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[1] C.T.F.T. : Centre Technique Forestier Tropical. The C.T.F.T. was incorporated into the CIRAD as a forestry department in 1984.
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Tropical silviculture in dense African forest (Part 3)

Photo 1.
Light filters through tree crowns, but the rays of the sun that reach the ground are of particular importance to foresters, who should develop photology as one of the foundations of forestry research.
Photo Sarlin.

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RÉSUMÉ

Sylviculture tropicale en forêt dense africaine (partie 3)

L'article présente la troisième partie de l'étude sur la sylviculture en forêt dense africaine. Dans les deux premières parties, l'auteur discutait des principales méthodes de foresterie développées jusque-là. Dans cette partie, il examine les causes d'échec. Il considère que le facteur déterminant pour le succès des plantations est la lumière du jour, que les jeunes plantules reçoivent généralement insuffisamment. L'auteur décrit ensuite le programme de recherche entrepris par le Centre technique forestier tropical (CTFT, centre technique maintenant intégré au Cirad) sur ce thème afin de déterminer la quantité de lumière délivrée par chaque système sylvicole, la quantité optimale de lumière demandée par chaque espèce étudiée et l'effet de l'illumination latérale. Ces études utilisent des calculs graphiques, des mesures aux instruments, et des dispositifs expérimentaux particuliers.

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

ABSTRACT

Tropicale silviculture in dense African forest (Part 3)

The article presents the third part about tropical silviculture in dense African forest. In the first two parts of this article, the author discussed the principal methods of forestry employed in the dense humid forests of Africa. In this part, he examines the causes of failure. He considers that the determining factor for the success of plantations is daylight, of which young seedlings generally receive far too little. The author goes on to describe the research programme undertaken by the Centre Technique Forestier Tropical (CTFT, technical centre now integrated into CIRAD) in this field to determine the amounts of light provided by each forestry system, the optimum amount of light demanded by each species and the effects of lateral illumination. These studies use graphic calculations, instrumented measurements and special experimental apparatus.

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

RESUMEN

Silvicultura tropical en bosque espeso de África (Parte 3)

Este artículo es la tercera parte sobre silvicultura tropical en bosques espesos de África. En las dos primeras partes el autor expuso los principales métodos de silvicultura empleados en los bosques espesos húmedos de África. En esta parte examina las causas de fracaso. Considera que el factor determinante para el éxito de las plantaciones es la luz solar, generalmente los jóvenes pimpollos no reciben suficiente luz. El autor pasa a describir el programa de investigación llevado a cabo por el Centro Técnico Forestal Tropical (CTFT, centro técnico actualmente integrado en el CIRAD) en este campo para determinar las cantidades de luz proporcionadas por cada sistema forestal, la cantidad óptima de luz requerida por cada especie y los efectos de la iluminación lateral. Estos estudios utilizan cálculos gráficos, mediciones instrumentales y aparatos experimentales especiales.

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

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Research

If we review what has been achieved with the different silvicultural methods I have described, the results are not always encouraging: some techniques have never progressed beyond the experimental stage, others seem to have been completely abandoned, and those that remain in use are the Taungya method and the Limba and Okoumé methods, which can only be used with certain species.

Now that it is possible to make comparisons with the benefit of hindsight, we must attempt to identify the reasons for failure and build up a research programme accordingly: in the current situation, **priority must be given to research**.

To my mind, there are three main reasons:

- Inadequate knowledge of the temperament of the species concerned, which leads to errors when attempting to establish them.
- Inadequate recovery and growth of planted saplings, which produces stunted and misshapen trees and prevents the rapid formation of a closed canopy,
- The excessive frequency and duration of maintenance work, which not only make plantation costs prohibitive but also result in widely dispersed and overextended worksites, a situation which is incompatible with the human and material conditions encountered in dense forests zones.

These three reasons for failure in fact come to the same thing: **poor sapling growth.** It is obvious that the number and frequency of maintenance operations will be in inverse proportion to the growth rate of the plantations: vigorous and fast-growing saplings require less maintenance as they quickly dominate the new growth surrounding them. This essential consideration, which might be referred to as the Law of the Jungle, is peculiar to tropical forests and comes fully into play in its natural element: any planted sapling which is dominated by natural regrowth will soon be suppressed by it; even a plantation of fast-growing species like Okoumé or Limba will disappear under a canopy of umbrella trees if they are not systematically removed.

This means, on the one hand, retaining only the plantation methods that promote good tree growth, and, on the other hand, developing cheap and efficient techniques for eliminating competing species that grow faster than the planted saplings.

The determining factors for the growth of planted saplings can be summarised as follows:

1- Water

In dense forests, which are those that concern us here, this does not tend to be a limiting factor, as rainfall is usually ample in tropical forest climates (from 1500 mm to several metres per year) and failures can only be ascribed to ecological errors: in any event, the plantation method is irrelevant and human actions are not at issue, as they obviously make no difference to the amount of rainfall at any one time.

2- Soil

It is well known that soils have an influence on plant growth, but it has to be acknowledged that our knowledge on soil-plant interactions in dense forests is very patchy, as these interactions are often unclear and masked by other more obvious factors. Generally speaking, only the forester's choice of a deep, fresh, permeable soil, from which all impermeable rocky zones and areas with too much sand are removed, can have any influence on the success or failure of the future plantation. Although we certainly lack sufficient knowledge at present, the plantation method chosen bears absolutely no relation to the influence of the soil type.

3- Temperature and humidity

The same comments can be made for these two parameters as for water and soil: nature supplies the right conditions in abundance in dense tropical forests (temperatures ranging from 20°C to 30°C, humidity from 50% to 100%), creating the "warm, moist greenhouse conditions" described by the first explorers. Barring ecological errors, they should not be limiting factors. However, the plantation method chosen could have some influence, as yet unknown but deserving attention: the differences in temperature and humidity from one station to another under dense forest canopies and in full sunlight have been measured for a long time, and we know that the differences are smaller under the forest canopy and that average temperatures are 1°C to 3°C lower. This is illustrated by the two thermo-hygro-

Photo 2.
C.T.F.T. - Gabon. Ikoy-Handja silvicultural station.
Niangon trees 9.5 years after planting.
Photo Leroy-Deval, 1965.

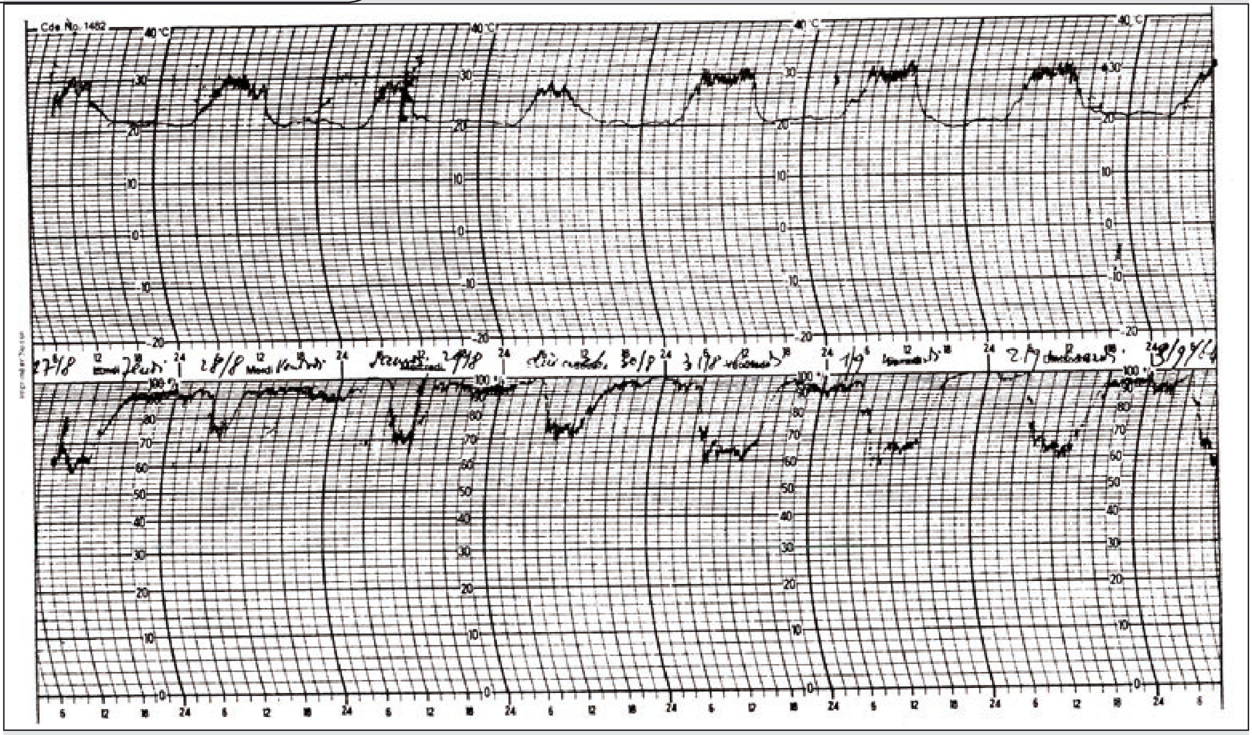

Figure 1.
C.T.F.T. - Gabon. Thermo-hydrograph readings (temperature and humidity) taken on open ground (dry season).

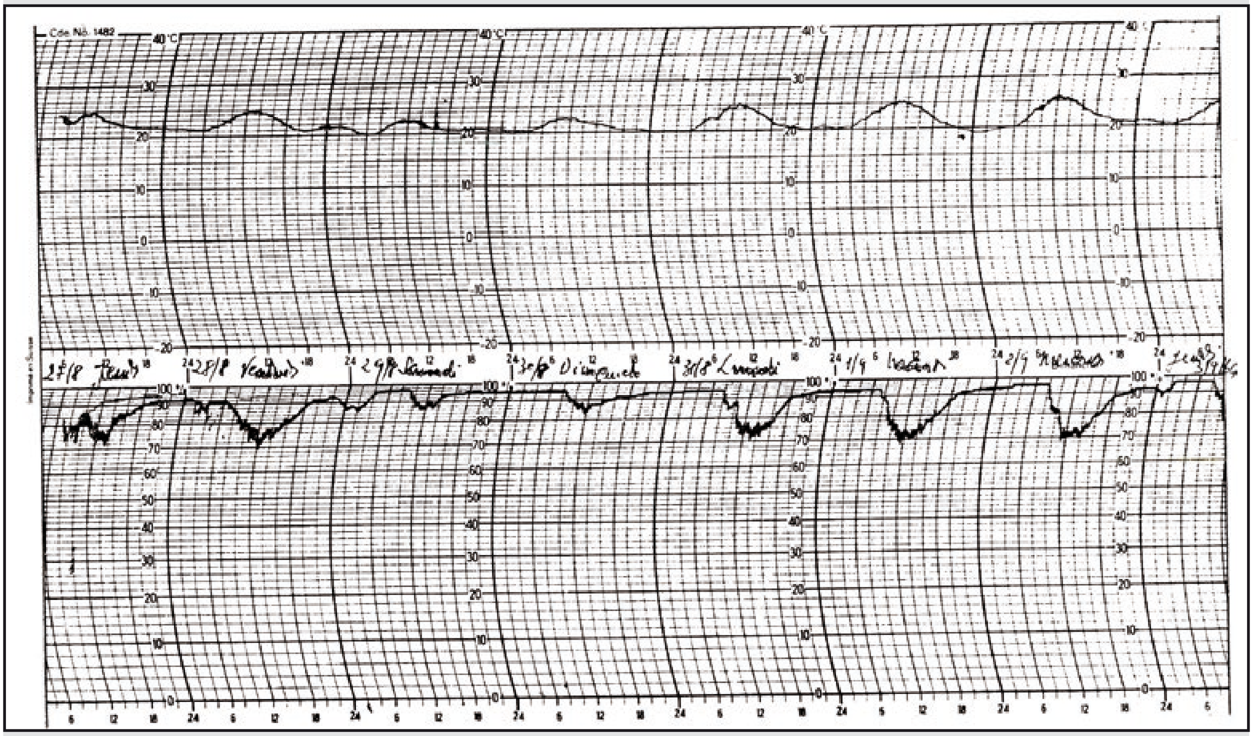

Figure 2.
C.T.F.T. - Gabon. Thermo-hydrograph readings taken under forest canopy (dry season), showing the attenuation of temperatures and humidity.

graph readings shown below (figures 1 & 2), taken in the dry season in Gabon. It is therefore clear that different plantation methods can expose saplings to very different amounts of light that will produce differences in temperature and humidity, and that the resulting physiological responses (respiration, transpiration, etc.) will be highly variable depending, for example, on whether the Evenly Spaced Planting Spot method under dense forest canopy is used, or the Taungya method.

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Photo 3.
A 10 year-old Limba plantation.
Bakou N'Sitou (Congo-Brazzaville).
Photo Groulez, 1961.

Photo 4.
A Niangon plantation in the Yapo forest station.
Côte d'Ivoire.
Photo Mariaux.

For lack of knowledge on species requirements in this case, the temptation is to admit that they prefer natural dense forest conditions, but there is a particular need for experimentation to remedy the gap in knowledge.

4- Light

This is most probably **the determining factor for plant growth** and, because foresters can act on chlorophyll assimilation, which is conditioned by the amount of light, it is also the **easiest factor to influence**.

And yet, the impression is that we have never used the full potential of light, as if we feared the effects of its abundance in tropical climates. Is this an extrapolation to the plant kingdom of the responses of men from a different continent, who perceive the light of the tropics as particularly dangerous? Is it due to the illusion that the greenhouse atmosphere of the dense forest understory provides optimum conditions for plant growth, despite its shadowy dimness?

There are many reasons, which for a long time have masked the plain fact that **the main commercial timber species in dense forests are light-demanding species that regenerate not in the understory, but in forest clearings**. This is exactly what Prof. AUBRÉVILLE noted when he wrote: "*growth is very largely dependent on the amount of light received by the crown. This has never been in doubt, of course, but in the constantly warm, moist equatorial forest environment, it was believed that plants would grow even in poor light*".

Finally, what is certain is that without exact measurements taken with reliable instruments, which has only become possible in the last few years, foresters could easily be mistaken about the amount of light reaching the ground in naturally regenerating clearings or along plantation strips, because they had not appreciated the importance of the height of the dominant story (about 40 m), which is directly related to the amount of light intercepted; it was difficult to imagine that, as we know now, a narrow deforested strip 2.50 m in width at the base only receives 5 to 10% of the total light reaching open ground.

We are now beginning to understand, experimentally, the consequences of poor light on the growth of the main planted species:

- Okoumé trees have never been grown successfully in dense forests in narrow deforested strips of the AUBRÉVILLE type because they are a light-demanding species.
- The growth of Niangon trees (*Tarrielia ulilis*) planted under light cover, as with Martineau method, show much better growth by 30 years of age than trees of the same species planted in narrow deforested strips (MARTINOT-LAGARDE report, table I).
- Niangon trees planted in narrow deforested strips in Côte d'Ivoire reached an average height of 5 to 6 m in eight years, but the same species planted on open ground in Gabon grew to 8 to 12 m over the same time (Ikoy-Bandja Station).

Table I.

Number of large trees	Martineau plantation	Narrow Deforested Strip plantation
150 largest per hectare	31.1	22.7
50 largest per hectare	38.2	34.8

▪ Sipo (*Entandrophragma utile*), which is considered to grow very slowly in narrow deforested strips, grow by an average of 1 to 1.50 m in height per year in full light (Gabon).

▪ In a young narrow deforested strips plantation of Doussié trees at Bonepoupa (Cameroon), SCHIRLE measured the incident light received at the height of each sapling and attempted to establish a relationship with the size of the saplings by correlating the results with measurements of their circumference. Figure 3 plotted from these data shows an obvious correlation between the intensity of light received by the tree and its 1.30 m circumference.

Many more examples could be given, as most commercially valuable dense forest species seem to behave, in plantations, like light-demanding species: *Aucoumea klaineana*, *Terminalia superba*, *Khaya ivorensis*, *Entandrophragma utile*, *Triplochilon scleroxylon*, *Afzelia africana,* etc.

To conclude, it seems clear that of all the factors determining growth, light appears to have the most obvious effect and is any case the easiest to act upon: amounts of light can be varied as required by adjusting the canopy at the time of plantation and during the first years of a tree's life.

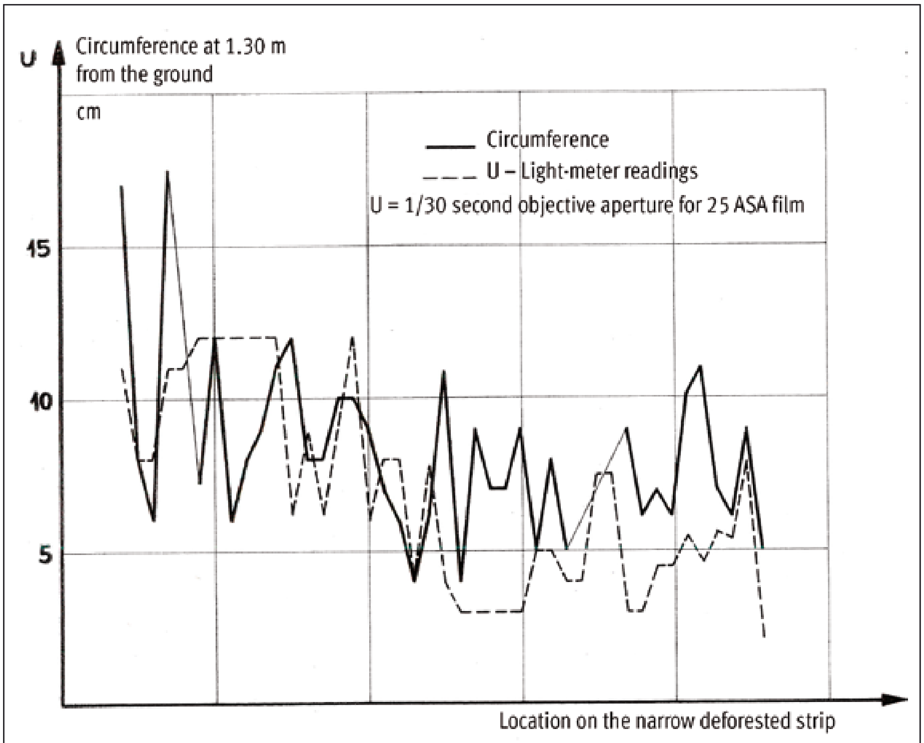


Figure 3.
Variation in the growth of Doussié saplings and in the light reaching their crowns in a narrow deforested strip plantation at Bonepoupa (Cameroon). M. Schirlé.

More generally, the tendency seems to be that in dry tropical zones, the limiting factor for regeneration and planting is water, while in humid tropical zones, the limiting factor is usually the amount of light.

However, it is obvious that light can have negative and inhibiting effects and that there cannot be any hard and fast rule: rules can only be established through meticulous experimentation.

Studies on light

This is the reason why the *Centre Technique Forestier Tropical* has given priority in recent forestry research to the light factor, through studies on light and the development of plantation methods making maximum use of light. The critical points to be determined seem to be as follows:

1. The amount of light reaching plants with each silvicultural method (narrow deforested strips, rows, Taungya, T.S.S. etc.).
2. The optimum quantities and quality of light demanded by each of the main commercial species.

Essentially, the aim is to determine, for each species, the silvicultural methods best suited to it by measuring its requirements for light and the amount of light supplied by each technique. We need to focus less on empiricism and impressions and more on figures, which alone can allow valid comparisons, albeit in the knowledge that although the value of figures is not absolute, they should be sufficiently indicative.

Studies, often just recently begun, have focused on:

Determining the amount of light received by saplings or seedlings with each sylvicultural method

These studies can be undertaken in two different ways.

A. Based on instrument readings

These studies involve placing light meters next to the saplings planted with each sylvicultural method. Readings can then be taken of the amount of light received by saplings planted with the different methods: Limba, Okoumé, T.S.S., Narrow Deforested Strips, etc. This seems to be the most promising method, as it supplies readings taken in the conditions of the actual plantation. The light meters should be heliographs or actinometers that give the amounts of solar energy received at a given spot during a full climatic cycle (at least one year), rather than luxmeters that only give instantaneous readings of light intensity that are difficult to process. Unfortunately, our attempts to conduct experiments in Gabon in the last few years have been unsuccessful, as we have been unable to find instruments with the right combination of robustness and accuracy:

Photo 5.
C.T.F.T. - Gabon. The Ikoy-Handja silvicultural station (plantation method with new growth), showing excellent growth of 3.5 year-old Niangon saplings.
Photo Leroy-Deval.

▪ Heliographs of the Gorczensky type proved to be much too fragile to remain in place in the forest for several months to a year without continuous surveillance, as they have to be protected from tornadoes, are vulnerable to classic incidents such as strong gusts of wind and falling branches and readings have to be taken each week.
▪ Spherical actinometers are almost as fragile and have proved inaccurate in the poorly lit conditions of the forest floor or narrow deforested strip plantations, as shown by the two tables in figure 4 and figure 5 that give readings taken in a plantation of Okoumé (thinned and not thinned), in Gabon during the dry season.
▪ Luxmeters only give readings for a particular moment and require observers using chronometers in cloudless conditions (the sun may be hidden for one observer and not the other at the same moment).

To summarise, the principle of the instruments themselves is obviously not at issue: the difficulties inherent to dense tropical forests mean that specially adapted instruments have to be designed, such as the heliograph powered by a photovoltaic cell recently constructed by BORREL, a research engineer with the French Meteorological Office, which we are currently testing in Gabon.

This is a silicon cell photometer that supplies energy to a motor driving a totalising meter. These cells have a silicon barrier layer and are used to supply the energy needed to operate observation instruments on board some American satellites. BORREL assembled a solarmeter with a silicon cell that produces a constant yield 20 times greater than a selenium cell. The silicon cell drives a measuring motor that rotates at a speed proportional to the energy received and has an integrated time function, thanks to a counter coupled to the motor. The entire apparatus needs 1 microwatt to start up.

The first coupled instrument installed a few months ago in Gabon has performed satisfactorily so far: it is very robust, not sensitive to high winds and convenient to use as the measurements are totalised. For reference, the first measurements were of the amount of light reaching the dense forest understory expressed as a percentage of the light reaching open ground. After 40 days of continuous observations during the rainy season (April to May 1965), the percentage was about 3.5%.

It should be noted that this figure is rather different to the 7 to 8% obtained by Prof. AUBRÉVILLE in Cameroon, using a spherical actinometer, which is closer to the measurements made in Côte d'Ivoire by P. CACHAN and J. DUVAL using luxmeters (table II).

It is clear that with such small percentages, the calibration of the instruments and the density of the forest have a significant influence, and that ultimately, the important points are the order of magnitude and the duration of the observations: any measurements made over less than a full climatic year will be less than conclusive. What these figures clearly show, however, is the highly effective protection provided by dense forest, and it is easy to see why the temperature in the understory can be 2 to 3°C lower than outside the forest.

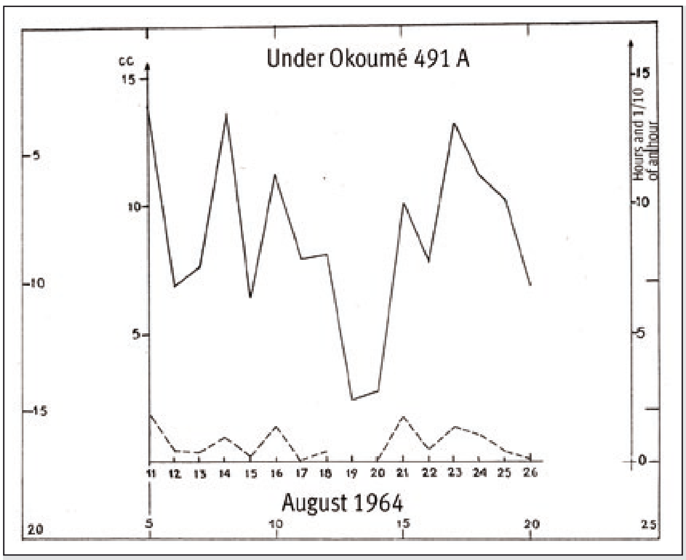


Figure 4.
C.T.F.T. - Gabon. Actinometer readings (dotted lines) and number of hours of sunlight (solid lines) under cover of an Okoumé plantation (Mondah forest reserve). On 19 August, the light was too dim for the actinometer to give a reading.

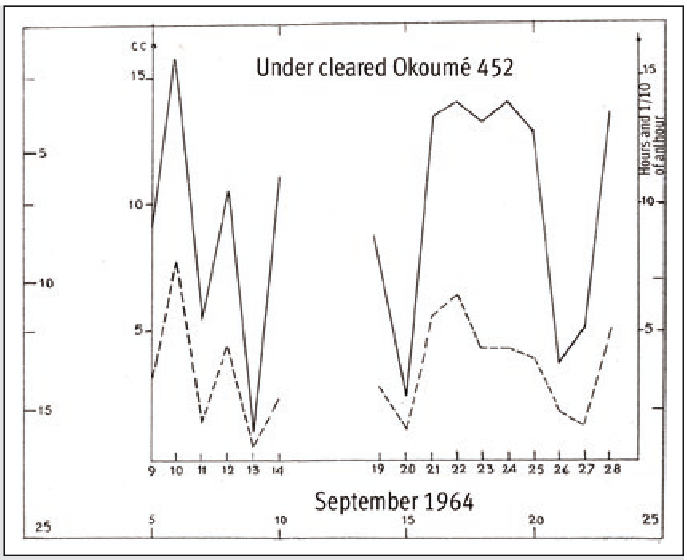


Figure 5.
C.T.F.T. - Gabon. Actinometer readings (dotted lines) and number of hours of sunlight (solid lines) in a clearing in an Okoumé plantation. Mondah forest reserve. The readings are much higher than those in figure 4.

Table II.

Date	Light at the top of the canopy	Light in the understory	Percentage of luminosity
15.04.1960	130,000	290	0.4%
9.06.1960	100,000	800	0.8%
5.08.1960	27,000	450	2.0%

To conclude, the amount of light reaching the ground can be determined from actinometer readings, and this is indeed the only rigorous way of doing so; although this is still dependent on better instrument accuracy, it seems that this is now close to being achieved.

B. Based on calculations

Calculation methods such as those used in photology and astronomy can accurately determine relative amounts of light over a year at a point at a given latitude corresponding to a forest clearing of a given size in a forest formation. ROUSSEL, a French water and forests administrator and an eminent specialist in forest photology, describes one of these methods, based on plotting a graph of particular elegance, which he calls the "total illumination circle" and summarises as follows:

"*One theoretical method involves using certain photometric and astronomic considerations to attempt to determine, in openings with well defined characteristics, the pattern of distribution of diffuse light (from clear or cloudy skies) and direct light (from the sun only), and from this to calculate the probable and average values for the light or the overall radiation received during a growing season or a full year at the main reference points. We know that the scholarly research of G. MONNET provides the essential considerations required to determine the value of direct radiation in a wide variety of stations. For our calculations here, however, we will use a simplified method, in fact already described in the Revue Forestière Française (April 1953), which is based on both direct solar radiation and diffuse radiation from a clear or cloudy sky. The main points of the essentially graphic method known as the* ***total illumination circle*** *are given in figures 6 and 7.*

Direct solar radiation and diffuse radiation each contribute about half of the overall radiation received in the course of a year. This simple distribution is the outcome, in particular, of recent work by BLACKWELL (1954), who indcates that in London, over five years and during the period of active growth only, 52% of radiation on average is from the sky alone and 48% from the sun. The distribution for an entire year is very close to 50-50. In Vienna, STEINHAUSER, ECKEL and SAUBERER (1955) showed, for measurements made over a long duration, 48.5% of diffuse radiation and 51.5% of direct solar radiation. In France, at a latitude of 47° North, it therefore seems justified to adopt a simple 50%/50% proportion. At this latitude, of about 100,000 small calories per year received by one square centimetre of horizontal ground, 50,000 are therefore from the sun and 50,000 from the sky only. Diffuse light comes from the entire sky (the apparent hemisphere that arches over the place of observation). Although it is incorrect to assume that the light from the sky is identical in any direction at a given moment in a given day, the luminosity is fairly constant in the frequent case of even cloud cover. In a clear blue sky, the luminosity is greater close to the position of the sun, but it moves from East to West during the course of each day. Finally, it is variable and sta-

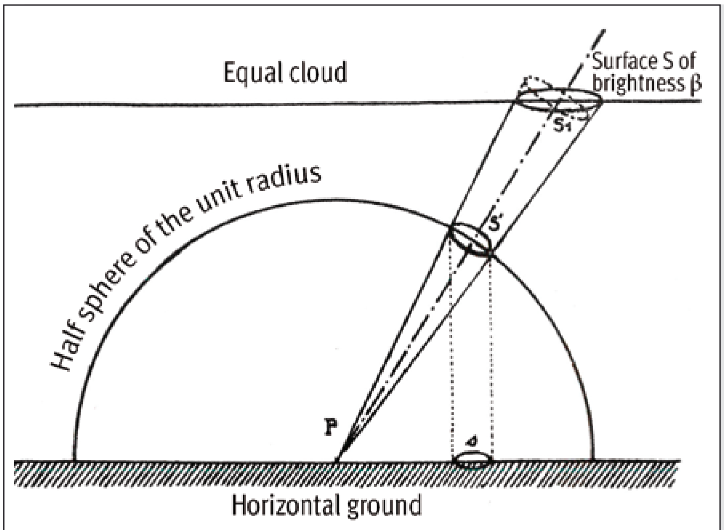


Figure 6.
Diagram showing that the illumination produced at P by a horizontal cloudy surface S of brilliance β is equal to the product of s (orthographic projection of S) by β.

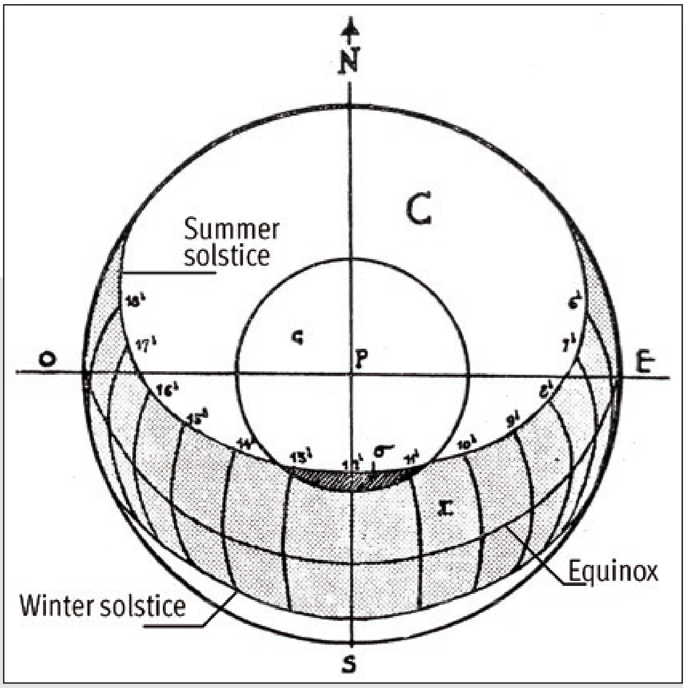


Figure 7.
A total illumination circle. The total relative light reaching P, at the centre of a circular clearing, is equal to the ratio of c (orthographic projection of the upper edge of the clearing) to C (orthographic projection of the reference hemisphere) plus the ratio of σ (orthographic projection of the upper edge of the clearing that overlaps all trajectories of the sun) to Σ (orthographic projection of all trajectories of the sun), the sum of which is divided by 2.

Photo 6.
Limba is clearly a light-demanding species.
Photo Sarlin.

tistically equal everywhere over a long period in the case of a cloudy sky (with moving clouds) when the sun is sometimes apparent and sometimes not. As far as we know, at latitude 47° North, no zones have been identified in the sky where clouds preferentially gather. Generally speaking, it can therefore be assumed that over an entire year, the brilliance (or more accurately the luminance) of the sky is fairly constant in any direction, except perhaps for a generally lower luminosity to the North. By simplifying the matter in this way, it becomes possible to proceed as follows: given a reference hemisphere centred on the station where the amount of light is to be determined, then projecting the apparent contour of a forest clearing or strip onto this hemisphere, and then projecting the same contour horizontally over the station (the so-called orthographic method), the relative amount of diffuse light is equal to the ratio of the projected area of the clearing to the projected surface of the reference hemisphere (or circle with the same radius). For example, if we obtain 50% as the ratio of the projected contour of a circular clearing, seen from the central station, to the horizontal projection of the reference hemisphere, this means that over one year and per square centimetre, the centre of the clearing receives about 50% x 50,000 = 25,000 small calories."

"*Sunlight is provided by the sun, whose position varies depending on the day and the hour of observation. But the sun does not shine all the time. In the Besançon region, for example, the sun only appears during 40% of possible hours of observation. But in this case also, no zones in the sky can be identified where the sun either regularly appears or is hidden. Therefore, statistically, there is an equal probability that the sun will shine at a given time of year, at any point of a given solar trajectory between those of the summer and winter solstices. This simplifies the problem, because if we know the orthographic projection of all of the sun's trajectories above a station on open ground, and we have the projection of the apparent edges of a clearing or strip, it is possible to determine the approximate hours during which sunlight may reach a given point in the clearing, and also the hours when the sun will necessarily be hidden. Orthographic projections also have the interesting property, recently discovered, of correcting, approximately, the fact that because the sun is low in the sky early and late in the day, it provides much less direct light than in the midday hours. If we compare, on the projection of all of the sun's trajectories, the area occupied by the different sectors corresponding to the hours of the day, for example using BLACKWELL's long-duration measurements, we obtain two sets of ratios as shown in table III.*

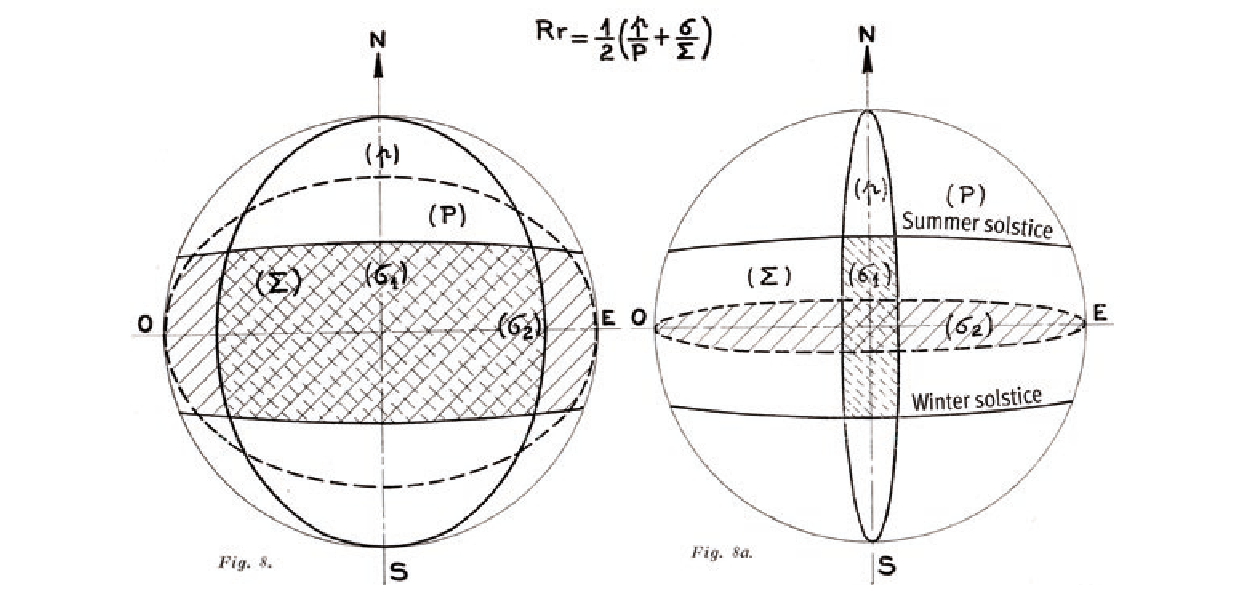
Thus, while the "total illumination circle" indicates that, in a given station, the sun may shine from 11:00 to 13:00 hours each day, the area occupied by the projection of the apparent contours of the clearing amounts to 25% of the total projected area of the sun's trajectories. The direct radiation actually received during these two hours then amounts in fact to 23% of the total direct radiation received on open ground:
25% x 50,000 = 12,500 small calories per square centimetre in theory, as against:
23% x 50,000 = 11,500 small calories per square centimetre actually received.

There is a small source of error in the fact that the automatic correction is less marked when comparing the difference between direct sunlight received in summer and winter.

To conclude, then, by adding the figure for diffuse radiation (sky) to the figure for direct radiation (sun), both obtained with the method we have just described, we have an indication of the total radiation received at a given point in a forest clearing or strip, with an approximate margin of error of 10 to 20%."

Table III.

Local times of day	**5 to 6 18 to 19**	**6 to 7 17 to 18**	**7 to 8 16 to 17**	**8 to 9 15 to 16**	**9 to 10 14 to 15**	**10 to 11 13 to 14**	**11 to 12 12 to 13**
Percentage of area	5%	8%	10%	13%	18%	21%	25%
Percentage of radiation actually received	4%	8%	11%	14%	19%	21%	23%



Figures 8 and 8a.
Total illumination circles for a latitude between 0° and 5°: figure 8 represents the graph for a strip 2H in width; figure 8a is the graph for a strip H/4 in width.
P = surface of the reference circle;
p = surface of the ellipse formed by the projection onto this circle of the section of the reference sphere intercepted by the strip.
Σ = surface on the reference circle delimited by the orthographic projections of the sun's trajectories at the two solstices.
σ = part common to p and Σ;
$σ_1$ = for a strip running North to South;
$σ_2$ = for a strip running East to West.

Based on these studies by Forests Administrator ROUSSEL, and on his advice, I applied the same method to the equatorial latitudes: this is justified by the work of DECOSTER, SCHUEPP and VANDER ELST, who showed in 1955 that in the equatorial zone, the ratio of direct to diffuse radiation is still approximately 0.5 / 0.5, even though the total amount of radiation is much greater than in temperate regions (140,000 to 150,000 calories/cm²/year at Léopoldville).

I was thus able to construct the **total illumination circles** for the equatorial latitude (cf. figures 8 and 8a) by plotting an orthographic projection of the most characteristic trajectories of the sun (solstices and equinoxes). By making the graphic calculations corresponding to certain typical dimensions of forest strips or clearings, I was then able to determine the relative amounts of light reaching the ground in dense forests at several points in strips and clearings of different dimensions. The results are summarised in the graphs in figures 9, 10 and 11, where:
▪ the X-axis shows the width of the strips or the diameter of the clearings expressed in terms of the height of the surrounding forest (H = 40 m);
▪ the Y-axis shows the corresponding percentage of relative illumination (ratio of the light reaching the point considered in the strip or clearing to the total light reaching open ground).

These graphs concern strips running North to South and East to West, and forest clearings: the graph in figure 9 shows the variations in the light reaching the ground at the centre of the strips; the graph in figure 10 is a simplified version of figure 9 at a larger scale for easier interpretation of the results for narrow strips and small clearings.

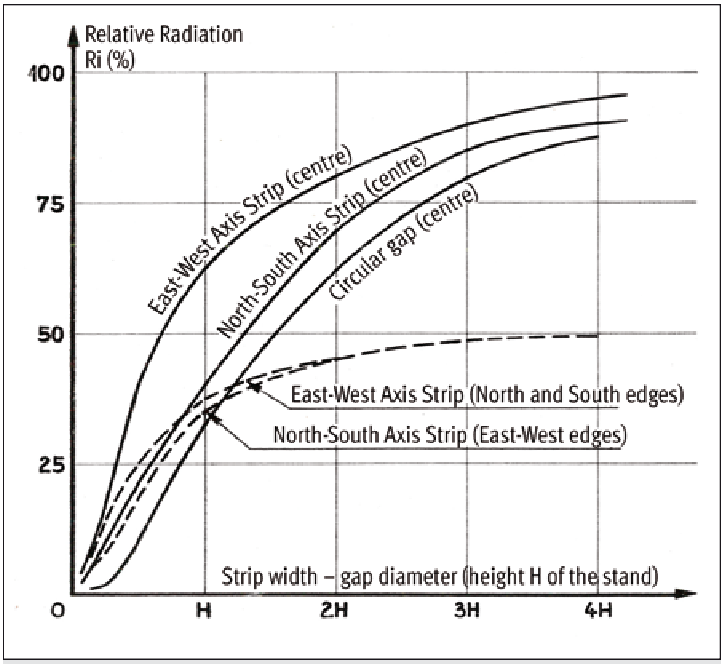


Figure 9.
Curves showing the variations in the relative illumination Ri reaching the ground according to the width of the strip or the diameter of the clearing opened up into the forest stand (expressed in terms of the height H of the stand).

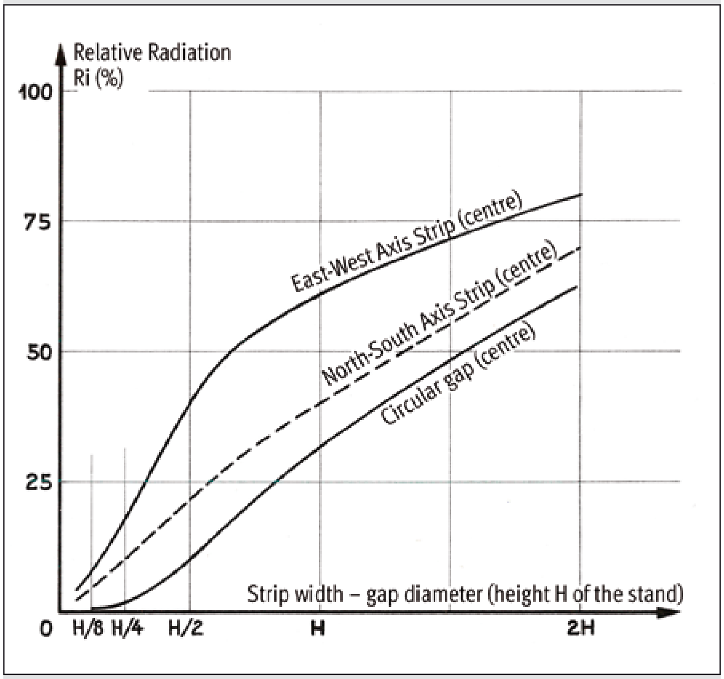


Figure 10.
The same curves on a larger horizontal scale.

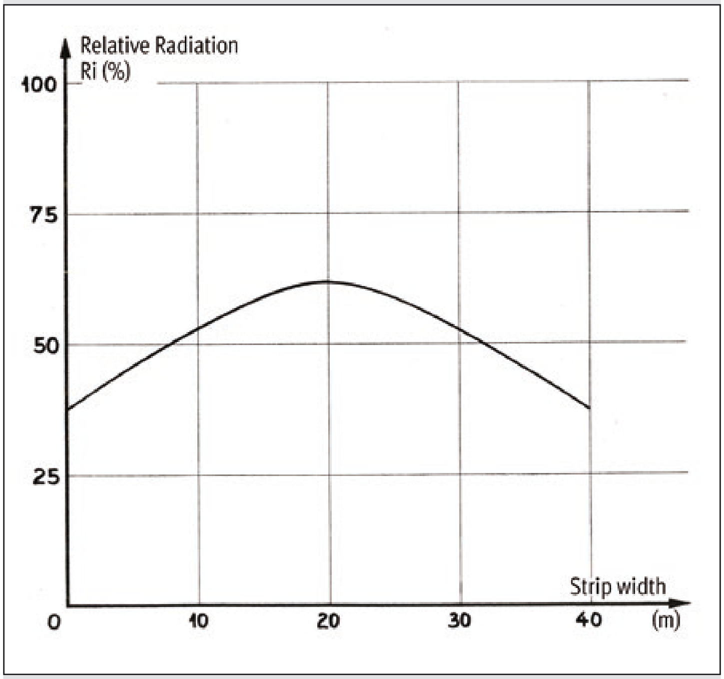


Figure 11.
Variation of relative illumination Ri reaching the ground along the profile of a strip 40 metres in width (W = H).

Numerous comments can be made about these graphs, including:

▪ First of all, the figures plotted by these curves must be slightly lower than they are in reality, because they do not include the light coming laterally from the forest around the strip or clearing. We have seen that the total relative light reaching the understory amounts to about 3.5% (BORREL solarmeter), to which the lateral component can be considered to contribute about 2 to 3%; the corresponding value thus has to be added to the figures plotted on the graphs, so that in strips of the same width, there will always be more light reaching the centre of strips running East to West than the centre of strips running North to South, which seems perfectly logical.

▪ There will always be less light reaching the centre of a clearing of a given diameter than the centre of a strip of the same width running in any direction, so that.

▪ To obtain 50% of relative illumination (Ri), the width of strips running East to West should be 6H/10 = 24 m, and the width of strips running North to South should be 13H/10 = 52 m, and 16H/10 = 64 m for a circular clearing,

▪ Ri = 40% for a 20 m-wide strip running East to West, but only 22% for a strip running North to South, while the figure for a circular clearing of the same size will be only 10%.

▪ The light received along the edges of strips does not vary greatly whatever their direction; in strips more than 80 m in width, i.e. twice the height of the dominant story, the light received is constant and approximately equal to 50% of the total illumination whether the strips are running North to South or East to West.

▪ The relative illumination reaching the ground along the profile of the strip varies considerably, as shown in figure 11 (graph also plotted from the total illumination circle); in a strip whose width is equal to the height of the stand, Ri varies from 37% along the edges to 62% in the centre of the strip, which is almost double. This observation could have major practical consequences for plantations of particularly light-demanding species.

▪ A 2.50 m wide strip (l = H/16) opened up into natural forest receives barely 5% of relative illumination. **This observation is crucial**, because it may be the main reason for the disappointing results of narrow deforested strip plantations: it suggests that even taking lateral illumination into account, **the trees receive no more than 7 to 8% of relative daylight.**

▪ The destruction by girdling or poisoning of a standing tree with a 20 m crown provides only 10% of relative illumination; this increases to 22% for a tree crown 30 m in diameter and 32% for a 40 m crown. **These figures may explain the slow growth rates observed with natural regeneration methods.**

We will discuss the interpretation of these graphs in our comparison of the different methods.

It may be objected that we cannot be sure that 10%, 20% or 30% of relative illumination is not enough to obtain excellent growth rates for the main commercial species in dense forests. From numerous observations, we believe that this idea would be mistaken, but as far as we know, there have been no specific studies backed up by figures on this point. This is why we are currently undertaking the necessary research in different forest stations in Africa.

Determining the optimum amounts of light required to obtain satisfactory growth rates for saplings of the main forest species

The idea is to determine this by growing saplings of the same species, and initially of the same height, on the same plot but in different light conditions: this is done by erecting two parallel series of panels 0.75 m apart on bare ground, like a «corridor», to form a palisade on either side of the saplings to be planted, and of the heights shown in table IV (determined from the graphs above, figures 10 & 11).

The corridors must run strictly East to West (table IV).

The experiment will last for 2 to 3 years, after which the average height of the saplings in each corridor and their vigour will indicate the optimum light conditions sought.

These are the two fundamental studies that should provide the basis for improving silvicultural methods in dense forest environments. The calculations for the former have been completed but they will need to be confirmed by instrument readings as soon as their development has been finalised; the latter study is now under way. However, again based on the recent studies of ROUSSEL, we are also undertaking the following study.

Table IV.

Ri	Height of the palisade	Observations
12%	4.50 m	These theoretical heights
25%	2.25 m	should be increased
50%	1.15 m	by the average heights
75%	0.45 m	of the saplings planted
100%	0	in the corridor.

Determination of the influence of lateral light on the growth of a given forest species during its first years of life

ROUSSEL recently demonstrated the inhibiting influence of lateral light on the growth of young oak saplings (*Revue Forestière Française* - February 1965). We believe that extending this experiment to the main dense forest species could produce valuable lessons on their temperament, but especially on the influence of new growth. This has always been considered beneficial up to now, but without any valid scientific proof: could its main virtue in fact be the protection it affords from lateral illumination?

The experimental protocol devised simply involves comparing the growth of several rows of saplings, some of which are shrouded and others left in full light.

This concludes our brief description of the research we currently consider to be the most important, because the results could radically change and improve current silvicultural methods.

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