is recommended.

Samba/Gmelina: This mix is to be used in the moist semi-deciduous forest zone, where late thinning will favour the Gmelinas.

If the reforestation manager decides to associate in a single-tree mixture a species whose initial recommended density is 500/700 stems/ha/ (principal species) with a secondary species for which 1 100 - 1 500 stems/ha is recommended, the density adopted for the mix must be the highest, i.e. 1 100/1 500 stems/ha.

If the mix is effected by alternating row by row, with an interval of 3.75 m between rows (to allow mechanized upkeep), the principal species is planted at intervals of 3.75 m along the row and the accompanying species at intervals of 2/2.5 m along the row.

In this case, the accompanying species basically plays a training role, keeping regrowth under control and training the trees belonging to the principal species.

However, at the end of the principal species' rotation cycle, the forest manager must be able to harvest secondary species logs marketable as timber and/or construction wood (posts, saw-wood).

To optimize this harvest, the conformation of the secondary species stems must be satisfactory. From the silvicultural standpoint, conformation and planting density are closely linked; it is thus necessary to adopt a planting density that is not prejudicial to the secondary species, while at the same time intervening vigorously on the dominant storey, formed by the principal species, when the first thinnings are carried out.

The following table summarizes the recommended densities:

| Planting densities | 700 stems/ha | 1 100 stems/ha | 1 500 stems/ha |
|--------------------|---|--|--|
| Mix: | Framiré + Fraké Fraké + Samba Framiré + Samba | Mahogany + Badi Mahogany + Niangon Cedrela + Gmelina Okoumé + Mahogany Gmelina + Samba | Framiré + Teak Fraké + Teak Samba + Teak Gmelina + Teak Cedrela + Teak |

The mix rate can be established in relation to the stand's vocation.

| | Stand vocation | Mix rate | |
|-----------|--------------------------|-------------|--------------|
| | | at planting | at cycle end |
| Species 1 | Principal + accompanying | 40 - 50% | 25 - 35% |
| Species 2 | | 50 - 60% | 65 - 75% |
| Species 1 | Single-tree | 30 - 50% | 10 - 50% |
| Species 2 | | 50 - 70% | 50 - 90% |

The number of main species stems planted should allow a selection to be effected within this species during thinning operations.

6.4 - Recommendations

The management of mixed stands is a delicate business that has not yet been the subject of detailed systematic experimentation. However, the CTFT has for many years now been cultivating behaviour trial plots of mixed species.

Analysis of the data can provide silvicultural guidelines for certain mixes. However, the manager must clearly define his objectives before the stands are planted. A stand's objective conditions the silvicultural rules that will be applied to it (planting density, mix rate, thinning schedule and thinning rates, rotation, volumes harvested, ...).

The provisional silvicultural rules adopted for a principal species/accompanying species mix are those of the principal species. The accompanying species must in fact be treated so that it does not compete with the trees of the principal species that are scheduled for full maturity (which gives rise to the need for thinning from above of the accompanying species, where trees are in proximity to the dominant partner).

For a single-tree mixture the recommended species have compatible silvicultural rules, adjustable in particular in relation to the proportions of the mix (the latter evolve in relation to the thinnings performed). Silvicultural action thus makes it possible to favour a given species, particularly when the second species' growth is disappointing.

In Côte d'Ivoire, reafforestation operations first began in 1930 in moist evergreen forest. On the basis of the numerous applications of the various enrichment and reforestation methods implemented, it was possible to begin to gain an understanding of the auto-ecology of certain moist forest species. Numerous behaviour trials have made it possible to define a range of species suitable for reforestation operations. At the same time, the choice of reforestation methods and species has evolved in the light of acquired knowledge and technical and economic imperatives.

It must be realized that present reafforestation policy is subject to strict economic imperatives that have led to the selection:

- of species that are easy to propagate and that show good rooting capacity when planted out;
- of species that grow with no cover and at a fast initial pace so as to limit the number of tending operations necessary to ensure the successful growth of young plantations;
- of species with high volume increments and consequently transplanting with a medium-length rotation cycle. One of the aims is to ensure staggered short-term production that can partially substitute for natural forest.

For each homogenous ecological zone, the selection of species requiring no shade, with root systems able to recover from possible injury during transplanting, a fast growth-rate and the ability to grow in mono-species stands is thus achieved by the use of behaviour-trial plots.

After these preliminaries, the silviculturalist must resolve the following problems for each species selected as suitable for reforestation use:

- identification of the provenances suited to each reforestation zone;
- definition of the types of transplants required and their production techniques;
- identification of the minimum densities necessary to obtain well-shaped trees,
- adventitious vegetation control operation schedules and methods;
- whether or not artificial pruning is necessary to improve the quality of the wood;
- definition of the thinning regime, adjusted in relation to site fertility;
- the influence of exploitable diameter on the rotation cycle and the nature of the logging products.

Of course this document is only a very incomplete memorandum for those in charge of timber-oriented reforestation operations, and for silviculturalists in particular. The CTFT results are presented as concisely as possible from the standpoint of transferring the research findings to the development phase.

In certain cases, in particular as regards the silvicultural rules for species such as Gmelina, Badi and Pine, some recommendations are only of a provisional character as they are based on trials of a fragmentary nature or that are still in progress.

It is considered that silvicultural research efforts on timber-oriented plantations should be pursued in the following directions:

- continuation of efforts to identify new fast-growing, coverless timber species;
- improvement of tending, pruning, etc. operations for young stands;
- establishment of growth models for the various species used for industrial reforestation purposes. These growth models must allow adjustment of the average intervention rules in relation to site conditions or particular stand characteristics.
- the establishment or pursuit of supplementary silvicultural programmes for those species whose silvicultural rules are still only provisional.

④ study of the association of certain species in mixed plantations and the silvicultural rules for the stands thus established.

Such a programme, with its long-term span, could only be implemented in close collaboration with the users of research findings. As regards the silvicultural rules established by the research programme, it is probable that they will sometimes have to be adapted to special cases, in the light of which it will be possible to achieve a better understanding of the reality. Development-research feedback will thus be welcomed for its potential contribution to those production models which have to cover a wide range of options.

The following recommendations concern the choice of reforestation species:

| Zone | Pure stands | | Mixed stands | |
|-----------------------------|---------------------------|--|---------------------------------------|--|
| | Long cycle | Medium cycle | Long cycle | Medium cycle |
| Moist evergreen forest | Niangon Okoumé Badi | Framiré Gmelina Pines | Mahogany + Niangon Mahogany + Badi | |
| Moist Semi-deciduous forest | Teak Badi | Framiré Fraké Samba Cedrela Gmelina Pines | | Framiré + Fraké Samba + Fraké Framiré + Teak Samba + Teak Gmelina + Teak Fraké + Teak |
| Pre-forest | Teak | Gmelina | | Gmelina + Teak |

It is obvious that the proposed silvicultural rules invite many comments. In particular, as regards the planting densities, two groups of species can be distinguished:

- Species for which the stand effect is indispensable to good stem conformation (especially straightness), such as Teak, Cedrela or Gmelina. Good-quality stands require compliance with the minimum density thresholds, especially at planting time.
- Species whose shape is not greatly affected by density, such as Terminalia. For these species it is possible to opt for widely spaced planting (5 x 5 m, i.e. 400 stems/ha). This solution entails a dynamic silvicultural approach, including in particular pruning to avoid the presence of large knots in the wood. These low planting densities also make it possible to eliminate the first thinning, which is always expensive. With the use of improved planting stock it may be possible to further reduce planting density.
- Such widely spaced planting may also suggest the possibility of temporary associations with interplanted food crops (maize and groundnuts in particular) until the canopy begins to close. Such interplanted crops are also a useful way of facilitating the control of undesirable adventitious vegetation and enhancing the stands' profitability. These annual crop associations, effected during the initial years of the stand's lifetime, would make it possible to reduce the number of tending operations and assure an annual food harvest. But these considerations are already bringing us to the borderland with agro-forestry.

It is not our intention here to draw up an exhaustive list of the research to be undertaken. Dynamic reforestation should encourage us to channel our energies towards activities that can produce quick results, and yet not make us lose sight of the fact that forestry will always be a long-term business.

We also feel it is important to draw attention yet again to the body of experience available on plantation silviculture in lowland moist forest zones. Nevertheless, recourse to industrial plantations must not mask the need to prevent the impoverishment and excessive degradation of natural forest. Their management could decrease the necessity for the labour-intensive silvicultural techniques and alterations in the natural environment inherent in commercial reforestation. This process is in fact not without its hazards, especially from the phytopathological standpoint.

Experience also shows that it is necessary to control shifting cultivation in the vicinity of forest stands, and would suggest the desirability of combining, whenever possible, the management of natural stands with reforestation. The latter solution would be reserved for degraded stands which must be converted into even-aged plantations.

7 - PLANTATIONS OF FIFTY-EIGHT LESSER-KNOWN SPECIES NATIVE TO AFRICAN MOIST FORESTS

Fifty-eight species native to the African closed forest zone have been planted with no shelter on trial plots on various sites with climatic conditions corresponding to moist evergreen forest, transitional evergreen/semi-deciduous forest and semi-deciduous forest.

The trial plots were established from 1981 onwards on the following sites in Côte d'Ivoire:

- Yapo, in moist evergreen forest,
- Mopri, in transitional semi-deciduous/evergreen forest,
- Sangoué, in semi-deciduous forest.

In the research zone in question, the mean annual rainfall ranges from 1 200 mm/year to 1 800 mm/year. The duration of the dry season is between 3 and 6 months.

The information contributed by these trials is of the greatest importance. They prove quite simply that many natural forest species can be successfully planted with no cover.

Their initial growth is satisfactory: the mean height increment often exceeds 1 m/year. The chief silvicultural parameter requiring attention is the need for painstaking and repeated tending until the trees are free of regrowth.

Due to their ecological characteristics, some species were introduced on several sites. The planting site totally cleared, either manually (Yapo) or mechanically (Mopri and Sangoué). The trees were planted on open ground at intervals of 3 m x 3 m.

LIST OF SPECIES TESTED ON BEHAVIOUR-TRIAL PLOTS ON THE THREE SITES (YAPO, MOPRI AND SANGOUÉ)

| <u>Species</u> | <u>Scientific names</u> |
|-------------------------|------------------------------------|
| 1 Abale | <i>Petersianthus macrocarpa</i> |
| 2 Aboudikro | <i>Entandrophragma cylindricum</i> |
| 3 Bassam mahogany | <i>Khaya ivorensis</i> |
| 4 White mahogany | <i>Khaya anthotheca</i> |
| 5 Broad-leaved mahogany | <i>Khaya grandifolia</i> |
| 6 Senegal mahogany | <i>Khaya senegalensis</i> |
| 7 Adjouaba | <i>Dacryodes klaineana</i> |
| 8 Aiélé | <i>Canarium schweinfurthii</i> |
| 9 Akatio | <i>Chrysophyllum africanum</i> |
| 10 Ako | <i>Antiaris africana</i> |
| 11 Akoua | <i>Antrocaryon africana</i> |
| 12 Amazakoué | <i>Guibourtia ehie</i> |
| 13 White aniégré | <i>Aningeria robusta</i> |
| 14 Aribanda | <i>Trichilia lanata</i> |
| 15 Azobé | <i>Lophira alata</i> |
| 16 Azodau | <i>Afzelia bella v. gracilior</i> |
| 17 Ba | <i>Celtis mildbraedii</i> |
| 18 Badi | <i>Nauclea diderichii</i> |
| 19 Bahé | <i>Fagara macrophylla</i> |
| 20 Bété | <i>Mansonia altissima</i> |
| 21 Bi | <i>Eribroma oblonga</i> |
| 22 Bodo | <i>Detarium senegalense</i> |
| 23 Bon | <i>Cordia Platythyrsa</i> |
| 24 Bossé | <i>Guarea cedrata</i> |
| 25 Dabema | <i>Piptadeniastrum africanum</i> |
| 26 Dibétou | <i>Lovoa trichilioides</i> |
| 27 Difou | <i>Morus mesozigia</i> |
| 28 Eho | <i>Ricinodendron africanum</i> |
| 29 Emien | <i>Alstonia boonoi</i> |
| 30 Etimoé | <i>Copaifera salikouna</i> |
| 31 Faro | <i>Daniellia ogea</i> |
| 32 Silk-cotton tree | <i>Ceiba pentandra</i> |
| 33 Iatandza | <i>Albizia ferruginea</i> |
| 34 Ilomba | <i>Pycnanthus angolensis</i> |
| 35 Iroko | <i>Chlorophora excelsa</i> |
| 36 Ko melega | <i>Berlinia confusa</i> |
| 37 Kosipo | <i>Entandrophragma condollei</i> |
| 38 Kotibé | <i>Nesogordonia papaverifica</i> |
| 39 Koto | <i>Pterygota macrocarpa</i> |
| 40 Lati | <i>Amphimas pterocarpoides</i> |
| 41 Lingué | <i>Afzelia africana</i> |
| 42 Lo | <i>Parkia bicolor</i> |
| 43 Lohonfé | <i>Celtis adolphi federici</i> |
| 44 Lotofa | <i>Sterculia rhinopetala</i> |
| 45 Makoré | <i>Thieghemella heckelii</i> |
| 46 Melegba | <i>Berlinia grandiflora</i> |
| 47 Movingui | <i>Distemonanthus benthamianus</i> |
| 48 Niangon | <i>Heritiera utilis</i> |
| 49 Oba | <i>Bombax buonopozense</i> |
| 50 Ouara | <i>Cola gigantea</i> |
| 51 Ouochi | <i>Albizia zygia</i> |
| 52 Poré-poré | <i>Sterculia tragacantha</i> |
| 53 Pouo | <i>Funtumia africana</i> |
| 54 Rikio | <i>Uapaca guineensis</i> |
| 55 Sipo | <i>Entandrophragma utile</i> |
| 56 Sougué | <i>Parinari excelsa</i> |
| 57 Tali | <i>Erythrophleum ivorense</i> |
| 58 Tiama | <i>Entandrophragma angolense</i> |

7.1 - Major results after ten years

Moist evergreen forest

The mean annual rainfall exceeds 1 600 mm/year, the length of the dry season averages less than 4 months and the mean annual water deficit is less than 300 mm/year.

Oba, Badi, Niangon, Aribanda, Bon, Pouo, Makoré and Tali show a mean height increment of over 1.5 m/year, and their mean diameter increment exceeds 1.5 cm/year.

All these species have a good survival rate.

Attention is also drawn to the good behaviour of Bassam mahogany, Lingué, Koto, Akoua and Ouochi.

Transitional evergreen/semi-deciduous forest

The mean annual rainfall is between 1 300 mm/year and 1 600 mm/year. The dry season averages from 3 to 5 months. As a general rule, the mean height increment is less than 1.5 m/year.

The species which have mean diameter increment exceeding 2 cm/year and a good survival rate are: Badi, Silk-cotton tree, Oba, Ouochi, and Poré-poré.

Lingué, Koto and Bété also behave satisfactorily under plantation conditions.

Semi-deciduous forest

The mean annual rainfall ranges from 1 000 mm/year to 1 400 mm/year. The duration of the dry season is 4 to 6 months. The mean annual water deficit is less than 700 mm/year.

Only 26 percent of the tested species showed a mean height increment exceeding 1 m/year.

The species that combine a good survival rate with sufficient initial growth are: Badi, Oba, Poré-poré, Ouara, White Mahogany, Broad-leaved Mahogany, Senegal Mahogany, Lingué, Koto and Bété.

7.2 - Findings and recommendations

The best growth rates are recorded in the moist evergreen forest zone. The initial height increment is about 1 m/year up to the age of 5 years. After this settling-in phase, the mean height increment stabilizes at around 1.5 m/year.

In the semi-deciduous forest, the initial growth recorded is generally lower. At the age of 10 years it is of the order of 1 m/year.

LIST OF SPECIES WITH A SURVIVAL RATE EXCEEDING 75%
AND A MEAN DIAMETER INCREMENT OF OVER 1.5 CM/YEAR

| NATURAL STAND | | |
|------------------|---------------------|-----------------------|
| Evergreen forest | Transitional forest | Semi-deciduous forest |
| Oba | Silk-cotton tree | Oba |
| Akoua | Oba | Poré-poré |
| Melegba | Poré-poré | White Mahogany |
| Badi | Badi | Br. l. Mahogany |
| Makoré | Bon | Sen. Mahogany |
| Pouo | Emien | |
| Quochi | Koto | |
| Lingué | | |
| Niangon | | |
| Koto | | |
| Bon | | |
| Tali | | |

The technological quality of the wood is one of the fundamental criteria for the choice of a reforestation species. Taking this parameter into consideration, the species that show good plantation behaviour (survival, growth, shape) and are to be given priority for reforestation purposes are the following:

SPECIES TO BE PROMOTED FOR REFORESTATION PURPOSES

Evergreen forest: Oba, Makoré, Bassam Mahogany, Niangon, Badi, Pouo, Koto, Lingué

Semi-deciduous forest: Silk-cotton tree, Oba, Badi, Koto, White Mahogany, Broad-leaved Mahogany, Senegal Mahogany, Lingué, Bété.

Some of these species (Mahogany, Niangon, Sipo, Makoré, Badi, etc.) have already been used in the past for reforestation purposes. The successful use of these species is based on the strict control of tending operations during the early years and on the adoption of high planting densities that ensure the quick closure of the canopy.

For species with relatively slow initial growth (Sipo, Niangon, Makoré), widely-spaced planting has seldom proved successful, taking into account the natural mortality or that due to insufficient tending. This type of planting involved retaining a portion of the pre-existing cover (strip planting method, undergrowth method, ...).

GROWTH RESULTS OF THE SPECIES TESTED ON THE THREE EXPERIMENTAL SITES

| Species | Yapo site | | | | Mopri site | | | | Sangoué site | | | |
|-----------------|--------------|------------|-----------|----------|--------------|------------|-----------|----------|--------------|------------|-----------|----------|
| | Age (yrs) | Alive % | C (cm) | H (m) | Age (yrs) | Alive % | C (cm) | H (m) | Age (yrs) | Alive % | C (cm) | H (m) |
| Abale | 8 | 0 | | | | | | | 10 | 0 | | |
| Aboudikro | 7 | 74 | 32.2 | 5.4 | | | | | | | | |
| Bassam mahogany | 8 | 76 | 45.5 | 12.1 | | | | | | | | |
| White mahogany | 8 | 98 | 28.1 | 6.2 | | | | | 10 | 100 | 56.2 | 11.9 |
| Br.-1. mahogany | 8 | 96 | 36.8 | 8.8 | | | | | 10 | 98 | 52.7 | 13.3 |
| Sen. mahogany | | | | | | | | | 10 | 98 | 52.3 | 9.2 |
| Adjouaba | 7 | 55 | 16.2 | 2.1 | | | | | | | | |
| Aiéle | 7 | 47 | 37.6 | 10.1 | 8 | 65 | 34.3 | 9.0 | | | | |
| Akatio | | | | | 10 | 0 | | | | | | |
| Ako | 6 | 61 | 32.5 | 4.7 | 10 | 18 | 55.9 | 11.0 | | | | |
| Akoua | 7 | 94 | 49.8 | 8.6 | | | | | | | | |
| Amazakoué | 8 | 78 | 30.3 | 6.9 | | | | | | | | |
| White aniégré | | | | | 8 | 12 | 28.4 | 4.8 | | | | |
| Aribanda | 8 | 59 | 57.2 | 13.7 | 10 | 4 | 43.0 | 9.4 | | | | |
| Azobé | 8 | 98 | 31 | 11.7 | | | | | | | | |
| Azodau | 8 | 80 | 25.9 | 7.2 | 10 | 33 | 40.5 | 8.1 | | | | |
| Ba | | | | | 10 | 43 | 39.1 | 8.9 | | | | |
| Badi | | | | | 10 | 59 | 66.2 | 15.0 | | | | |
| Bahé | 7 | 90 | 24.8 | 7.0 | 8 | 37 | 51.8 | | | | | |
| Bété | 6 | 96 | 34.2 | 7.4 | 10 | 96 | 38.9 | 9.9 | | | | |
| Bi | 8 | 96 | 36 | | 10 | 33 | 43.3 | 11.4 | | | | |
| Bodo | 6 | 73 | | 2.3 | | | | | | | | |
| Bon | 6 | 100 | 54.1 | 10.0 | 8 | 92 | 39.4 | 9.5 | | | | |
| Bossé | 7 | 39 | 13.3 | 2.5 | 0 | 0 | | | | | | |
| Dabema | 8 | 49 | 35.6 | 8.1 | | | | | | | | |
| Dibétou | 8 | 0 | | | 10 | 0 | | | | | | |
| Difou | 6 | 94 | 28.9 | 5.6 | 8 | 57 | 25.2 | | | | | |
| Eho | 8 | 33 | 50.4 | 9.4 | 10 | 14 | 100.1 | 14.8 | | | | |
| Emien | 6 | 98 | 46.7 | 7.0 | 8 | 90 | 58.0 | 10.5 | | | | |
| Etimoé | 6 | 100 | 15.1 | 3.4 | 8 | 80 | 20.3 | 4.1 | | | | |
| Faro | 4 | 51 | 16.5 | 2.5 | 8 | 63 | 27.6 | | | | | |
| Silk-c. tree | | | | | 10 | 88 | 92.0 | 14.1 | | | | |
| Iatandza | | | | | | | | | | | | |
| Ilomba | 6 | 29 | 39 | 4.7 | 10 | 0 | | | | | | |
| Iroko | 8 | 86 | 34.8 | 6.9 | 10 | 0 | | | | | | |
| Kosipo | 7 | 84 | 28.6 | 5.5 | | | | | | | | |
| Kotibé | 5 | 94 | 21.7 | 4.4 | 10 | 16 | 50.7 | 4.2 | | | | |
| Koto | 8 | 82 | 39.7 | 10.0 | 10 | 80 | 53.3 | 14.2 | | | | |
| Lati | | | | | 8 | 6 | 39.0 | | | | | |
| Lingué | 8 | 100 | 40.4 | 11.6 | 10 | 100 | 36.3 | 11.0 | | | | |
| Lo | 7 | 98 | 23.8 | 5.1 | 8 | 41 | 48.0 | | | | | |
| Lohonfé | 8 | 37 | 37.8 | 3.9 | 10 | 0 | | | | | | |
| Lotofa | 8 | 45 | 18.3 | 3.1 | 10 | 67 | 31.9 | 5.3 | | | | |
| Makoré | 7 | 96 | 43.1 | 10.9 | 8 | 27 | 31.3 | | | | | |
| Melegba | 7 | 76 | 45.5 | 6.5 | | | | | | | | |
| Movingui | 5 | 71 | 21.9 | 6.3 | | | | | | | | |
| Niangon | 8 | 90 | 40.1 | 14.4 | 8 | 8 | 43.3 | | | | | |
| Oba | 8 | 51 | 83.8 | 4.2 | 10 | 43 | 109.1 | 12.2 | | | | |
| Ouara | | | | | | | | | | | | |
| Ouochi | 7 | 80 | 40.1 | 8.4 | 8 | 43 | 57.5 | | | | | |
| Poré-poré | | | | | 10 | 92 | 63.0 | 12.2 | | | | |
| Pouo | 8 | 90 | 47.5 | 12.5 | 8 | 49 | 46.7 | | | | | |
| Rikio | 8 | 51 | 59.5 | 12.3 | | | | | | | | |
| Sipo | 6 | 88 | 31.1 | 7.2 | 8 | 20 | 45.3 | | | | | |
| Sougué | 5 | 86 | 36.5 | 9.4 | | | | | | | | |
| Tali | 5 | 96 | 33.9 | 12.0 | | | | | | | | |
| Tiama | 8 | 69 | 25.4 | 5.7 | 10 | 0 | | | | | | |

The results now available, ten years after planting, clearly show that:

- most species are perfectly able to tolerate planting in full light
- the chief constraint on the successful planting of timber species is the need for careful and repeated tending over a period of 5 to 10 years.

One of the successfully tested solutions for controlling adventitious vegetation is the use of soil-covering plants such as Pueraria or Leucenea. This technique does not decrease the number of tending operations but allows effective control of weeds whilst assuring excellent soil protection.

The silviculture of long-rotation timber trees is very demanding at the time of planting and during the stands' initial establishment. The basic silvicultural recommendations for successful planting are the following:

- good-quality planting stock,
- 40 x 40 x 40 cm planting pits,
- application of starter fertilizer,
- maximum spacing 3 m x 3 m,
- pre-emergency weedkiller treatment,
- the use of a soil-covering plant (Pueraria, Leucenea ...),
- constant tending until the first thinnings.

In many cases, the studies regarding the optimum thinning schedule are not yet finalized or have not yet begun, but the silvicultural data acquired is considerable and awaits full exploitation.

CHAPTER 4

EVOLUTIONARY TRENDS AND NEEDS

During the past several decades, foresters have concentrated their studies on the problems regarding transplant production, competition and productivity. Their results provide ample proof of the seriousness of their research efforts.

These research endeavours must be continued in a number of different directions:

- The study of new species;
- The soil/growth relationship;
- Production models;
- The study of mixture stands;
- The silviculture/breeding/technology relationships;
- Plantation management.

1 - THE STUDY OF NEW SPECIES

The increasing scarcity of wood from natural forests has led to trials of numerous species transplanted to open terrain (BERTAULT 1982, DUPUY 1990).

Promising species are: the Kapok tree (*Ceiba pentandra*), the Oba tree (*Bombax buonopense*), the Bété tree (*Mansonia altissima*), the Puou tree (*Funtumia elastica*), the Rikio tree (*Uapaca guineensis*), etc.

For each of the afore-mentioned species, the traditional approach would be: transplant production, competition trials and productivity studies.

2 - THE SOIL/GROWTH RELATIONSHIP

This site study component is indispensable if we are to improve on the relationship between the reforestation site and the species planted.

The purpose of the soil/growth relationship study is to allow us to evaluate the influence that this parameter might have on reforestation productivity. Physical (texture, structure, depth, ...) as well as chemical (pH, chemical reserves, deficiencies, ...) and hydric soil studies are required. In this regard, the dynamic aspect of the water element is a fundamental one in tropical zones, inasmuch as it is the principal limiting factor here.

With respect to stand development, we also need studies on:

- fertilization to correct deficiencies;
- drainage for the reforestation of hydromorphic and low-lying areas;
- working the soil and herbicides active in the hydric balance of young plantations.

3 - PRODUCTION MODELS

Once the first generation of yield tables is completed, research efforts must be continued to develop more effective production models.

These should integrate silvicultures adaptable to different production models. The financial aspects are taken into consideration after the technical aspects to help in decision-making.

4 - STUDIES OF MIXED STANDS

This is one aspect of silvicultural techniques that must be developed here. There are many reasons for associating a number of different species in the planting process:

- to limit impact of plant protection problems in single species plantations;
- in order to facilitate weed control, and limit forest fires by multi-story stands;
- to reduce the extent of the first early thinning by reducing density and thereby the onset of competition in the overstorey;
- to develop species combinations which maintain and improve fertility.

Two priority courses of action should be explored. The first would involve the creation of two-storey stands of the coppice-with-standards type, by associating a dominant timber species with a dominated fuelwood species such as Fraké, Framiré or Samba ... with Teak.

The second course of action would be to associate timber species with Acacias (such as *mangium*, *auriculiformis*, ...) that can enrich the soil, particularly with nitrogen.

And finally, the planting of species that grow in the shade under a cover or canopy of Leucaena remains a technique to be explored and promoted: the first results of such plantings have been encouraging.

5 - RELATIONSHIPS BETWEEN GENETIC IMPROVEMENT, SILVICULTURE AND TECHNOLOGY

Research in genetic improvement, a step that precedes silviculture, has made possible a higher quality plant material. Genetic research findings should allow us to reduce density, and in certain cases, to advance toward very wide spacing (*Terminalia* spp. *Samba*, ...) This kind of silviculture should be tested and evaluated.

The search for quality wood also leads to the development of artificial pruning.

The impact of thinning systems and planting density on the characteristics of woods should be quantified by wood technology studies.

6 - PLANTATION MANAGEMENT

Plantations are a tool for the regeneration of our forest heritage.

Their high cost justifies the considerable amount of research that has been carried out during the past decades, in order to optimize their creation and management. The perpetuation of a natural or manmade forest depends, at the present time, on forest management.

Overexploited natural forests must be partially regenerated by plantations particularly in sufficiently fertile degraded zones.

The development of yield tables for the principal reforestation species constitutes a decisive step in plantation management. Such tables, in particular, allow forestry operations to be tailored to site fertility, and future yields to be evaluated.

The optimization of management planning and interventions are the two factors that guarantee rational plantation management.

At the present time, reforestation is an integral part of tropical forest management. Through the selection of quick-growth species, staggered production to regenerate natural formations that are far too often over-exploited becomes possible.

Reforestation, which is inseparable from natural forest silviculture, is relevant where a site is unquestionably suitable for forestry.

It then permits the conversion of part of the heavily degraded natural stands into productive even-aged plantings.

The principal problem today is the financial evaluation of reforestation operations that are far more costly than the extensive management of natural formations.

The right answer depends, in particular, on models that integrate the technical and financial aspects of the problem. Inasmuch as the final objective of intensive reforestation is the harvesting of wood, the technological and development component will strongly condition the flexibility of the model.

Computer software for forest management must therefore be developed. Even-aged plantations are obviously an ideal research framework for such activities.

A forest tends to be considered as an enterprise in which an investment should result in a long-range profit. On the other hand, however, it should also produce regular income to cover current annual expenses, as well as minimize the amount of working capital tied up by these expenses.

This objective can only be achieved if each of the stands is managed independently from all of the others. One must therefore proceed from silvicultural management to integrated forest management by programming volume and income distribution.

In the long run, expert systems of forest management (administrative, technical and fiscal management) must be the ultimate goal. Such a system would, in particular:

- define the ground rules governing operations needed to create plantations;
- define the forestry operations needed to obtain a level of wood production that meets the forestry objectives;
- adapt harvest programming to the medium-term economic conditions.

CONCLUSION

When tropical forests first began to be exploited, logging concentrated on a few species. Foresters, concerned that this type of forest might be impoverished, turned their attention toward enrichment plantations to compensate for the wood removed by logging.

As time went on, the number of commercial species increased tenfold within a few decades. Approximately one hundred tropical forest species are now of commercial interest.

In fact, the forest was still very "rich" at the time of the first enrichment and planting trials, as successive exploitation shows. The interest in enrichment forests was due to a material constraint, namely, the material lack of clearing facilities, as well as the desire to avoid, insofar as possible, modifying the ecosystem.

Manual methods can bring about excellent results, if they are correctly applied. Unfortunately, however, socio-economic and technical constraints have put an end to such methods, in favour of more intensive operational methods.

Intensive methods were justified by the increasing impoverishment of the natural forests, as well as by a form of competition between forestry and agriculture, and by technological progress. Furthermore, not enough was known about the silviculture of natural stands to convince decision-makers to implement these methods.

After several decades of research, we are now confident that we possess the knowledge necessary for reforestation in humid tropical zones. At the same time, we have been able to develop silviculture operations in natural forests. As a consequence, forest managers today have at their disposal all the technical tools they need to conserve natural forests, or to convert them into even-aged plantations. All they need then do is choose the technical options they wish to use in terms of existing constraints and their ultimate goals.

CHOOSING THE BEST TECHNIQUE

The first concern of the forest manager is to make an inventory of and map the stands, in accordance with a typology adapted to the goals of forest management.

This should be established in terms of the available range of silvicultural techniques.

The parameters for consideration are, in particular:

- Cover, or continuous canopy (photo-interpretation);

- The abundance of commercial species (statistical inventory);
- The site potential (topography, fertility, vulnerability, etc.);
- The human and agricultural pressure (intensity, type of crop).

This should make it possible to map the forest area and to plot the homogeneous units which would justify a uniform silvicultural treatment.

The size of these plots depends on the means available; one plot would normally consist of several dozen hectares. Indicatively, minimum plot size should be in the order of:

- 10 hectares for manual reforestation techniques;
- 30 hectares for mechanized reforestation techniques;
- 50 hectares for enrichment techniques in natural forests.

Plot size should take into account technical and economic requirements. This operational basis might possibly undergo some changes as further studies are made.

Grouping these land units to series of operations such as protection, production or regeneration should make it possible to schedule the silvicultural operations to coincide with the implementation of management plans.

The chronological sequence of the management operations should take into account the technical limits imposed by the implementation of a given technique:

Per Hectare Costs of the Different Silvicultural Techniques

| Technique | Labour Cost MD/ha | Equipment Cost M/ha | Estimated Cost 1989 FCFA/ha |
|------------------------------|----------------------|------------------------|--------------------------------|
| Improvement Natural Stand | 15 | 0.5 | 50 000 |
| Enrichment | 60 | 1 | 150 000 |
| Manual Conversion | 120 | 1 | 300 000 |
| Mechanized Conversion | 50 | 15 | 800 000 |

The principal limiting factor, in reality, is the cost of implementing each of these techniques, beginning with the first year. The costs to be incurred later on refer to maintenance (cleaning, clearing, délianage), or to development operations (trimming, pruning, thinning) of the existing stands.

Relative Requirements: Labour Equipment/per Hectare during the First Year

| Technique | Labour cost MD/ha | Equipment cost M/ha | % per hectare |
|------------------------------|----------------------|------------------------|---------------|
| Improvement Natural Stand | 7 | 0.4 | 50% 80% |
| Enrichment | 30 | 0.4 | 50% 80% |
| Manual Conversion | 60 | 0.8 | 50% 80% |
| Mechanized Conversion | 15 | 12 | 30% 80% |

Labour Costs per Hectare for the Different Silviculture Techniques

| | Improvement Natural Stand | Enrichment | Reforestation | |
|--|------------------------------|------------|---------------|------------|
| | | | Manual | Mechanized |
| Time Required (in years) per ha | 10 | 10 | 6 | 4 |
| Rotation (in years) | 25 | 45 | 35 | 25 |
| Average Volume for Harvesting at End of Rotation (m ³ /ha) | 20 | 140 | 180 | 180 |
| Labour Cost per m ³ for Timber (MD/m ³) | 1 | 0.4 | 0.5 | 0.2 |
| Labour Needs for a 100 ha/year programme (M/year) | 3 | 8 | 40 | 13 |

The technique of improving and enriching natural stands turns out to be the least costly in terms of labour, but takes the longest time to be implemented. The improvement of natural stands is a rather simple technique, which nevertheless requires that there be a sufficient abundance of commercial species, on the one hand, and the possibility for natural regeneration, on the other.

Mechanized reforestation is costly, but it is easy to implement, and produces high yields. Non-mechanized reforestation, on the other hand, requires a very considerable amount of manual labour.

Obviously, the technical aspects have been subordinated here to an overall review of the forestry issue, and are only relevant as a criterion for decision-making in a global management strategy.

IS REFORESTATION PROFITABLE?

Although often criticized for its high costs, intensive mechanized reforestation remains, nonetheless, an interesting technique. A comparison of closed forests in temperate zones with tropical closed forests can teach us a great deal in this regard.

| Operation | Tropical Forest | Temperate Forest |
|--------------------------|------------------------|------------------------|
| Clearing and Planting | 200 000 to 400 000 CFA | 150 000 to 250 000 CFA |
| Maintenance and Thinning | 300 000 to 400 000 CFA | 300 000 to 400 000 CFA |

The forestation costs are lower in the temperate zones, however, growth is much lower as well.

Forest plantations in humid tropical zones offer numerous advantages with regard to growth and productivity.

Initial growth is very strong, with the maximum volume increments reached within 5 to 15 years for tropical species, as against 50 to 100 years for tropical species, as against 50 to 100 years for temperate species. In point of fact, the exploitable age is considerably lower in tropical zones, at equal exploitable diameters. It is 10 years lower for biomass products (pulp, fuelwood), and between 20 and 50 years for timber.

| Reforestation Species | Exploitable Age (Years) | Total Timber Volume (m ³ /ha) | Average Timber Increment (m ³ /ha/yr) |
|-----------------------|-------------------------|--|--|
| Douglas | 65 | 390 | 6.0 |
| Epicéa | 110 | 510 | 4.6 |
| Maritime Pine | 60 | 140 | 2.3 |
| Fraké | 25 | 230 | 9.2 |
| Cedar | 28 | 253 | 9.0 |
| Teak | 60 | 330 | 5.5 |

During the same amount of time necessary for one rotation for a fast-growing temperate species such as Douglas Fir, two rotations of Fraké or Cedar species can be obtained, and consequently, one-and-a-half times more timber. This ratio increases in the case of conventional reforestation species such as Epicéa or Maritime pine. As a result, the timber yield from the reforestation of tropical species is actually two to four times greater than that obtained from temperate species.

Nevertheless, reference has often been made to the low rate of return from forest planting in the tropics, and this has frequently been used as a justification for abandoning this technique.

There are a number of different reasons for the present-day dissatisfaction with reforestation efforts. In the first place, it should be noted that this technique has not always been employed in a correct manner: the site must always be matched to the species.

Structural causes are sometimes at the root of the problems associated with unsatisfactory end results of reforestation efforts in humid zones. A correct time-table must be established for the operations, and it must be observed. High quality plant material adapted to the site must be planted at the correct time, and carefully maintained thereafter.

The most difficult problem at the present time is the lack of financially remunerative outlets that might justify forestry investments. This problem, however, goes far beyond the forestry sector alone, and involves a considerable number of other raw materials.

The question we must ask ourselves then, is what is actual worth of this stumps. When we know this we can plan for the conservation and management of tropical forest resources: whose role is not merely to produce timber.

The third vital point we must not forget is that forest trees are a permanent and long-term crop not ideally suited to financial speculation. The forests real role goes far beyond mere patterns of production.

As a biological component, the forest directly affects the equilibrium of our environment.

Natural or planted forests induce many ecological and socio-economic effects that are difficult to grasp and quantify.

Within this framework then, forest rehabilitation through reforestation is no longer a simple financial operation for direct profit, and such an approach would imply a truncated version of reality.

The technical grounds for tropical forest reforestation mainly favour a focus on bush fallows that have already been cleared.

Compared to temperate zones, the investment return for rotation is at least twice as high for identical establishment costs. The real problem lies in the very low commercial value of the commodity: investment in forest therefore in no way rivals investments in other, more profitable, crops. It is quite probable that the increasing scarcity of this multiple-role resource could lead to a reassessment of its commercial value. The interests at stake are not only financial.

The current internal rate of return for reforestation in temperate zones does not top 4% for species whose rotation takes 50 years, and the price of m³ of standing timber is 15 000 Francs CFA/m³ (Epicéa, Fir, Douglas Fir).

The internal rate of return for the same value of m³ of stumps of identical exploitable size can go as high as 10% for species such as Fraké, Cedar, Framiré, etc.

Infact it is very difficult to limit the discussion to a financial analysis based on the mere market value of wood and on long-term maturities.

The very rationale for reforestation is an implicit admission of failure: of our inability to preserve the natural forest.

While is our urgent task today to protect a portion of the natural formations from total destruction by correct forest management, reforestation remains the principal tool, in many cases, for rapidly establishing production forests. The management of natural formations is extensive by its very nature. As a less expensive method of operation, it abundantly satisfies the need for protection, conservation and production.

The prime function of reforestation is production, which implies a very high outlay for establishment. *Ex situ* conservation of genetic resources through conservation plantations is another function of reforestation.

Recent trials have shown that a considerable number of natural forest species can be planted. Behavioural tests in Côte d'Ivoire demonstrated that the Lingué (*Afzelia africana*), the Bété (*Mansonia altissima*), the Tiama (*Entandrophragma angolense*), and the Pouo (*Funtumia africana*), can tolerate full light. During their initial period of growth (an average annual 0.50 - 1 m), careful maintenance is needed for only 5 to 7 years, to allow them to break free from the regrowth.

People have actually planted trees for several millenia now. Forestry and agriculture are the two sides of resource renewal of the plants mankind finds useful for its needs.

The growing potential of the material means for forest clearing poses the problem of how to conserve our forest heritage and how to renew it. Reforestation is a technical aspect of this problem.

As for the financial aspect, it would be useful to ask ourselves at this point whether the application of the internal rate of return to forests is justifiable, and whether it does not legitimize, inaction in the sector.

This problem calls into discussion the economic assessment of forestry interventions. The parameter of time is a heavy factor in forestry projects. Can one really evaluate long-term forestry operations with short-term tools?

We endorse LESLIE's view (1987), that "the legitimacy of an especially low interest rate for forests has, like the zero interest rate, been rejected by most economists, but this does not prove that the idea is necessarily a bad one".

Although the financial aspect of the question has an exaggerated importance today, we must not lose sight of the fact that the life span of a tree of ten far exceeds the length of one human generation. Fifty years ago, tropical foresters were already planting trees. Were they visionaries, or utopians?

Recent history has shown how clear-sighted they were: we gratefully harvest the fruits of their labours today, knowing that we too must continue to plant trees for the future.

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