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SYLVICULTURE EN FORÊTS DENSES HUMIDES D'AFRIQUE

Tropical silviculture in dense African forest (Part 2)

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Photo 1.
A three-year-old Limba plantation (Bokou N'Sitou-Congo-Brazzaville).
Note the girdled trees still standing as they wither.
Photo Forestry Service.

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RÉSUMÉ

Sylviculture tropicale en forêt dense africaine (partie 2)

Dans la deuxième partie de l'article, l'auteur expose les méthodes sylvicoles employées dans la forêt dense d'Afrique à l'aide d'une régénération artificielle. La méthode « Taunguya » n'est pas très répandue dans les zones forestières. La méthode « Limba », employée au Congo, sert à établir une plantation de stumps (souches de jeunes plants) de limba (Terminalia superba) à intervalles de 6 à 9 m ou 12 à 14 m dans une forêt naturelle complètement détruite. Avec la méthode « Okoumé », utilisée au Gabon sur 16 000 ha, les arbres sont plantés à intervalles de 4 à 5 m par semis direct ou plantation de jeunes plants, ou après déforestation. La méthode « Martineau », utilisée en Côte d'Ivoire dans les années 1930, implique une plantation serrée (2 500 très jeunes plants par hectare) en forêt naturelle, avec une ouverture progressive lente de la canopée. La méthode des « Layons » est très extensive, et produit un enrichissement des peuplements par l'introduction de jeunes plants dans les layons par éclaircies de la forêt naturelle à 25 m d'intervalle (13 000 ha en Côte d'Ivoire). La méthode des « Placeaux » introduit de jeunes plants très serrés dans des carrés de forêt naturelle. Les arbustes concurrents et les arbres de la canopée sont progressivement et lentement éliminés.

Mots-clés : sylviculture, méthode, exploitation forestière, restauration forestière, plantation, productivité, forêt tropicale dense humide, Afrique.

ABSTRACT

Tropicale silviculture in dense African forest (Part 2)

In the second part of the article, the author explains forestry methods employed in the dense forests of Africa based on artificial regeneration. The "Taungya" method is not at all extensively applied in forest areas. The "Limba" method, employed in the Congo, was to establish a plantation of Limba stumps (Terminalia superba) at intervals of 6 to 9 m or 12 to 14 m in a completely destroyed natural forest. With the "Okoumé" method, used in Gabon over some 16,000 ha, trees are planted at intervals of 4 to 5 m by direct seeding or after destruction of the forest. The «Martineau» method, used in Côte-d'Ivoire in the 1930s, involves close planting (2,500 seedlings per hectare) in natural forest, with very gradual removal of the canopy. The "Deforested Strip" method is very extensive, and produces enriched stands by introducing seedlings into strips cut vertically into the natural forest at 25 m intervals (13,000 ha in Côte-d'Ivoire). The "Patch" method introduces closely planted saplings in 4 x 4 m squares in the natural forest. Shrubs and canopy are then gradually removed from these squares.

Keywords: forestry, method, logging, forest restoration, plantation, productivity, tropical humid forest, Africa.

RESUMEN

Silvicultura tropical en bosque espeso de África (Parte 2)

En la segunda parte del artículo el autor explica los métodos forestales basados en la regeneración y empleados en los bosques espesos de África. El método «Taungya» no está muy extendido en las zonas forestales. El método «Limba», empleado en el Congo, consiste en establecer una plantación de cepas de limba (Terminalia superba) en intervalos de 6 a 9 m o de 12 a 14 m en un bosque natural completamente destruido. Con el método «Okoumé», usado en unas 16 000 ha de Gabón, los árboles se plantan en intervalos de 4 a 5 m mediante siembra directa o después de la destrucción del bosque. El método «Martineau», utilizado en Costa de Marfil en los años 1930, consiste en una plantación espesa (2 500 pimpollos por hectárea) en un bosque natural, con una retirada muy gradual del dosel arbóreo. El método «Franjas deforestadas» es muy extensivo, y produce grupos enriquecidos introduciendo plantío en franjas taladas verticalmente en el bosque natural a intervalos de 25 m (13 000 ha en Costa de Marfil). El método «Bancal» introduce plantíos muy espesos en zonas cuadradas de 4x4 m en el bosque natural. Arbustos y dosel se retiran gradualmente de estos bancales.

Palabras clave: silvicultura, método, explotación forestal, restauración forestal, plantación, productividad, bosque húmedo tropical, África.

Methods based on artificial regeneration

The Taungya method

A. Aims

"*Taungya*" is a Burmese word referring to slash-and-burn cultivation. In all tropical forest countries, slash-and-burn means destroying the forest by felling and burning the trees, which is the first and essential step before planting crops, the vast majority of which need light in order to grow. In theory, the resulting ash enriches the soil with minerals, but because the topsoil in tropical forests is destroyed by burning, along with the biological life it contains, there is no real certainty that the operation has a net positive effect.

The aim of the Taungya method is to ensure that the tree to be planted will benefit from the work done by farmers to prepare the ground for their crops: letting in light, tilling, fertilising and caring for the crops. In principle, this technique provides saplings with the best growing conditions and brings the cost price of the plantation down to very economic levels.

B. The technique

The technique is very simple: after preparing the crop-field, the forester, or the forestry workers, plant out saplings in rows in between the crops. The farmer then hoes and weeds around the saplings several times a year for the two or three years of the crop cycle. When the field is abandoned, the forester continues to maintain the plantation for the number of years considered to be necessary.

Under these conditions, there is therefore some doubt as to whether this is really a forestry technique: the only important points are to determine the transplanting method for each species, which will depend on the total amount of light available until the saplings become established, and the optimum spacing of the planted trees.

Because of the sudden exposure to light, planting bare-rooted saplings is not advisable; it is preferable to transplant them as soil plugs or stumps as these will be much more tolerant to increased transpiration until the root system has had time to become functional. There can be no fixed rules to determine plantation distances because these depend on the type of intercrop and on local farming practice, but the saplings can be quite closely planted at 1,000 to 1,250 stems/ha.

If the forester wishes to retain control over the plantation and ensure that certain standards for success are complied with, he will need to own the land to be cultivated. In practice, this is always the case, as these plantations are undertaken in parcels of state forests that are granted temporarily to those who will be cultivating them. They can then establish the duration of crop farming and the distances to be maintained between crops and forest plantations.

C. Costs

These are highly variable depending on species and how long the plantation is to be maintained, but in principle, they are very low because they only have to cover nursery and maintenance in the last years, which can vary from 20 to 50 man-days/ha.

D. Results

Having been applied first in Burma, Java and India at the beginning of the 20th century, the technique was introduced into Africa, first in Nigeria and later in Côte d'Ivoire (1932). It is still employed in savannah areas (Teak, Gmelina), but was never used extensively in dense forests, because:

- only species that demand full light can be used, which accounts for the method's success in Asia with *Shorea robusta*[1];
- the method encourages parasite attacks, because biting insects (such as psyllids) and borers, which are the main enemies of forest plantations at present, tend to thrive in well-lit conditions;
- it suppresses, from the outset, the secondary forest regrowth that promotes self-pruning and facilitates manual pruning while recreating a forest ambience. This, to my mind, is the most serious criticism that can be made of this method, as it produces not a forest but a crop of trees;
- the maintenance work required from farmers in the early years is not always of a high standard and the saplings subsequently taken on by the forester are often deformed by lianas and badly pruned;
- farmers are sometimes very reluctant to agree to "cultivation contracts" as they are very unwilling to accept the constraints and surveillance involved.

[1] *Shorea robusta* C. F. Gaertn.

Photo 2.
A plantation of *Khaya ivorensis* on cleared forest soil. Three-year-old trees in the Banco Forest (Côte d'Ivoire).
Photo A. Aubréville, 1927.

In Africa's dense forests, apart from teak plantations in the northern zone, which are well suited to the technique, it has been successfully employed for some Bilinga plantations (*Nauclea trillesii*[2]) in Nigeria, because although it is a light-loving species, it has a natural aptitude for self-pruning.

Finally, there were great hopes for Framiré (*Terminalia ivorensis*[3]) because of its very rapid growth with the Taungya method, but as the majority of these plantations in Côte d'Ivoire began to die back after 15 to 20 years, there is a possibility that the technique itself was at fault by suppressing the subsequent regrowth and thus exposing the tree boles to sunlight from crown to collar.

Results for the other species for which the method was attempted (Khaya[4], Lovoa[5], *Terminalia superba*[6], *Triplochiton scleroxylon*[7]) were variable, so that no large-scale planting was ever applied. Finally, we should mention the sylvo-agricultural methods used by some forestry services under public works contracts: the agricultural plantations that the forest plantations are to benefit from are undertaken directly by the Forestry service using industrial cultivation techniques, in the hopes that the resulting harvest will offset the costs of the forest plantation. These methods have only been used for banana plantations, which we will discuss with regard to Okoumé[8] and Limba[9] plantations.

The "Limba" method

Terminalia superba, sometimes called Limba and sometimes Fraké in the timber trade, is a gregarious species commonly found in African deciduous forests. It forms large natural stands (2 to 10 exploitable trees per ha), particularly in the dense forests of northern Côte d'Ivoire, Ghana, Nigeria, the Cameroons, the Central African Republic, the two Congos and Gabon, and in the Mayombé coastal range in the west of the latter three countries. As it is highly prized for veneer wood, there are large plantations of the species in the two Congos and especially in the Mayombe range, where the native Limba fetches premium prices on the market.

A. Aim

As Limba thrives in full light, naturally grows very straight and seems to have an aptitude for self-pruning, the planting method developed aims to bring it into full light as quickly as possible and to suppress as much competition on the ground as possible by carefully clearing any secondary regrowth that could thwart its development: as the natural habit of the species can be relied on, the beneficial effect of the secondary vegetation on tree growth and self-pruning is only a secondary consideration. The efforts made to determine optimum growing conditions from the outset and promote rapid development of the saplings is also explained by the ecological conditions in the distribution range of the species: annual rainfall of 1,300 to 2,300 mm distributed over 7 to 8 months, but often with a short dry season in between which has to compensate for a longer dry season lasting for 4 to 5 months (which are usually ecologically dry). To give the saplings every chance of being well established by the first dry season after planting, any competition on and above the ground has to be eliminated as far as possible. Finally, it should be noted that this technique does not require a particular type of terrain, but that preference should be given to fresh deep soils (alluvial, Mayombe quartz-schist, etc.). The method ultimately developed in the Congo consists of planting directly into the soil of a natural forest that has been clear-felled beforehand. The trees are planted at their final spacing in Congo-Brazzaville and usually at half the final distance in Congo-Léopoldville[10].

[2] *Nauclea trillesii* (Pierre ex De Wild.) Merr.
[3] *Terminalia ivorensis* A. Chev.
[4] *Khaya* spp.
[5] *Lovoa* spp.
[6] *Terminalia superba* Engl. & Diels.
[7] *Triplochiton scleroxylon* K. Schum.
[8] *Aucoumea klaineana* Pierre.
[9] *Terminalia superba* Engl. & Diels.

Photo 3.
Limba trees six months after planting as stumps (Bakou N' Silou-Congo-Brazzaville).
Photo Forestry Service.

B. The technique

This involves the following successive operations:

1. Reconnaissance and grid-mapping of the terrain

In January-February, in other words the middle of the rainy season, rows are opened up vertically in the natural logged forest to be used for the future plantation, moving in the NS and EW directions and using a hand compass and chain; squares of about 1 km x 1 km are marked out in this way and subdivided into smaller 100 m x 100 m squares (the figures are in fact multiples of the plantation spacing). At the same time, any zones not suitable for planting are noted (swamps, degraded stands, stands of palms, etc.).

[10] Now the Democratic Republic of Congo.

2. Destruction of the pre-existing forest

This is done with the traditional slash-and-burn method used in African forests: clearing and felling of small trees, burning the brash, girdling large trees and often partially burning them to collar height. Burning is only possible over large areas because of the length of the dry season (4 months) and the resulting water deficit. In practice, the deforestation operation takes place in four stages:

- shrubs and lianas up to 12 cm in diameter are cleared with machetes during the last three months of the rainy season (March to May);
- trees less than 30 m in diameter are cut down with axes during the first half of the dry season (May to August);
- trees more than 30 cm in diameter are destroyed by poisoning, or girdling with axes, at the start of the second half of the dry season (August);
- the brash and stumps of some large trees are burned at the end of the dry season (August, September).

3. Opening up the plantation rows

This is done by cutting rows with machetes into the unburned plant debris every 6-7 m (half of final spacing) or 12-14 m (final spacing), around September-October.

4. Planting

This is done using only stumps 1 m to 1.50 m in height, with the roots cut back to 30-35 cm in all directions; this technique is based on systematic tests of seedling transplant and recovery.

The planting stages are as follows:

- seeds are collected in July and immediately placed in containers to germinate. In September, as soon as the second leaf appears, they are planted out every 50 cm in well fertilised nursery beds and quickly uncovered;
- in October-November of the following year, the 15 to 16 month -old saplings are pruned back to just below the woody portion (to 1 m to 1.50 m in height), often after puddling the roots;
- in October to December, they are transplanted into 40 cm x 40 cm x 40 cm holes every 6-7 m or every 12-14 m.

In practice in Congo-Brazzaville, two stumps were placed side by side in each planting hole to avoid having to replace those that fail to take root; if both were successful, one would be removed during subsequent clearing.

5. Maintenance

Machetes are used to clear around the saplings three times a year for the first four years and two or three times a year in the 5th, 6th and sometimes 7th years. Regrowth from slash and burn deforestation is secondary regrowth, made up of very fast-growing species such as the umbrella tree (*Musanga cecropioides*[11]), which soon overtops the Limba saplings if they are in competition; the undergrowth also comprises a great many lianas, which seem to be encouraged by the initial burning as well as by the light. Maintenance work therefore lasts for 6 to 7 years and often greatly weakens the undergrowth by cutting it back to 2-3 m in height during those 7 years; as the Limba trees are over 10 m in height by that time, the straightening effect of the shrouding regrowth is also much weaker.

[11] *Musanga cecropioides* R. Br.

C. Cost of the method

As this method is entirely manual, its cost can only be expressed in man-days/ha. For large worksites, with 700 ha planted a year, the Congo-Brazzaville forestry service counted 135 man-days/ha as follows:

1. General infrastructure, general duties: 20 man-days/ha.
2. Plantation work: 115 man-days/ha, as follows in table I.

Based on 300 days of work per year, 450 workmen are therefore needed to maintain 1,000 ha/year.

D. Results

This method was used to plant 6,500 ha of Limba in Congo-Brazzaville; we have no reliable figures for Congo-Léopoldville, but they are certainly lower.

The success of these plantations, the oldest being 15 years of age, can be assessed from the 10% sampling surveys conducted each year:

1. Diameter growth: 2.5 cm to 3.1 cm per year for 12 m x 12 m to 14 m x 14 m spacing, but only 2.2 cm for 6 m x 6 m spacing; planting at the final spacing is therefore beneficial.
2. Growth in height: from 1.40 m to 1.80 m per year.
3. Growth in volume: after 10 years the bole volume per tree varies from 3.275 m^3 (6 m x 6 m spacing) to 3.300 m^3 (12 m x 12 m spacing), and increases per ha of plantation from 20-25 m^3 (12 m x 12 m spacing) to 45 m^3 (6 m x 6 m spacing); at this plantation age, the volume per hectare is much greater when trees are closely planted if the individual bole volume is lower.

Table I.

Type of work	Cost in man-days/ha	
Prospecting, grid mapping	3.1	
Bush clearing	8.6	
Felling	9.7	
Burning	0.7	
Clearing along plantation transects	11.7	
Girdling	11.7	
Total to prepare the ground		45.5
Nurseries		10.5
Plantations and replacements		6.7
Maintenance year 1	7.5	
Maintenance year 2	7.9	
Maintenance year 3	10.6	
Maintenance year 4	8.8	
Maintenance year 5	6.8	
Maintenance year 6	9.6	
Total maintenance		51.2
Total per hectare		113.9

The "Okoumé" method

Aucoumea klaineana, a characteristic Burseraceae in the western and coastal sectors of equatorial Africa, produces the much prized timber known as Okoumé. The centre of its range of distribution is in Gabon, but it extends as far as Guinea to the north and Congo-Brazzaville to the south. We notice that its northern limit coincides with the climatic Equator, which may be a satisfactory explanation for the fact that it extends no further: the trees fruit in December and January, which is the height of the dry season north of the equator but the rainy season further south, so the trees would not germinate easily or develop at the higher latitudes; the eastern and southern limits are explained by the gradually lower rainfall, as Okoumé trees need at least 1,600 mm of rain per year to grow well.

A. Aim

Like Limba, Okoumé thrives in full light and is also found in any patches of light of any size (fields of African crops, logged-over forest patches, roadsides, large canopy gaps where trees have fallen). Its light-demanding character is confirmed by the fact that the "Narrow Deforested Strips" planting method had to be abandoned as it did not provide the trees with sufficient light. The method used today is based on providing full light from the time of planting, or at least within the three months that follow; however, unlike Limba plantations, maintaining dense regrowth is considered to be essential to "educate" young Okoumé saplings (self pruning, straightness), because plantations where too much of the accompanying regrowth is cleared usually produce low-branching and misshapen young trees.

The climate in Gabon corresponds to the range of distribution of the species with 1,600 mm to 3,500 mm of rainfall per year over the 7-8 months of the dry season (October to June) and 4 to 5 months of the misty dry season (June to October).

The introduction of Okoumé in various other countries with a different climate (Cameroon, Côte d'Ivoire, Madagascar, Guyana) seems to indicate that, as regards vegetative growth at least, rainfall is the only important limitation.

The soil factor does not seem to have much importance: Okoumé grows in any soil that is not too dry or waterlogged; for many years it was thought to prefer siliceous and sandy soils, but in fact, this is not case, and it would be more accurate to say that it grows as well in these soils as in clay soils.

B. The technique

A great many modifications has been made in developing the technique as it is used today, which involves the following operations:

1. Reconnaissance, grid mapping and mapping

This is done in the year before planting and the first task is to open up rows along NS and EW transects in the logged forest to be transformed into an Okoumé plantation; 1 km x 1 km squares are marked out and subdivided into 200 m x 200 m squares, using a portable compass and chain. A map is then drawn up showing the main topographic features and circumscribing zones unsuitable for planting (swampy and rocky areas, slopes steeper than 20%, etc.). The main forest roads are also plotted from this map.

2. Destruction of the pre-existing forest in two stages

- Mechanical deforestation using bulldozers of the D 7 Caterpillar or CD 8 Continental type (125 to 175 Hp) to bring down all trees 30 cm in diameter and pile them up into parallel windrows 50 m apart, which will be destroyed quite rapidly by natural processes (rot, etc.).
- Girdling of all trees more than 30 cm in diameter; this operation can be replaced with poisoning by phytohormones, but the latter does not seem more effective.

Both types of work are preferably conducted during the dry season as both workers and machines are much more effective and the caterpillar tracks cause less damage to the forest floor.

3. Marking out plantation rows

The position of each tree to be planted is marked with a wooden stake driven into the ground. Spacing has been highly variable: 3 m x 3 m, 2 m x 2 m, 1,50 m x 1,50 m, 5 m x 5 m, 6 m x 6 m, and is currently 5 m x 4 m. Although the final spacing has been fixed for many years at 12 m x 12 m, ideas have differed widely on how to achieve this. Those in favour of close planting (1.50 m to 2 m) have had to admit that this is extremely wasteful in terms of the number of saplings and can cause many to be misshapen; because we now know that girdled trees will destroy about 30% of saplings as they fall, the 5 m x 4 m spacing has been adopted in order to use fewer saplings and allow regrowth between the rows, which should leave about 400 saplings per hectare for thinning.

4. Establishing the plantation

Either by direct seeding in January-February during the fruiting period (6-8 seeds per seed hole, planted to wing depth).

Photo 4.
A plantation of Okoumé. After final thinning at 15 years, the trees are 12 m apart on average. La Monclah, Gabon. Photo Leroy-Deval.

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Or by planting small 3 to 4-month-old saplings (3 leaves) in soil plugs in April to May during the last months of the rainy season. These saplings will have been educated in January-February in rough nurseries in which the soil is hoed and loosened with a rake and the seeds are planted 5 cm apart in rows 10 cm apart.

Or by using stumps transplanted in October-November, at the start of the next rainy season. In Gabon this method is used only to replace failed saplings because it is thought that saplings do not take root as well as with the two former methods; the stumps are saplings with a stem about an inch thick pruned down to about 0.80 m, with roots pruned to 0.20 m.

By using all three techniques, plantation work can be conveniently spread out across the entire rainy season. A point to mention is that a method for conserving Okoumé seeds by refrigeration has been developed so that a year's worth of seeds can be kept in reserve for the next plantation.

5. Maintenance

This consists of clearing around the saplings with machetes three times a year for three years; mechanical clearing with a rotary flail has been tested, but the results were not satisfactory. During clearing, plants that grow faster than the Okoumé saplings are cut back as far as possible without suppressing them completely, so that enough shrouding vegetation is left to ensure that the young trees grow straight without low branches; this is a difficult operation indeed, especially with species like the umbrella tree, whose exuberant growth can produce shoots 4 to 6 m in length each year. Probably as a result of deforestation with bulldozers that strip the forest floor, these umbrella trees proliferate to a remarkable extent in Okoumé plantations and have become the main constraint for plantation managers. However, trials have shown that they are particularly sensitive to poisoning by phytohormones: spraying the trunk just once is enough to shrivel them and spraying just once during the second year after planting would probably suppress them entirely.

Nevertheless, it is highly probable that a fourth year of maintenance would be very useful as it would help the young Okoumé trees to fully overcome the competing regrowth.

Photo 5.
A three-year-old plantation of Okoumé at N'Koulounga (Gabon). Note the umbrella trees in the undergrowth growing back under the Okoumé trees.
Photo Sarlin.

6. Thinning

Thinning operations are still at the trial stage. The aim is to thin only once, 15 years after planting, to reduce the density of the Okoumé plantation to 60-65 trees/ha (12 m x 12 m).

However, drastic thinning on this scale could cause accidents (crown dieback, tree fall, etc.). The volume of thinnings produced by these operations could be as high as 30 to 150 m^3/ha, depending on the success of the plantation, and could be used to supply paper mills.

C. Cost of the method

In Gabon, costs are expressed in man-days and machine-hours. Each Okoumé reforestation site requires 1,000 ha of planting each year and maintenance over 3,000 ha. Organised in this way, the estimated cost per hectare are of a plantation is 80 man-days and 5-6 bulldozer hours, calculated as follows (table II).

Each 1,000 ha site therefore requires an average of 275 workmen working 300 days a year and machinery consisting of three or four 125 to 175 Hp bulldozers working for a total of 6,000 hours per year.

D. Results

At present, 16,000 ha of Okoumé plantations have been established in Gabon, including 14,000 ha using the "Okoumé" method and 2,000 ha planted along strips 30 m in width and 20 m apart at different within-row distances. Planting is currently proceeding at a rate of 2,000 ha per year, with plans to increase this to 3,000 ha. Planted areas in other countries are much smaller (1,200 ha in Cameroon, less than 100 ha in Côte d'Ivoire) or concern arboretum trials (Madagascar, Surinam, Niger, Ghana, Indonesia, India, etc.). Results from the plantations in Gabon are monitored in the same way as for Limba plantations by means of regular measurements and inventories, which may be summarised as follows:

1. Diameter growth

1.8 to 2.2 cm per year up to 15 years of age and slowing thereafter, but under conditions that are not yet fully determined, because the distances between trees, the amount of light brought in and the quality of the soil play an important role from then on. From observations made in natural stands, there is general agreement on an average yearly

Table II.

	Per hectare	
	Man-days	Machine hours/year
In the year before planting (from January 1959)		
Reconnaissance and grid mapping	0.77	
Marking transects	0.80	
Girdling	4.30	
Total	5.87	
In the year of planting:		
Machines (from the start of the dry season)	1.24	3 h 20 mn
Clearing rows, opening secondary forest roads		37 mn
Corrective felling	2.65	
Staking 5 m x 5 m	1.97	
Tree nursery work (February 1960):		
Collecting seeds	0.50	
Preparing seedbeds	0.30	
Sowing	0.20	
Maintenance	0.10	
Collecting seeds for direct seeding	1.40	
Direct seeding (February 1960)	3.10	
Replacing failed saplings	1.30	
Additional girdling	3.09	
Clearing (1st and 2nd)	8.00	
Total	23.00	3 h 57 mn
Year 2: 3rd, 4th and 5th clearings	12.00	
Year 3: 6th. 7th and 8th clearings	12.00	
Annual maintenance work:		
Main forest roads	9.00	48 mn
Moving machinery		6 mn
Camps	10.10	12 mn
Other work	6.60	
Total	25.70	1 h 6 mn
Approximate overall total	80.00	5 h 3 mn

increase of 1.25 cm to 1.50 cm up to 70 years of age, which establishes a 60 year rotation to obtain Okoumé trees with an average diameter of 0.80 m at breast height at that age.

2. Height growth

1.50 m to 2 m per year, and a total height of 25 m - 30 m for Okoumé trees 15 years of age.

3. Volume growth

At 12 years, the standing timber of average sized Okoumé trees amounts to 0.400 m^3 to 0.600 m^3, increasing to 0.750 m^3 to 1 m^3 at 15 years of age; it is hoped that at 60 years of age, in plantations of 60-65 trees per hectare, they will produce 200 à 300 t of peeler logs.

It should also be mentioned that Okoumé trees tolerate average planting densities when young: 12-year-old plantations at a density of 400 stems/ha (5 m x 5 m) have a standing paper pulp volume of 150-200 m^3/ha, hence the idea of creating plantations of this type to contribute to paper mill supplies.

E. Various trials

Among the many trials conducted to test the method (transplanting, seed conservation, spacing, sprouting possibilities, etc.), various agricultural experiments should be mentioned here, including plantations of Okoumé with coffee, cacao, palms and bananas. The latter has been most highly developed and shown to be of interest in certain cases: mixed plantations established at the same time can be difficult to manage as the banana trees quickly overtop the Okoumé; on the other hand, a pure banana plantation managed for three years, followed by a pure plantation of Okoumé appears to be of interest provided the banana trees are fertilised, which increases their yield but also leaves the soil sufficiently fertile for forest regrowth to develop after uprooting the banana trees, and for a plantation of Okoumé to become established under normal conditions. Many additional trials would nevertheless be needed to establish the cost-effectiveness of such an operation, which would demand a great deal of labour.

The Martineau method

A. Aim

This is the first method used over large areas in Côte d'Ivoire, from 1930. The techniques that were being developed from 1925, when the Côte d'Ivoire forestry service was set up, to 1930 were still at the experimental stage in small plots and were all based on the principle of natural regeneration.

M. MARTINEAU, the head of the Côte d'Ivoire forestry service, then devised his method of "close underplanting", of which 200 ha, dating back to 1930-1931, currently remain. This seems to be one of the first adaptations to dense tropical forests of the method for establishing plantations by large-scale underplanting, where the aim is to systematically replace heterogeneous forests with even-aged plantations of commercial species.

B. The technique

This involved planting 2,500 saplings of commercial species per hectare under natural forest cover in which all undergrowth up to 10 cm in diameter was previously cleared with machetes. The canopy was then gradually eliminated by girdling, in principle one year, two years and five years after planting. The parcels were to be maintained by clearing around the saplings, and the artificial stand obtained in this way would be gradually thinned every five years from the 10th year onwards. This was therefore a "prudent" method of introduction, with very gradual removal of the canopy,

Photo 6.
A 2 x 2 m plantation under forest cover planted in 1930 (Niangon, Mahogany, Dibetou).
Yapo Forest (Côte d'Ivoire).
Photo Bégué, 1935.

hence its description as "underplanting". The species used were Niangon[12] as a priority, and also Mahogany, Dibétou[13], Bossé[14] and Avodiré[15] in proportions ranging from 1 to 20%. Most of these plantations were established in the Yapo forest and some in the Banco.

How was this theoretical method applied in practice?

This is known partly from the studies by Prof. AUBRÉVILLE ("*Dix années d'expériences sylvicoles en* Côte d'Ivoire"[16]), and partly from photographs taken in 1935 and the work records for each parcel, some of which are unfortunately incomplete or imprecise, but from which the following can be deduced:

1. That the saplings introduced were collected in the forest as natural seedlings, and that they were of small size (15 to 40 cm in height); the conditions for establishing them successfully were therefore not ideal, and we now know that this factor is of paramount importance for the success of forest plantations.
2. That girdling to eliminate the canopy was not always done at the right time and – this is a purely personal comment – that it was not always very effective because 30 years after planting, there were still 40 to 50 trees of unwanted species per hectare in the Yapo and Banco parcels.
3. From the photographs taken in 1935, that the plantations were carefully cleared of all natural regrowth at least for the first five years, so that trees 8 to 10 m in height were fully exposed to daylight from collar to apical shoot.
4. That these three observations suffice, in my opinion, to account for the irregular aspect pointed out by Prof. AUBRÉVILLE of the 5 to 6-year-old MARTINEAU plantations, in terms of both tree sizes and habit.

The cost per hectare can be estimated at 185 man-days, distributed as shown in table III.

12 *Heritiera densiflora* Kosterm., *Heritiera utilis* Kosterm., Heritiera spp., *Tarrietia densiflora* (Pellegr.) Aubrév. & Normand.
13 *Lovoa trichilioides* Harms.
14 *Leplaea cedrata* (A. Chev.) E. J. M. Koenen & J. J. de Wilde.
15 *Turraeanthus africanus* (Welw. ex C. DC.) Pellegr.
16 "Ten years of sylvicultural trials in Côte d'Ivoire".

However, I believe it should be emphasised that the saplings introduced were natural seedlings and that the calculation should include high nursery and transplanting costs, given the density of 2,500 saplings/ha of a size that would ensure optimum rooting and growth (1.50 m - 2 m).

C. Results

The first thinning operations were only undertaken after 23 years in the most favourable parcels (Yapo forest), while the others were only thinned after 30 years. There are certainly many reasons for the delay, but I believe that the main reason lies in circumstance: the first thinning operation should have been undertaken 10 years after planting, in other words in 1940-1941, and had to be postponed until the end of the war because of the disorganisation of the Water and Forests Service (*Service des Eaux et Forêts*). It is more than likely that when sufficient manpower became available once more, the sight of plantations 15-20 m in height with a density of at least 2,000 stems/ha would have given the workers good reason to fear the dangers of falling timber during tornados and to delay the work from year to year until 1953. This is the well-known problem that arises when thinning is done too late: the longer the work is delayed, the greater the danger.

In any event, the Niangon plantations and some of the mahogany plantations established in this way are now an impressive sight: those in the Yapo forest have been thinned following a marking operation in 1960. According to MARTINOT-LAGARDE, the figures in table IV are characteristic of a 30-year-old plantation.

Table III.

Plantation	35
Maintenance up to 8 years	115
Maintenance in the following years	35
	185

Table IV.

Number of stems/ha	500-1,000
Basal area	20 m^2
Average diameter of the best 300 trees/ha	24 cm
Best 150	29 cm
Best 50	34 cm
Volume/ha	180-200 m^3

He considers that under normal maintenance conditions, the 300 best trees/ha can be expected to grow by an average of 1 cm per year. In any case, despite the delayed work and the inevitable tree-fall damage, the future commercial value of the plantations as they stand today is considerable, and the technical value of the MARTINEAU method applied to Niangon plantations with a few Mahogany trees has been well established.

On the other hand, the recommended densities seem too high: from 20 years of age, the Niangon trees already have large buttresses and widely spreading roots and it seems unlikely that a "canopy radius" of just 2 m around their axis, which a density of 600 stems/ha would produce, would provide them with the best growing conditions. This is still more true for the final spacing planned: a density of 250-300 stems/ha would only give the roots a radius of 3 m around the axis of the tree, which is most certainly not enough for trees 70-80 cm in diameter with large winged buttresses.

The Narrow Deforested Strips method

A. Aim

This method was recommended and developed by Prof. AUBRÉVILLE and was used in Côte d'Ivoire from 1932 to 1949 over a very large area of about 13,000 ha altogether. It should not be forgotten that this method is deliberately extensive, and that its author, who considered that the MARTINEAU method was too costly for large areas, was looking to develop a more cost-effective technique even if this meant reducing the number of planted saplings per hectare and considering forest enrichment as a first step in transforming the natural forest: its transformation into a stand of commercial species would not be complete until the second rotation, with the help of natural regeneration if necessary.

B. The technique

This involved opening up vertical gaps along parallel and equidistant transects in dense forest, in which nursery-raised saplings were planted at regular intervals. The idea was to establish vigorous saplings of noble species in the best growing conditions, with their crown in the light but with their stems in the forest ambience of the surrounding natural vegetation. This implied opening up strips at least 2 m wide on the forest floor but considerably wider in the upper storey to prevent the combined effects of lianas, tornadoes and light from closing up the gaps in the canopy.

The width and spacing of these rows varied a great deal, depending on the way lessons were drawn from experience:

- From 1931 to 1934: rows were opened up 10 m apart, and saplings planted within these rows at distances of 2 m, 2.50 m or 5 m. It soon became apparent that with such close spacing between the rows, letting enough light down to the saplings in fact meant destroying the entire pre-existing forest, so that the labour costs involved were similar to those required for the MARTINEAU technique. The spacing between the rows was therefore increased considerably from 1934 onwards.
- From 1934 to 1949: the spacing between rows was increased to 20 m, then 25 m, with the saplings planted along the strips at intervals of 2 m-2.50 m. But even with the wider spacing, letting light in for the saplings meant destroying virtually all of the dominant storey. Experience showed that if the strips were narrow up to a dense canopy, the saplings did not grow well and made frequent clearing necessary. Therefore, M. AUBRÉVILLE soon recommended drastic clearing as from the first year. In 1935, he wrote:

"*The conclusions to be drawn from experience are now clear: there is much to be gained from drastic clearing no later than the first year after planting. The recommendations are therefore:*
1. Open up wide strips along the transects by clearing upward growth entirely to a height of 8 to 10 m and clearing the ground across a width of 2 m;
2. Tightly girdle all trees with dense, low-growing crowns that prevent light from reaching the floor of the strip."

Anyone with experience of plantation work in dense forests would have to admit that applying such rules would be tantamount to destroying almost the entire dominant storey and part of the understory. And the impression on

Photo 7.
A 10 x 2m plantation of Mahogany and Tiama in rows cut into secondary bush in 1931. Yapo Forest (Côte d'Ivoire). Photo Bégué, 1935.

Photo 8.
A plantation in rows cut vertically into dense forest in Côte d'Ivoire
Photo Allouard, 1938.

visiting these old "Narrow Deforested Strips" plantations in Côte d'Ivoire is that the rules were only very loosely followed, an impression confirmed by the parcel worksheets showing the insufficiency of the labour force.

C. Cost of the method

A study of costs has to consider the two spacing patterns separately.

▪ Rows 10 m apart: the costs average 86 man-days/ha for the 10 m x 5 m spacing and 110 man-days/ha for the 10 m x 2.50 m spacing. But it is interesting to note that 50% of these man-days were used from the 10th to the 20th year after planting; this is partly due to over-cautious girdling to clear the vegetation during the first years, but it also underlines one of the characteristics of this method, which is that the work is spread out over many years.

▪ Rows 25 m apart: the anticipated cost was 35 man-days/ha, of which 22 were before planting and 13 for clearing and improvements spread over six years after planting, which would have made the method very economical. But the reality was rather different: although highly variable, the number of man-days required was higher than anticipated, often twice as high and sometimes three times higher, and especially, the work often lasted for 20 years. However, it must be underlined, again, that the initial plantation work was insufficient due to the labour shortage, so that the work undertaken took longer and was more expensive. It is therefore difficult to form a valid opinion about the cost and duration of work in a plantation of this kind under normal circumstances and with sufficient means. The information we have gathered suggests 50 man-days/ha spread over 10 years. But, in any case, the considerable disadvantage of the duration of plantation work must be underlined: for example, it is much easier to apply a technique that requires three years of maintenance at a cost of 10 man-days/ha/year than a method that would theoretically require only three man-days/ha/year for 10 years, because in practice, for an annual programme of 1,000 ha of new plantations, the first year would require maintenance across 3,000 ha and the second across 10,000 ha. Given the specific difficulties of organising, supervising and employing labour in dense tropical forests, maintenance is always a decisive factor in the success of plantations over large areas.

D. Results.

Apart from purely descriptive observations that can be made from tours in the forest, which have little value as evidence, results from studies of the inventory sheets have to be interpreted with the utmost caution, because:

As yet, there has been no thinning (barring a few exceptions) of these plantations in narrow deforested strips, even though the oldest were planted more than 30 years ago. Most of the trees in the strips are 2.50 m apart, and the promoters of the method had worked on the principle that thinning would not be necessary because, or so they hoped, natural elimination would ensure that only one fifth of the planted trees reached the dominant storey. But the growth of these trees was mainly conditioned by the quantity of light reaching them through the vertical gaps: therefore, several elite trees are likely to be found growing side by side, some of which will inevitably have to be eliminated given the 2.50 m spacing. The natural elimination process will have been altered by the uneven light and will therefore have to be assisted by thinning, which will often be drastic. Personally, I believe it should have been done before, as I am convinced that the growth and shape of the elite trees has been adversely affected;

Under these conditions, the statistics published from the inventories can be of little value until the final thinning has been accomplished. This is why the interpretation of the inventory results given by BERGEROO-CAMPAGNE cannot be accepted without reservation: he characterises the parcels by "the average diameter and height of the 50 best specimens counted per hectare, since the plan is ultimately to raise 50 trees per enriched hectare". He therefore considers that the best 50 trees are suitably spaced from the outset and that they will form the final stand. However, a few minutes of observation along the strips are enough to show that this is an act of faith: producing exploitable trees with a minimum diameter of 70-80 cm necessarily implies thinning that will destroy other elite specimens and thus alter the previous statistics.

It therefore seems hazardous to provide a robust opinion on the results obtained for these 13,000 ha of "Narrow Deforested Strips" plantations. Nevertheless, the above discussion suggests applying a reduction coefficient, which cannot be determined before thinning but is clearly important, to the results of the first inventories: given that the trees were planted in rows initially 2 m to 2.50 m apart, that the current spacing between trees 70-80 cm in diameter is estimated at 8-12 m depending on the size of the crown, which is a specific characteristic, and that an acceptable spacing would be 5-6 m at best but 15-20 m distant from the next group, it seems reasonable to apply a reduction coefficient to the statistics. The theoretical calculation for plantations in strips 25 m apart, which represent 85% of the enriched areas, gives a result of around 30 to 40 exploitable trees per hectare; from observations in situ, this seems to be the maximum, as the number will often be nearer 20, which is already an excellent result compared to the figures for natural forests, so that "enrichment" is clearly what has taken place. But an uncompromising comparison between these methods must also consider manpower needs and the duration of plantation work: producing what will probably amount to 20 exploitable trees per hectare in Côte d'Ivoire will have required 60 to 100 man-days/ha for 16 to 20 years. Again, we must underline the experimental nature of these plantations and the difficult circumstances in which they were established, and remind the reader of the 50 man-days/ha previously suggested as a possible figure for a plantation that has been robustly managed from the start: production of 30 trees/ha with a workforce of 50 man-days/ha working for 10 years can therefore be considered. A final factor to be considered is the growth rate. The comparisons made by MARTINOT-LAGARDE between the best narrow deforested strip parcels and average MARTINEAU-type parcels show that trees grow more slowly in narrow deforested strip plantations, which is normal as they have less light: the measurements made in 20 to 30-year-old plantations show 0.6 cm to 1 cm annual growth in diameter for the classic species (Niangon, Mahogany[17], Dibétou, Framiré[18] and Avodiré), which appears to imply a 100 year rotation to obtain trees 70-80 cm in diameter.

It would seem that better use could be made of the natural conditions that exist in dense tropical forests.

The Evenly Spaced Planting Spot method

Belgian Foresters have attempted to adapt the reforestation technique used by ANDERSON in the Scottish moors to the particular conditions of dense tropical forests.

A. Aim

ANDERSON's planting spot technique consists of close planting of the species to be regenerated in spots of the same size that are distributed uniformly over the terrain but very widely spaced. This method claims to reconcile the advantages of close planting with the lower costs of wide spacing. According to its protagonists, the method can be applied very flexibly in tropical forests, because it is suited to every kind of formation to be enriched or reforested (dense forests after logging, secondary forests, degraded forests, etc.), while also allowing for any planting technique (direct seeding, soil plugs, stumps).

The Belgian authors also emphasise the importance of avoiding disturbance to the natural ecological environment by destroying as little undergrowth as possible in the forest to be enriched.

[17] *Swietenia mahagoni*.
[18] *Terminalia ivorensis* A. Chev.

B. The technique

The method involves the following operations in succession:

1. Nurseries: to be established in the forest as temporary nurseries under canopy to produce plants that are used to growing in the shade.
2. Preparing the ground: 4 m x 4 m squares are marked out running north to south and east to west, with each centre 10 m distant from the next. Inside each square, only lianas and herbaceous growth are eliminated; all shrubs are carefully preserved.
3. Plantation: the saplings are planted as closely as possible inside each square to form a stand as quickly as possible.
4. Canopy clearing: once the saplings are well rooted in, competing shrubs inside the spots are very gradually removed; some high canopy trees are then also removed with great caution.

C. Cost of the operation

The figures for the manpower required only concern the operations described above and amount to about 25-30 man-days/ha; manpower for clearing and thinning should be added.

D. Results

These are reported to be excellent for the main dense forest species of commercial interest, but the descriptive notes on the work undertaken only concern the first few years of the trials and we have no information on subsequent developments. However, my experience with plantations in dense forests suggests the following reservations:

- The concern to ensure that the planted saplings grow in the shade of the natural canopy could seriously compromise the needs of the main commercial species by adversely affecting their growth, which would considerably lengthen the duration of maintenance work;
- Supervising the work over large areas is likely to be problematical because the concern not to destroy the undergrowth means that the strips marking out the spots must be very lightly cut and will therefore not remain clear for very long;
- Again over large areas, opening up the canopy very gradually and cautiously, which seems to be the rule, necessarily implies a great many operations over time, and I fear that this method would lead to the same difficulties as the large-scale use of natural regeneration techniques.

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