634.0.17 Pinus caribaea: 634.0.242(883)

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# ANALYSIS OF 11 YEARS' GROWTH OF CARIBBEAN PINE IN A REPLICATED GRAECO-LATIN SQUARE SPACING-THINNING EXPERIMENT IN SURINAM

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# 1. GENERAL INFORMATION ABOUT CARIBBEAN PINE

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## 1.1. THE SPECIES IN ITS NATURAL HABITAT

According to BARRETT and GOLFARI (1962) *Pinus caribaea* MORELET, a pine species from Central America, comprises three geographical varieties, viz. *P. caribaea* MORELET *var. bahamensis* (GRISEB.) BARRETT *et* GOLFARI (from Bahama and Caicos Islands), *P. caribaea* MORELET *var. caribaea* (from Cuba and Isle of Pines) and *P. caribaea* MORELET *var. hondurensis* (SÉNÉCLAUZE) BARRETT *et* GOLFARI.

The latter is the one mostly used in Surinam plantations as its growth is favourable, and foreign seed can be obtained in sufficient quantities from commercial sources.

The natural habitat of *P. caribaea var. hondurensis* stretches from British Honduras down to and including Nicaragua, where this variety preferably grows on acid, well-drained soils at altitudes from 0–900 m a.s.l. Annual rainfall ranges from 960–3560 mm with dry periods of 2–6 months. Temperatures average 21–27 °C, with extremes of 7 and 37 °C.

*P. caribaea* MORELET is characterized by its long needles arranged in fascicles of three (sometimes four or five), and its slender cones (5–10 cm or more in length) with bracts ending in a small and flabby spine. The three varieties differ e.g. in their seeds, their growth, their outward appearance and colour of their seedlings, and in the number of resin ducts in their needles. The number of seeds per kilogram is about 50.000. On good sites the trees may attain heights of some 40 m with a diameter of 120 cm at breast height, but figures of 30 m and 50 cm respectively are more common maxima. The bark is brown with fissures typical of pine trees; it is often thick, providing the tree adequate protection against mild grass fires.

The natural habitat of *P. caribaea var. hondurensis* often resembles that of an open pine forest. sometimes mixed with a poor hardwood vegetation consisting mainly of oak species, with an undergrowth of grasses, herbs and shrubs. The undergrowth frequently burns and young pines do not survive these fires, so that natural regeneration is jeopardized. Hurricanes constitute another threat: in Br. Honduras some 100,000 ha of pine forest were blown down in 1963. Wasteful and illegal cutting add to the factors causing the often poor condition of these natural forests.

The potential of the pine forests in Central America as to the production of lumber, and the circumstances outlined above are best illustrated with some data from an FAO survey carried out from 1962–1965 in Honduras (FAO, 1968). This country has some 2.7 million hectares of pine forest, mainly *P. oöcarpa* and *P. caribaea*, with a total standing stock of 134 million $m^3$ under bark. The average pine timber volume was 62.2 $m^3$ per hectare. Annually 650,000 $m^3$ were lost by forest fires which left the stands ravaged to an extent of one fifth to one half. The mean annual increment was estimated to be 2.7–3.7 $m^3$ per hectare, a figure which could be doubled by simple but appropriate measures of management. Most of the soils under pine forest are unsuitable for agriculture. Since unemployment is widespread in these areas the chances for forestry are good.

Little is known about diseases of the Caribbean Pine in its natural habitat, save for the occurence of cone rust *(Cronartium conigenum)* which destroys the cones, thus hampering seed production. In its life cycle the rust needs certain oak species as an intermediate host. In addition, some fungi causing stem and root rots, and others causing needle diseases, such as *Pestalozzia sp.* and *Dothistroma pini*, are known to occur. Young seedlings are killed sometimes by damping-off fungi such as *Fusarium spp.*

As to mineral deficiencies, boron is named which causes dieback of the top together with resin exudation (BROWNE, 1968).

Dangerous pests are Scolytid beetles such as *Dendroctonus frontalis*, the southern pine beetle, and *D. valens* and *Ips bonanseai* both of which follow an attack of the first one. Perhaps enhanced by drought and fire, in past decennia these insects have destroyed many valuable trees. Cutting ants (*Atta spp.*) constitute another pest. They nip off needles, particularly the young ones from small trees so that these are seriously weakened.

Two species of mistletoe *(Arceuthobium spp.)* infest the Caribbean Pine.

Timber from *P. caribaea* is commercially known as Honduran Yellow Pine; in Europe it is known as Pitchpine. It is a relatively dense and hard softwood with a high resin content; the specific gravity ranges from 0.55–0.70. The sapwood is of a yellow colour, the heartwood is orange-brown. The wood is very suitable for permanent constructions, both in- and outdoors. Its high resin content makes it somewhat less suitable for pulp production; it might be used for plywood and particle board. In Central America the annual firewood consumption amounts to millions of cubic meters. Among the species widely used to this end, pine is included, though its qualities as a fuel are poor.

Locally, Caribbean Pine is tapped for resin. However, the world market for naval stores is dominated by the USA, where the closely related *P. elliottii* – formerly considered to be identical with *P. caribaea* – is exploited on a large scale.

## 1.2. THE SPECIES IN SURINAM

### 1.2.1. *Some Data about Surinam*

Surinam is situated on the north coast of South America, between 1°30′ and 6°00′ N latitude. Its climate is tropical and humid. The mean daily temperature in Paramaribo is 27°C with an annual fluctuation of 2° and a daily fluctuation of 9°C. In the interior, temperature fluctuations are larger. Total annual precipitation ranges from about 2000 to 2500 mm; its distribution follows a bimodal pattern. The main dry season is from September till November, though monthly rainfall then is generally still above 60 mm. The second, shorter dry season, though highly unreliable in its occurrence, is in February and March. For a tropical rainforest climate rainfall is too irregular. An annual mean of 5.7 hours of daily sunshine is registered, but there are only few days that no clouds pass in front of the sun. The relative air humidity is high, often about 95%, especially at night; during daytime in open places and with dry weather it may drop to 60%. It is highly correlated with rainfall. Strong winds are unknown, a trade breeze is only felt in the coastal area. However at the oncoming of rainshowers, squalls can blow over badly rooted trees.

Of the three main regions in which the Surinam land area is generally classified, viz. the Coastal Plain, the Coverlandscape and the Interior, mainly the second and a small part of the third are important for commercial pine planting. Soils in the Coastal Plain are in general very heavy, and often poorly drained; part of this region is cultivated for agricultural crops. The population of about 300,000 (1970) is mainly concentrated in the Coastal Plain. About half the population lives in the national capital, Paramaribo. The mountainous Interior is prohibitive for economic road-building, and thus will remain idle, at least for a long time to come. Soils in the Interior are deeply weathered, well drained and for the greater part covered with mesophytic rainforest.

The Coverlandscape, situated in between the Coastal Plain and the Interior, generally has sandy soils with some clay in the creekvalleys and along riverbanks. On very poor white sand the vegetation is sclerophytic, so-called savannah, whereas on unbleached sands and loamy sands a more or less luxuriant mesophytic forest thrives. Most of the forestry activities take place in this region; they consist of both exploitation of the indigenous forest and reforestation. Allweather roads can be built relatively cheaply. Nearly all soils here appear to be of low fertility, but still satisfactory for forestry purposes.

The field experiment discussed in this paper is situated in the Coesewijne region, and its soils can roughly be described as welldrained, more or less flat slightly loamy sands. They are classified (SLAGER and SARO, 1967) as a Dystropeptic Quartzipsamment. The upper 40 cm are yellowish-brown, with very little organic matter and a pH of about 4.5. The groundwater table lies below 180 cm.

### 1.2.2. *The Forestry Situation*

Although Surinam has only a relatively small population and is covered for more than eighty percent with forests, it is expected that in coming decades wood supply will fall short of domestic demand. The explanation for this is (i) the small share (some 20–40 $m^3$ per hectare) of exploitable timber in the total indigenous forest stock, (ii) the low output of forest exploitation and utilization, and (iii) the relatively small area that can be made accessible by roads. Regeneration of selectively exploited indigenous mesophytic forest is possible, but expensive and time-consuming. So wood supply has to be replenished mainly by both artificial regeneration of the indigenous forest and by planting of exotic species. This task, recognized by the Surinam government, is assigned to the National Forest Service.

In 1947 a new Forest Service was founded in Surinam. Besides executing tasks as securing a better wood supply by making accessible virgin forest areas away from the zone along the riverbanks exploited in the past, much attention was given to the possibilities of stepping-up the low production of the indigenous forests, and to converting these forests into plantations of fast growing indigenous or exotic species. Amongst the various exotic species tried was *Pinus caribaea* from Central America.

### 1.2.3. *History of the Caribbean Pine in Surinam*

On the initiative of the then Head of the Surinam Forest Service, I. A. DE HULSTER, seed was imported from British Honduras for the first time in 1948. In following years thousands of seedlings were planted out, at first at locations in the Coastal Plain, later on also in the Coverlandscape. Clearfelled strips of a few yards wide in the forest were planted with the young pines, but soon it was realized that full sunlight was essential and that planting in the open gave the best results. Attempts were made to plant in the so-called savannahs in the vicinity of Zanderij and elsewhere, as the low and scrubby vegetation could be cleared at low cost. However, the soils concerned were too poor to allow the Caribbean Pine to grow at an acceptable rate.

Other pine species were tried as well. For instance, in 1953 trials were started with *P. merkusii*, from Indonesia, *P. patula*, imported from South Africa, and *P. occidentalis* from Haiti. In subsequent years also *P. elliotti var. densa* from Florida and *P. radiata* from California were tried. A further series of trials in 1968 included in addition to some of the species mentioned, *P. insularis*, *P. strobus var. chiapensis*, *P. tropicalis* and the three varieties of Caribbean Pine. Though some species survived or even grew relatively well, their growth was slow as compared with that of the Honduran variety of the Caribbean Pine. In the years following 1950, the Blakawatra region became accessible by road, and in 1953 a nursery was established there. In this area most of the subsequent planting activities were concentrated. At present this nursery still exists. Initially, planting on the savannah soils was tried, and in 1956 a Dutch paper industry, interested in these pilot plantations, decided to finance the planting of some hundreds of hectares in the years to follow. This plan was realized mainly at Blakawatra and at Zanderij.

Planting distances were narrow, viz. 2 × 2 metres, as the main purpose was growing pulpwood. It was recognized after some years however, that planting on the more fertile soils characterized by a higher indigenous forest, would result in better growth, but the necessity of clearing the dense and heavy vegetation caused the establishment of plantations there to be much more expensive than on savannah soils.

By 1962 the area of the pine plantations amounted to some 1250 ha, but then the paper industry, after a final study regarding the feasibility of a sulphate pulp mill, withdrew for economic reasons and on account of the company's investment policy. The plantations were left to the Forest Service, as was agreed upon beforehand. The aim was changed to the multipurpose use of

Caribbean Pine, and from then on the primary goal was growing timber to alleviate the expected domestic shortage of timber. The rotation period was increased from 15 to 30 years (DIENST LANDSBOSBEHEER, Annual Reports).

In the years 1964 to 1967 planting activity was at a low level, due to limited funds. In these years the spacing-thinning experiment discussed in this paper, was established at Coesewijne. In 1968 the establishment of plantations was resumed with funds from the Five Year Plan (1968–1972). Since recent years, indigenous high forest is being clearfelled for export charcoal production. It is the intention to plant at least part of the clearcut areas with Caribbean Pine.

TABLE 1. Development of Total Area (in hectars) of Pine Plantations in Surinam from 1949

| | | | |
|---|---|---|---|
| 1949–'54 | some ha | 1964 | 1868 |
| '55 | 36 | '65 | 1901 |
| '56 | 49 | '66 | 1951 |
| '57 | 217 | '67 | 2005 |
| '58 | 284 | '68 | 2224 |
| '59 | 392 | '69 | 2441 |
| '60 | 478 | '70 | 2802 |
| '61 | 802 | '71 | 3617 |
| '62 | 1247 | '72 | 4534 |
| '63 | 1734 | '73 | 5568 |
| | | '76 | 6293 |

### 1.2.4. *Seed Supply and Nursery Techniques*

In Surinam, seed of *P. caribaea var. hondurensis* is imported from British Honduras. Till now this country only has supplied seed from non-selected trees. Imported seedlots are carefully dried upon arrival, after which they can be stored for some years without much loss of viability at temperatures of 8–10 °C below zero. In the nursery seeds are pregerminated on wet sand in shaded trays; occasionally the trays are sprayed with a fungicide (Ziram). Germination amounts to 40%. After 7 to 16 days the germinated seeds are transferred by hand to small bitumenized paper pots containing amongst others, pineforest soil. It is assumed that in this way mycorrhiza is introduced, as so far no problems have been encountered on this point. The fungus concerned is probably *Pisolithus tinctorius*, which often forms puffballs along roadsides in the pine plantations. The bitumenized paper pots are of conical shape, 13 cm high, 5.8 cm wide at the top and 5 cm at the bottom; they are locally produced form imported paper. Pots are closely stacked in rows 1.20 m wide, on a level site. No shade is needed, not even directly after transplanting. The ultimate survival rate is high (85–90%). Pots are watered regularly, with (acid) water from a nearby creek, by means of a sprinkler installation. After 5–6 months the seedlings are about 15 cm high, and ready for planting in the field. During these months a compound fertilizer (NPK) dissolved in water, is applied several times. Field-planting cannot be postponed long, because of the small pots used. At this stage plants cost about Sf. 0,10 a piece, all-in (1 US $ =

± Sf. 1,80 in 1974). Recently, paper multipots have been introduced; these reduce costs and take less space in the nursery. After some time in the nursery the multipots become separated, and can be handled in the same way as bitumenized paper pots. As multipots are of smaller size and less durability, part of the nursery stock still has to be grown in bitumenized pots to provide plants for filling-up e.g.

Formerly planting stock was raised by sowing out in beds directly under small mother trees to ensure infection of the young seedlings with the proper mycorrhiza. After some months the 10 to 15 cm-high seedlings were transferred to small containers, that were at first made of veneer, but eventually of polythene bags. Shade was necessary. Planting the young trees in the field without pots or adhering soilballs was tried, but the survival rate was low due to high transpiration rates in full sunlight.

### 1.2.5. *Preparation of Planting Sites*

Caribbean pine requires full sunlight, so the planting site is to be cleared completely. Normally D-8 caterpillar tractors with specially designed blades are used. Even the biggest forest trees are cut at the base, leaving the root system undisturbed. When dry, the felled wood is windrowed at intervals of 50 m and eventually burnt to reduce the amount of debris to a minimum. After burning the field is worked with a heavy disc-harrow, facilitating mechanized weeding afterwards, and somewhat improving soil conditions for planting.

Planting holes are made with a special heavy planting wheel with three spades, mounted behind a wheeltractor. Planting distances now are 3.50 × 2.20 m, which comes to some 1300 young trees per ha. Planting is done by hand. The bitumenized paper pots need not be removed, as roots penetrate them easily. Filling-up is generally rated at about 1–2 percent.

### 1.2.6. *Weeding*

Frequent weeding is necessary as the weeds soon smother the young trees. During the first few years it is done twice or three times a year, mostly by using a rotary-cutter between, and a machete in the rows. Weeding costs are very high, so that new systems are being tried, e.g. chemical weeding and controlled grazing bij goats.

After 5–6 years stands become closed and after a last weedkilling treatment with herbicide they need less maintenance. From then onwards trees are occasionally freed of e.g. lianas. Pine trees never are able to suppress all weed growth by their shade, but root competition might be an important factor, as *P. caribaea var. hondurensis* has a very strongly developed rootsystem, especially on less fertile sites. Pernicious weeds are e.g. the *Cecropia* trees which overtop the pines very rapidly. They are killed by applying herbicide (2–5% solution of phenoxyacetic acid compounds in diesel fuel) on the bark. Lianas too are dangerous, smothering small and big trees alike, and often bending the topshoot. Expecially in the burnt windrows weedgrowth is prolific, and only some broadleaved tree species are able to compete with the weed trees there.

### 1.2.7. *Intercropping and Fertilizing*

During the first years after planting the space between the young trees sometimes is utilized for catchcrops such as corn, pumpkins, watermelons, some vegetables and, especially in the burnt and fertile windrows, bananas. These crops are grown by contractors who pay for the temporal use of the cleared land, and are obliged to weed and fertilize the entire plantation. Growth improvement of the pines after fertilizing is striking, but for economic reasons fertilizers cannot be applied exclusively to the trees.

Some fertilizer experiments have been carried out in previous years, merely for promoting growth on the poor sites cleared in the initial period. Results however were not promising. So-called tree starter pellets were tried on better sites, but the response was only slight.

### 1.2.8. *Tree Form and Thinning*

At the age of 6–8 years the first thinning is to be carried out. The most important selection criterion is the tree's appearance, as many trees are misshapen, showing forks, crooks and so on. There is no market yet for the wood from the first thinnings, so felled trees are left in the plantations, where they are rapidly decomposed by fungi and termites. The tree population is reduced to a fixed number per hectare depending on the site-class.

A special malformation is the so-called foxtail. In its extreme form such trees completely lack normal branches and only bear long needles from top till base, but often the foxtail is less pronounced, and some branches are present. Sometimes after a few years a foxtail develops a more or less regular crown. These trees are often higher than the best normal ones, but they frequently bend over, and their wood is assumed to be of inferior quality. Though their growth is vigorous, and they take only little space in the canopy, it is advisable to remove them as early as possible. Since their rootsystem does not differ markedly from that of other trees, foxtails may compete more severely below than above-ground.

### 1.2.9. *Cost Factors and Production Estimates*

The cost of site preparation and planting amounts to 6 man-days, 12 service clock hours of a D-8 caterpillar tractor, and 4 service clock hours of a wheeltractor (construction of plantation roads included) per hectar.

During the first ten years the costs of tending (weed and cutting-ant control, thinning) amount to 54 man days, 12 service clock hours of a wheeltractor, 260 litres of a herbicide mixture and some kilograms of pesticide per hectar.

It is estimated that on the best sites a total production of 470 $m^3$ wood per hectar (165 $m^3$ pulpwood down to 10 cm diameter under bark, and 305 $m^3$ timber down to 20 cm diameter under bark) can be obtained in 30 years, assuming a total net mean annual increment of 15.7 $m^3$ per ha. As poorer sites also occur, the average total net production might be estimated at some 400 $m^3$ per ha in a 30 years rotation, with a total net mean increment of 13 $m^3$ per ha per annum (VINK, 1970).

### 1.2.10. *Wood Quality*

Recently some pine stands were prematurely cut and some timber was obtained for processing by the Forest Service. Most of this timber was used as rafters and boards in the construction of huts and sheds. Treatment with chemicals appeared to be essential as blue stain is a serious problem. When lying in the open for some weeks before hauling fresh timber can be stained to a considerable depth, whereas sawn lumber when stacked to dry, quickly stains when no preservative measures have been taken.

Although rapidly grown, the wood is neither very light nor soft; specific gravity is about 0.55 (oven dry wood), but there is quite some variation. Trees from stands on good sites have a lower wood density, with less variation than trees from poor sites (BERG, VAN DEN, 1973). From about the age of 15 years the wood makes a good kraft pulp.

### 1.2.11. *Pests and Diseases*

An important pest is the indigenous leaf-cutting ant *(Atta spp.)*, which uses leaves from several plant species as a substratum for its subterraneous fungus gardens. Needles are cut off – which may be detrimental especially for small trees – but the ants do not actually use them; they drop them en route. The underground nests can be eradicated with pesticides. An ingenious remedy is the use of Mirex pellets. The ants themselves carry the pellets into the nest, where the poison destroys the fungus gardens.

The dangerous pine beetles from southern North America have not been found yet in Surinam.

In 1961 a pernicious root disease was observed in a number of pine stands. From a centre the disease spreads gradually outward, killing the trees in a slow process. The rate of killing appears to diminish after some years however. This fungal disease is caused by a *Polyporacea*. Though it was isolated repeatedly, further identification has been impossible due to lack of fructifications. A striking symptom of the disease is the rapid discoloration of the foliage on infected trees, viz. from green through yellow to brown.

A needle blight is observed frequently, probably induced by nutrient deficiencies.

In 1961 a seedling disease caused by a *Cylindrocladium sp.* was recorded in the nursery, the attack probably being enhanced by very close sowing. Some years earlier a *Cronartium sp.* was recorded on seedlings but no further attacks were noticed afterwards. Nowadays nursery diseases such as damping-off are mostly controlled by spraying a fungicide like Ziram. Mole-crickets and other nursery pests are controlled with HCH.

### 1.2.12. *Selection and Genetic Improvement*

Since 1968 a selection programme is being executed, and clonal gardens have been established. Seed production in Surinam will not be satisfactory, as the humid conditions during the time of flowering hamper the dispersal of pollen. Provenance trials of *P. caribaea* varieties have started recently.

# 2. THE SPACING – THINNING EXPERIMENT

## 2.1. Materials and Methods

P. G. de Vries

### 2.1.1. *Origin and Purpose of the Experiment*

On June 10th., 1964, the then acting head of the Surinam Government Forest Service, P. J. D. Versteegh, contacted I. A. de Hulster, then head of the Forest Management and Mensuration Department of the Agricultural University, Wageningen, The Netherlands, and the first author, senior scientist in the latter Department, as to the possibility of establishing a scientific experiment with Caribbean Pine in Surinam to obtain production characteristics of known reliability under controlled conditions.

Though, since the introduction of the species in Surinam in 1949, total plantation area had increased to some 1800 hectars in 1964, very few exact data were known about its local production potential. There was a.o., no volume table available. Growth, though unsatisfactory under poor savanna conditions, showed sufficient promise on better soils to encourage extension of these industrial softwood plantations. The latter was deemed the more desirable, as the Surinam rainforest is devoid of softwoods, and exclusively consists of (over 250) hardwood species.

As a result of the above mentioned request, the Department and the Surinam Forest Service agreed to cooperate as follows. The senior author would conceive an experiment, advise and give personal guidance to its establishment in the field, supervise the collection of field data and the execution of treatments, process the field data and present the results. The Surinam Forest Service, on her side agreed to prepare the experimental site, execute planting, carry out weeding and felling if required, supply a crew for data collection, as well as materials and other local support as far as deemed necessary in the interest of the experiment.

It was agreed that three different initial square spacings, viz. $A = 2\frac{1}{2}$, $B = 3$, and $C = 3\frac{1}{2}$ meters would be included in the experiment, and that the latter would be designed as a four times randomly replicated 3 by 3 Latin Square (Fig. 1). This design permits of eliminating the initially unknown combined effects of soil fertility gradients and external competition factors, if any, from total variation, so that a residual variance of a more truly accidental nature may be obtained.

Intensive field work, such as data collection over a large area and under rather primitive and often adverse conditions in the tropics, requires more from the experimenter and his often non-professional temporary assistants than comparable work in temperate regions. Under the former circumstances relatively simple designs with few variables and a built-in protection against unknown and unforeseen factors is strongly recommended. Apart from some analytical drawbacks, the replicated Latin Square may in many cases balance fairly between the requirement of obtaining optimum information on the one hand, and practical considerations on the other.

The spacing experiment, in a later stage, would have to pass into a combined spacing-thinning experiment by applying to each spacing three different thinning intensities, viz. Z (low), M (medium), and S (high). For the same reasons as above the latter will constitute the fourth orthogonal factor of the design, which then becomes a four times randomly replicated Graeco-Latin Square (Fig. 1). Here too, there is an analytical drawback in relation to interactions, which now include the interaction, if any, 'spacing × thinning', of main interest. However, proper partitioning of sums of squares leaves a means of testing for the latter, provided that row and column effects are relatively small as compared with residual variation. This situation may be expected to occur at increasing age, as larger values tend to have larger accidental errors. In that case the analysis of the experiment might even be conducted as that of a four times replicated randomized block design, which fully permits of a test on interaction.

2.1.2. *Establishment of the Experiment in the Field*

In January 1965 a rectangular area of some 20 hectars of mesophytic high forest was cleared by treedozer, after exploitation of the commercial timbers. The level area is situated at Long. 55°28'30" W., and Lat. 5°18'5" N., at a location named Coebiti, in the transitional zone between the young and old Coastal Plains, and consists of slightly loamy sands. Following the felling, the ligneous material was shoved onto parallel windrows at 60-m intervals, and subsequently burned during the short dry season, leaving a considerable quantity of ashes. These ashes are known to have a pronounced stimulating effect on early growth of Caribbean Pine. At two sides the area remained enclosed by the original, about 35 m high mixed broadleaved forest, and at one side by a previously established pine plantation then about 12 m high. From these surroundings a competition effect might be expected over at least part

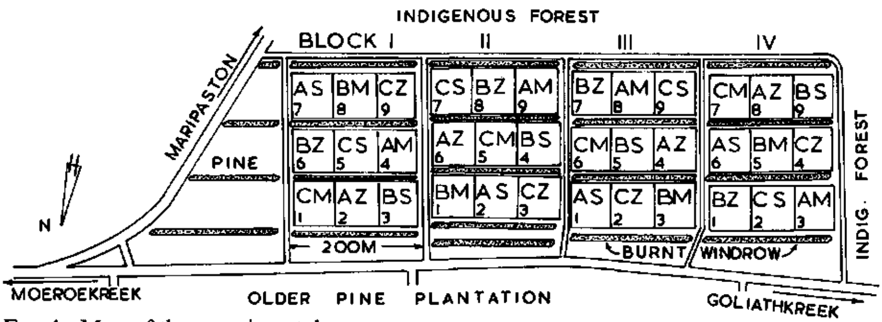


FIG. 1. Map of the experimental area.

of the area. The surrounding broadleaved forest, however, was felled in 1972 to give way to pine plantations.

The area was divided into 4 blocks by means of earthen roads some 200 m apart, at right angles to the burnt windrows. Within each block a 3 × 3 Latin Square was established randomly, using the 3 square spacings A = $2\frac{1}{2}$, B = 3, and C = $3\frac{1}{2}$ m, in plots of 60 × 60 m. Each series of three plots is situated in the space between two windrows.

For the experiment six-months-old transplants from British Honduran seed were used, raised in plastic bags in the Blakawatra nursery which is known to contain the proper mycorrhiza. Within the 60 × 60 m plots the planting lines were established very carefully by means of rods and a tape, the place of each plant being indicated by a small hole dug before distribution of the plants over the field. Planting was completed by the end of May, 1965.

Centrally within each 60 × 60 m plot the experimental plot (EP) proper was located, leaving buffer strips between adjacent plots (Fig. 2). Subsequent

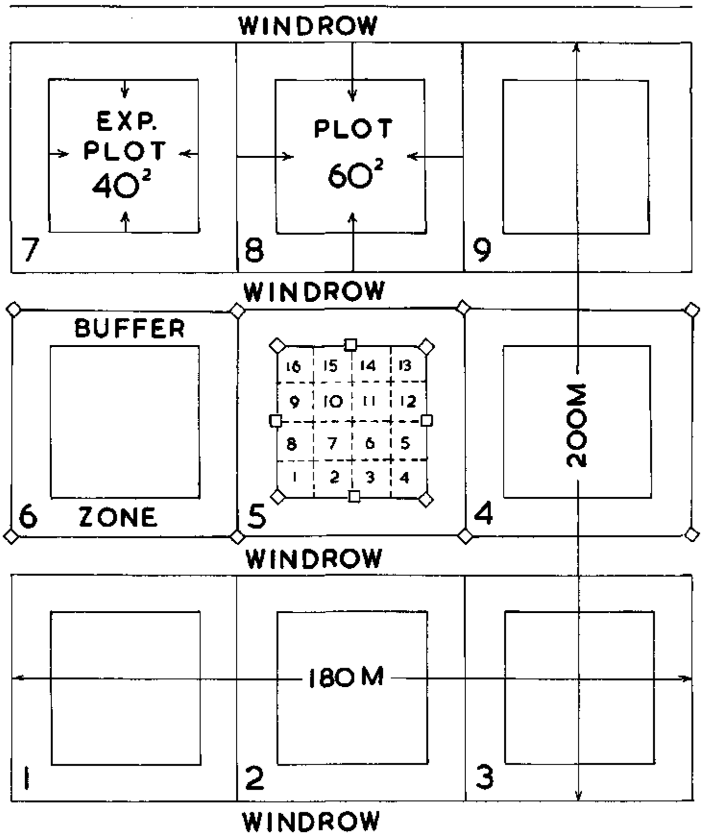



FIG. 2. Details of one Latin Square or Block.

thinning will be the same over an entire 60 × 60 m plot, but measurements are only taken in the EP. For convenience of orientation and administration, and for thinning purposes, each EP is further subdivided in 16 subplots (ESP).

Because of the fixed size of the 60 × 60 m plots and the necessity of buffer strips between EP's on the one hand, and on the other the requirement of having a sufficient number of trees within each EP to convey the (rather subjective) idea of a 'stand' in which the effect of sylvicultural measures may be observed as a whole, the sizes of the EP's necessarily vary with spacing. From an area-point-of-view this induces different weights of the observations. In the data analysis this circumstance will not be considered, and observations, as far as applicable reduced to a one hectar basis will be used.

TABLE 2. Legend of Sizes and Numbers.

| Spacing m | Number of trees per | | | | | Size of EP in $m^2$ | no. of rows | | isolation strip | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ha | plot $60^2m^2$ | 12 plots of $60^2m^2$ | EP | 12 EP's | | plot $60^2m^2$ | EP | no. of rows | width in m |
| $2\frac{1}{2} \times 2\frac{1}{2}$ | 1600 | 576 | 6912 | 256 | 3072 | $40 \times 40 = 1600$ | 24 | 16 | 4 | 10 |
| $3 \times 3$ | 1111 | 400 | 4800 | 256 | 3072 | $48 \times 48 = 2304$ | 20 | 16 | 2 | 6 |
| $3\frac{1}{2} \times 3\frac{1}{2}$ | 816 | 289 | 3468 | 144 | 1728 | $42 \times 42 = 1764$ | 17 | 12 | 2+3 | $7\frac{1}{4}+10\frac{3}{4}$ |
| Total in experiment | | | 15180 | | 7872 | Total exp. area 12.96 hectars | | | | |

The corners of the two types of plots were duly marked by poles of termite-resistant walaba *(Eperua sp.)* heartwood, with the spacing code painted on the heads. For each EP a separate map, showing the location of each plant was prepared, and on it the individual plants were numbered systematically. The ESP-boundaries follow from the system used in numbering. As thinned and missing trees are to be indicated on these maps, they will serve as a means of orientation in repeated enumerations.

Following the completion of planting-up the experimental area, remaining areas such as windrows and odd corners were planted, applying average spacing.

As the region is infested with leaf-cutting ants which may cause severe damage especially to young plants, local labour was instructed not to plant crops like cassava and corn in the fertile windrows, a custom often practiced during the first few years. Moreover, instructions were given to control newly established ant populations with the poison Mirex.

In young plantations of this type a ligneous weed vegetation, with f.i. Konkonikasaba *(Stigmaphyllon sp.)* and Bospapaja *(Cecropia sp.)* establishes itself very quickly. Growing at an annual rate of a few meters, the weed vegetation would soon smother the plantation entirely. During the first years the weeds were cut back twice, and special attention, also during the following years was given to lianas which cause the bending-down of growing pines.

After the first year the weed vegetation has been cut back almost annually during the dry season.

Because of the great care and attention bestowed on the experiment by officials of the Surinam Government Forest Service and by forestry scientists and students of the two countries, the plantation thrived.

At this place it seems appropriate to make special mention of my two students, H. L. KLOOTWIJK and M. UITTENBOGAARD who, unfamiliar with the rain-forest and braving many a jungle peril, had an important share in the realisation of the experimental design in the field. After having finished his studies, Mr. KLOOTWIJK most competently served as professional forester in the by then well-accessible district, but he lost his young life under most tragic circumstances in 1973.

2.1.3. *Stem Form of Caribbean Pine in Surinam. Volume Tables*

In order to quantify future timber production in the experiment, a volume table for Caribbean Pine in Surinam was considered indispensable. Such a table was not available until 1965. In that year the author collected the following data of 288 felled stems from 5 to 15-year-old plantations:

1) total length $H$ of each stem in decimeters;
2) stem girth over and inside bark in millimeters, at breast height (1.30 m);
3) midgirths over and inside bark in mm, of 1-meter stemsections;
4) midgirths of HOHENADL sections, over and inside bark in mm, at $.1H$, $.3H$, $.5H$, $.7H$, and $.9H$ from the top.

The circumstance that all plantations were still very young caused the bulk of the material collected to be within *DBHOB*-range 6–17 cm, and height range 6–16 m. Only about 25 older trees with dimensions surpassing the upper limits of these ranges could be secured from good sites. The largest diameter and height observed were 23 cm and 22 m respectively.

From the 1-meter sectional measurements, a.o. the following volume regressions were computed:

$$VOB = -1.09923 + 1.85911 \log DBHOB + 0.85998 \log H \qquad (1)$$

$$VIB = -1.64590 + 1.88108 \log DBHOB + 1.15928 \log H \qquad (2)$$

where *VOB*, resp. *VIB* are total stem volumes in cubic decimeters over, resp. inside bark, *DBHOB* is stemdiameter o.b. in cm at breast height, and $H$ is total tree height in meters. These two regressions were used for the first volume tables for Caribbean Pine in Surinam (DE VRIES, 1965).

The material from which the regressions were computed had a measured total volume of 20,166 $dm^3$ o.b., and 13,084 $dm^3$ i.b. Subsequent application of the two regressions to the same material yielded volumes of 20,095 $dm^3$ and 12,957 $dm^3$ respectively. Mean absolute procentual deviations of regression values from observed volumes amounted to 3.6% and 6.5% respectively. The larger value of the latter is caused by the relatively low correlation of *DBHIB* with *DBHOB*, even within height classes.

Overall-mean bark volume, expressed as a percentage of *VOB*, was computed from the above data as:

$$100\,(\Sigma VOB - \Sigma VIB)/\Sigma VOB = 35\%$$

Average bark percentages for trees of given *DBHOB* and *H* were computed from the above two volume regressions and agreed well with observed values.

Further computation showed that estimation of total stem volume o.b. by the product of stem-midsectional area and total height, leads to a significant 10% underestimation.

Finally, stem form was investigated by means of HOHENADL's form quotients. The results are summarized in Tables 3 and 4.

TABLE 3. Form Quotient Series for *DOB* at .9*H* from Top equals *DOB*(.9) = 100.

| 100× | *D*(.95) | *D*(.9) | *D*(.7) | *D*(.5) | *D*(.3) | *D*(.1) |
|---|---|---|---|---|---|---|
| o.b. | 109 | 100 | 84 | 67 | 46 | 20 |
| i.b. | 84 | 80 | 69 | 57 | 38 | 15 |
| RDBW | 25 | 20 | 15 | 10 | 8 | 5 |

RDBW is relative double bark width.

TABLE 4. Form Quotient Series for *D*(.9) = 100.

| 100× | *D*(.9) | *D*(.7) | *D*(.5) | *D*(.3) | *D*(.1) |
|---|---|---|---|---|---|
| o.b. | 100 | 84 | 67 | 46 | 20 |
| i.b. | 100 | 87 | 71 | 48 | 19 |

From Table 3 the rate of decrease towards the top, of double bark width (expressed as a percentage of the diameter o.b. at .9*H* from the top) is evident. Table 4 shows that stem form inside bark is fuller than that outside bark. As another measure for this difference, the mean value of the true stemform-factors was computed from the observations, the individual factors being:

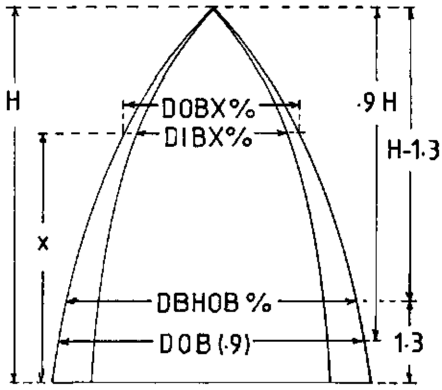
$$\lambda_{.9} = VOB/GOB(.9).H \text{ and } \lambda'_{.9} = VIB/GIB(.9).H$$

for stems with and without bark, respectively. Here *VOB* and *VIB* are the sectionally measured total stem volumes, and *GOB*(.9) and *GIB*(.9) are the crossectional areas to *DOB*(.9) and *DIB*(.9) respectively. The means for the 288 stems were:

$$\lambda_{.9} = 0.4947 \text{ and } \lambda'_{.9} = 0.5129$$

with standard errors of 0.0043 and 0.0036 respectively. Their difference of 0.0182 is statistically significant. So it is concluded that stem form i.b. is significantly fuller than stem form o.b. The former is close to an apollonic paraboloid (DE VRIES, 1965).

FIG. 3. Definition of relative diameters.




The form quotient series o.b. (Table 3, first line) can be approximated well by:

$$\log DOBX\% = 2.036 + 0.734 \log ((H-x)/H) \quad (3)$$

where (see Fig. 3) $DOBX\%$ is a diameter of $DOBX$ cms at $x$ meters above ground level, expressed as a percentage of $DOB(.9)$, the diameter o.b. in cm, at $.9H$ from the top. Then for $x = 1.3$ meter, the relative diameter o.b. at breast height is found from:

$$\log DBHOB\% = 2.036 + 0.734 \log (H-1.3)/H) \quad (4)$$

If the diameter at breast height is $DBHOB$ cm in a stem of $H$ meter, we have:

$$DOB(.9) = 100.DBHOB/DBHOB\% = 100.q \text{ cm} \quad (5)$$

where the definition of $q$ follows from the formula.

The form quotient series i.b. (Table 3, second line) can be approximated well by:

$$DIBX\% = 81.79 - (18.79/H)x - (63.0/H^2)x^2\% \quad (6)$$

where $DIBX\%$ is a diameter i.b. of $DIBX$ cm, situated at $x$ meters above ground level, expressed as a percentage of $DOB(.9)$. Now:

$$DIBX = (DIBX\%).DOB(.9)/100 = \text{(see (5))}: = q.DIBX\%, \text{ or (see (6))}:$$

$$DIBX = q\ \{81.79 - (18.79/H)x - (63.0/H^2)x^2\} \text{ cm} \quad (7)$$

With (4,7) the diameter i.b. at $x$ meter above ground level can be found, if $DBHOB$ and $H$ of a stem are known. Conversely, given $DIBX$ (e.g. 15 cm), the height $x$ above ground level where the stem i.b. attains this diameter, i.e. the commercial height $L$ inclusive of stump, is found by solving the quadratic equation (7):

$$x = L = H\{-0.1491 + (1.320492 - 0.015873(q')DIBX)^{\frac{1}{2}}\} \quad (8)$$

where $q' = 1/q$.

Obviously, the relations (4, 7, 8) can be used for sectional $VIB$ assessment to a specified top diameter of any stem with known $DBHOB$ and $H$. In case of 1-meter sections for instance, $L$ follows from (8), and in (7), $x$ is put equal to 0.5, 1.5, 2.5, etc. meter successively. The last $x$-value to be entered belongs to the mid-crossectional area of the last full-meter section below the top section.

Topsection volume is found as the product of topsectional midarea and top length.

The validity of the above procedure was checked by *DBHOB* and *H* inputs from within the respective ranges of the 288 observations. Total stem volumes computed this way appear to be in close agreement with the regression values (2) that constitute the volume table. As the latter corresponds well with the observed volumes as indicated above, total *VIB* estimation via the stemform procedure is quite acceptable within the observational range.

The second volume table for *P. caribaea hondurensis* in Surinam was provided by VOORHOEVE and BOWER (1971), This table is based on the original data of 288 stems collected by DE VRIES (1965), supplemented with 376 observations by the authors themselves, to a total of 664 stems. Owing to the plantations being 5 years older, the supplementary stems also include larger dimensions. The bulk of the entire material is in *DBHOB*-range 6–28 cm, and height range 4–25 m.

From these data the authors computed the following volume regressions:

Total stem volume o.b.: $VOB = 3.639 + 0.036972\ DBHOB^2.H$ (9)

Total stem volume i.b.: $VIB = 1.529 + 0.025616\ DBHOB^2.H$ (10)

For the commercial stem volumes i.b. to top diameters of $7\frac{1}{2}$, 15 and 20 cm respectively, excluding the volume of a 10-cm stump, they found:

pulpwood volume: $VIB(7\frac{1}{2}) = -12.73 + 0.026\ DBHOB^2.H$ (11)

small sawtimber volume: $VIB(15) = -98.16 + 0.026\ DBHOB^2.H$ (12)

sawtimber volume: $VIB(20) = -186.76 + 0.026\ DBHOB^2.H$ (13)

As a whole, the volumes by (9, 10) correspond well with those by (1, 2) resp. Only at the upper ends of the dimensional ranges, the 1965-*VOB* table is up to 10% lower than the 1971-*VOB* table. As indicated before, the former agreed well with its basic observations.

VOORHOEVE and BOWER (1971) rejected the allometric model (1,2) used by DE VRIES (1965) in favour of (9,10), because of the former's inherent slight negative bias. However, the observed magnitude of the negative marginal bias is too large to be explained by the logarithmic procedure applied in data processing with the allometric model. The discrepancy between the two tables is due to the different curvatures implied by the two underlying models. Models (9, 10) imply a simple quadratic relationship between *DBHOB* and volume within a given height class, while models (1, 2) are more adaptable in this respect, as can be seen from the exponent values in (1, 2).

The above authors also found that the allometric model gave no significant improvement over the 'combined variable' model (9, 10). Most probably, they tested the quotient of residual variances of the two models at the 95%-confidence level by the *F*-distribution. However, in cases like these it might be advisable to choose for the model that yields the (though not significantly) smaller residual variance.

We are of the opinion that the volume table model should be given further attention as, basing on the above considerations, we have the impression that the 1971-tables tend to a positive bias. This impression is further motivated as follows.

The entire 1971-material not being at our disposal, total merchantable volumes i.b. for top diameters of 7½ and 15 cm were computed by the relative stemform procedure described earlier, for dimensions within the 1965-observational range. These values were compared with the corresponding regression values from (11) and (12) respectively. Again, the latter appeared to be 4–8% higher, though they are already exclusive of a 10-cm stump volume. As stump volume is of the order of 1% in *VIB*(7½) and of 2% in *VIB*(15), the actual discrepancy is even larger. We did not investigate *VIB*(20) in this way, as our data are too limited. Moreover, large stems may have a relative stem form that on an average differs significantly from that of the relatively small 1965-material.

It is considered appropriate to note here that VOORHOEVE and BOWER's (1971) table 5 (merchantable *VIB* to top diameter 20 cm i.b.) shows a nasty typographical error in the *DBHOB*-entries; these should start and end with 24 an 42 cm, instead of with 20 and 40 respectively.

From (10) through (13) it follows that, irrespective of stem dimensions, the three types of commercial volume can be obtained by making practically constant absolute deductions of about 14, 100, and 188 $dm^3$, respectively, from total stem *VIB*. Evidently, this implies fixed mutual differences between the three types of merchantable volume, as illustrated by (11) through (13). This property was not confirmed by our data. On the contrary, our data suggest a decreasing difference between *VIB*(7½) and *VIB*(15) with increasing diameter, within a given height class.

We will accept the tables by VOORHOEVE and BOWER (1971) for volume estimation in the spacing-thinning experiment, though we are aware of the possibility that they may be positively biased. For purposes of comparison of experimental treatment effects however, we assume that this constitutes no serious problem.

### 2.1.4. *Statistical Foundation of the Experimental Analysis of Variance*

In the following the theory of the analysis of variance pertaining to the experiment at hand will be discussed, using the linear algebraic approach by real vectors and vector spaces (CORSTEN, 1967).

As a model for an observation $x$ in a replicated Graeco-Latin Square design we take:

$$x = \mu + \phi_m + \omega_i + \eta_j + \delta_h + \pi_k + \theta_{hk} + \varepsilon \qquad (14)$$

where $x$ is assumed to consist of contributions due to:
general level $\mu$
blocks (= replications) $\phi_m$ (m = 1, . . ., 4)
rows $\omega_i$ (i = 1, . . ., 12)

columns $\eta_j$ ($j = 1, \ldots, 12$)
spacings $\pi_h$ ($h = 1, 2, 3$ for the square spacings of $2\frac{1}{2}$, 3, $3\frac{1}{2}$ m resp.)
thinning intensities $\delta_k$ ($k = 1, 2, 3$ for low, medium and high intensity, resp.)
interaction 'spacing × thinning' $\theta_{hk}$
a stochastic quantity $\varepsilon$ assumed to be distributed as $\varepsilon \simeq N(0, \sigma^2)$.

In the model only the 2-factor interaction between spacing and thinning intensity is included, as this interaction is of main interest. The other 2-factor interactions are either confounded with a single factor, or with the entire observational space. Moreover, in the experiment under consideration, no real meaning can be attached to these. Consequently, they are excluded from the model. The same holds for the higher-order interactions.

The 36 observations $x$ (14) generate the vector:

$$X \simeq \mu.r + \Sigma_m^4 \phi_m.f_m + \Sigma_i^{12} \omega_i.w_i + \Sigma_j^{12} \eta_j.y_j + \Sigma_h^3 \pi_h.p_h + \Sigma_k^3 \delta_k.d_k + \\ + \Sigma_h^3 \Sigma_k^3 \theta_{hk}.u_{hk} + \sigma.\chi_{36} \qquad (15)$$

where $X \in R^{36}$, the observational vectorspace.

The vector r, with all its 36 coordinates equal to 1, spans the subspace of general level, named N, of dimension one.

The four vectors $f_m$, each having 9 coordinates equal to one and the other 27 coordinates equal to zero, span the subspace of blockeffects, named F, of dimension 4.

The twelve vectors $w_i$, each having 3 coordinates equal to one and zeros for the rest, span the subspace of row effects, named W, of dimension 12. Similarly, the 12 vectors $y_j$ span the subspace of column effects, named Y, also of dim. 12.

The 3 vectors $p_h$, each having 12 coordinates equal to one and the rest equal to zero, span the subspace of spacing effects, named P, of dimension 3. Similarly, the three vectors $d_k$ span the subspace of thinning effects, named D, equally of dimension 3.

The 9 vectors $u_{hk}$, each having 4 coordinates equal to one and all others zero, span the subspace of effects due to interaction between spacing and thinning intensity, named PD, of dimension 9.

The vector $\chi_{36}$ is a stochastic vector with its 36 coordinates independently and standard-normally distributed.

As $N \subset F$, pure block effects are in subspace F* of dim. 3, being the orthogonal complement of N in F. Orthogonal basisvectors of F* are denoted by $f'_m$ ($m = 1, 2, 3$).

Further, $F \subset W$ (and $F \subset Y$), so pure row effects (resp. pure column effects) are in W* of dim. 8 (resp. Y* of dim. 8), being the orthogonal complement of F in W (resp. of F in Y).

As $N \subset P$ (and $N \subset D$) pure effects due to spacings (resp. due to thinning intensities) are in P* of dim.2 (resp. D* of dim.2), being the orthogonal complement of N in P (resp. N in D). Orthogonal basisvectors of P* and D* are denoted by $p'_1$, $p'_2$ and $d'_1$, $d'_2$ respectively.

The subspaces N, F*, W*, Y*, P* and D* are mutually orthogonal. Together they constitute a subspace of dim. 24 in $R^{36}$.

Finally, $P \subset PD$ and $D \subset PD$ which, as P and D have N as their crosscut, leaves the 4-dimensional subspace $PD^* \subset PD$. Orthogonal basisvectors for PD* can be found as the HADAMARD products:

$$u'_1 = p'_1 o d'_1 ; u'_2 = p'_1 o d'_2 ; u'_3 = p'_2 o d'_1 ; u'_4 = p'_2 o d'_2$$

By its definition, PD* is orthogonal to N, P* and D*. It also is orthogonal to F*, as the inner product u'.f' of any vector $\in$PD* with any vector $\in$F* is zero. However, PD* is entirely confounded with the unison of W* and Y*, i.e. with the latter's direct sum W* + Y* of dim.16. It follows that the orthogonal complement of PD* in W* + Y*, here denoted by WY*, is of dim.12, and contains pure, but mixed row- and column effects. Consequently, a test on this mixed row/column effect can be obtained by comparing the variance computed from WY*, with the residual variance. The latter is computed from a subspace named $T_3$ of dim. 12. If this test does not lead to rejection of the null-hypothesis: 'row- and column effects are absent', a test on the PD-interaction can be obtained by comparing the variance computed from PD*, with the residual variance. In the latter case, the option exists of pooling the residual variance with that computed from WY*. The subspace of residual effects, named $T_4$ then acquires dim.24, and the experimental analysis collapses to that of a replicated $3^2$ factorial, randomized block design (RRB-II).

Summarizing: The observational space of dimension 36 in a 4 times replicated 3 × 3 Graeco-Latin Square Design can be partitioned into mutually orthogonal subspaces as follows:

| Symbol | Dimension | Pure Effect |
|---|---|---|
| N | 1 | general level |
| F* | 3 | blocks |
| P* | 2 | spacings |
| D* | 2 | thinning intensities |
| WY* | 12 | mixed row/column |
| PD* | 4 | interaction + row/column |
| Subtotal | 24 | |
| $T_3$ | 12 | residual |
| R | 36 | total |

The observational vector X is orthogonally projected onto each of these subspaces. The squared vector component in each subspace (SS = Sum of Squares) is divided by subspace dimension (DIM $\simeq$ Degrees of Freedom). Then the quantity $s_i^2 = SS/f_i$, computed from a main- or interaction pure-effect space of DIM = $f_i$, is divided by $s_t^2 = SS/f_t$ computed from residual space T of

DIM = $f_t$. The quotient $s_i^2/s_t^2$ is distributed as FISHER's $F(f_i, f_t)$ under the null-hypothesis that there is no effect.

We now define the following equivalent symbolism:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *spacing:* h = | 1 | 2 | 3 | *thinning intensity* k = | 1 | 2 | 3 |
| | $2\frac{1}{2}$ | 3 | $3\frac{1}{2}$ | | low | medium | high |
| | A | B | C | | Z | M | S |

Subspace PD of dim.9 then is spanned by the 9 orthogonal vectors:

| line | col 1 | 2 | 3 |
|---|---|---|---|
| 1 | $u_{az}$ | $u_{am}$ | $u_{as}$ |
| 2 | $u_{bz}$ | $u_{bm}$ | $u_{bs}$ |
| 3 | $u_{cz}$ | $u_{cm}$ | $u_{cs}$ |

The three vectors on line 1 span a 3-dimensional vectorspace $A \subset PD$. Similarly, the group on line 2 spans $B \subset PD$, and the vectors on line 3 span $C \subset PD$, both of dim.3. The vectorsum of the elements on line 1 is identical with $p_a (= p_1)$, a basisvector of space P. Similarly, the vectorsum of the elements on line 2, resp. line 3, is $p_b$ $(= p_2)$, resp. $p_c$ $(= p_3)$. The vectors $p_a$, $p_b$, and $p_c$ span P of dim.3 as defined before.

Consequently, pure effects due to thinning intensity within the same spacing A, are in subspace A* *of dim.2, being the orthogonal complement of* $p_a$ *in* A. Subspace A* is assumed to be spanned by the two orthogonal contrastvectors a′ and a″. Likewise, pure thinning effects within spacings B and C, respectively are found in B* and C*, with orthogonal contrast vectors b′, b″ and c′, c″, resp.

It follows that the 6-dimensional subspace $(A^* + B^* + C^*) \subset PD$ is identical to $D^* + PD^*$. Hence, the former is partially confounded with row- and column effects, as these occur in PD*. This circumstance renders a test on 'thinning effects within the same spacing' less sensitive, unless the mixed row/column effect is found to be non-significant by testing the component from WY* as described earlier.

We will use this test in the 2-dimensional subspaces A*, B*, and C* to detect significant heterogeneity ('pseudo-thinning effects'), if any, in parameters of the unthinned stands, after the random orthogonal allocation of the different thinning intensities to identical spacings.

Alternatively, the three interaction vectors in column 1 span a 3-dimensional subspace $Z \subset PD$. Similarly, the vectors in columns 2 and 3 span 3-dimensional subspaces M and S respectively, both contained in PD. The vectorsum of the elements in column 1 is identical to $d_z$ $(= d_1)$, a basisvector of D. Similarly, the vectorsums of the elements in columns 2 and 3 are identical to $d_m$ $(= d_2)$

and $d_s$ ($= d_3$), respectively. The vectors $d_z$, $d_m$, and $d_s$ span subspace D of dim.3, as defined before.

Consequently, pure effects due to spacings within the same thinning intensity Z are in Z* of dim.2, being the orthogonal complement of $d_z$ in Z. In subspace Z* two contrast vectors z′ and z″ can be defined as an orthogonal basis.

Analogously, M* and S*, with orthogonal contrast vectors m′, m″ and s′, s″ respectively, are defined.

The 6-dimensional subspace $(Z^* + M^* + S^*) \subset PD$ is identical to $P^* + PD^*$, so that the former is partially confounded with mixed row/column effects. This again renders a test on 'spacing effect within the same thinning intensity' less sensitive, unless the row/column effect is non-significant (test on variance from WY*).

We will use the test in the 2-dimensional subspaces Z*, M*, and S* to detect significant differences in production characteristics between stands originating from different initial spacings, but subsequently subjected to the same thinning intensity.

Before any thinning actually has been executed, i.e. before the introduction of thinning intensity as an experimental factor, the experiment constitutes a replicated 3 × 3 Latin Square. This situation existed until 1972, when the stands had reached the age of 8 years. The model for an observation in a replicated Latin Square is:

$$x \simeq \mu + \phi_m + \omega_i + \eta_j + \pi_h + \varepsilon \qquad (16)$$

where the meaning of the symbols is the same as in model (14) for the Graeco-Latin Square. The Latin Square model implies the same subspaces N(dim.1), F*(dim.3) and P*(dim.2) as in the Graeco-Latin Square. However, PD* (dim.4) now is non-existent, and W* as well as Y*, each of dim.8, are pure row-, resp. column effect spaces. Further, D* (dim.2) is non-existent, and is added to subspace $T_3$ of residual effects, which yields $T_1$ of dim.14. Optionally, in case of non-significant row- and column effects, W* and Y* can be added to $T_1$, which results in a residual effect space $T_2$ of dim.30. The analysis then collapses to that of a replicated randomized block design with one factor on three levels (RRB-I).

Summarizing: In the 4 times replicated 3 × 3 Latin Square Design the observational space of dimension 36, can be partitioned into orthogonal subspaces as indicated on the next page.

In the case of the replicated Latin Square design, resp. in that of the replicated Graeco-Latin Square design, two orthogonal contrast vectors can be defined for subspace P* (viz. $p_1'$ and $p_2'$), resp. for the subspaces P* and D* (viz. $p_1'$, $p_2'$ and $d_1'$, $d_2'$), in such a way, that the orthogonal projection of X on the first contrast vector measures the linear effect in the relationship, if any, between factor level and value of a stand characteristic.

| Symbol | Dimension | Pure Effect |
|---|---|---|
| N | 1 | general level |
| F* | 3 | blocks |
| P* | 2 | spacings |
| W* | 8 | rows |
| Y* | 8 | columns |
| Subtotal | 22 | |
| $T_1$ | 14 | residual |
| R | 36 | total |

In other words, along the first or simple contrast vector the difference is measured between the values a certain stand characteristic attains at the two extreme levels of a factor. The extreme levels are A and C in spacing, and Z and S in thinning intensity.

As both factors are applied on 3 levels, a significant quadratic effect may be detected along the contrast vectors $p_2'$ and $d_2'$, respectively, as the composite contrasts A + C − 2B and Z + S − 2M (symbolic notation).

In subspace PD* four interaction contrast vectors can be defined. Along the first, viz. $u_1'$ the linear effect is measured by the contrast (AS–AZ)–(CS–CZ). Then the entire quadratic effect is measured by the vectorsum of the X-components along the three other contrast vectors, which are elements of the orthogonal complement of $u_1'$ in PD*.

If by the above analyses of variance the existence of a significant difference due to a factor is detected, the nature of this difference can be demonstrated more specifically by application of DUNCAN's Multiple Range Test to the experimental means.

### 2.1.5. *Collection of Field Data*

Till 1977 field data were collected in, and treatments applied to the experiment as specified below.

| Date | Stand age | Observer[1] | Type of data/treatment |
|---|---|---|---|
| Dec. 1966 | 2.3 | F. E. VREDEN, student | heights, mortality |
| Jan. 1968 | 3.3 | N. R. DE GRAAF, student | do., and dominant heights |
| Jan. 1970 | 5.3 | N. A. LEEK, student | *DBHOB*, dom. heights, mortality |
| Aug. 1972 | 8 | P. G. DE VRIES | complete enumeration, thinning |
| Aug. 1975 | 11 | P. G. DE VRIES | do. |

[1] with the indispensable assistance of employees of the Surinam Government Forest Service and/or local forestry students.

In a complete enumeration the following data are collected in each EP, after the weed vegetation has been cut back:

1. girth of all trees in mm at breast height, over bark;

2. about 30 total height measurements in dm by BLUME-LEISS hypsometer, distributed over the diameter cm-classes;
3. heights of dominant trees (top heights) in dm, viz. 16 top heights in the A and C spacings, and 24 in the B spacing. A top height tree is defined as the highest tree on an area of $10 \times 10$ m;
4. a count of forked, crooked or otherwise deformed trees, inclusive of 'fox-tails' and other aberrant crown types;
5. number and breast height girth of thinned trees.

A complete enumeration of the entire experimental area, inclusive of the computation and marking of thinnings in the $60 \times 60$ plots, and the often necessary re-establishment of plot boundaries, takes from 50 to 60 days, dependent on the available strength of the field party, prevailing weather and transport facilities.

### 2.1.6. *Thinning Regimes*

In a stand, average individual growing space can be considered as a measure to characterize the intensity of thinning. If for reasons of comparison, the $N$ trees in a stand are assumed to be distributed in an equilateral triangular spacing, resulting in an average mutual distance of $a$ meters, the hexagonal area of average growing space $W$ is:

$$W = 10^4/N = \tfrac{1}{2}a^2\sqrt{3}, \text{ which implies } N = 11{,}547/a^2$$

This area increases during stand life, and consequently can be related to dominant height, for instance by:

$$W = \tfrac{1}{2}a^2\sqrt{3} = k.h^{\beta}_{dom} \text{ (DE VRIES, 1964)}$$

where $k$ and $\beta$ are constants. By this relation we have that:

$$a = (2k/\sqrt{3})^{\frac{1}{2}}.h^{\frac{1}{2}\beta}_{dom}$$

Putting $\beta = 2$ we obtain:

$$a = (2k/\sqrt{3})^{\frac{1}{2}}.h_{dom} = (s/100).h_{dom}$$

in which case $s$ is named the stem distance percent or $s\%$ (HART, 1928). Its definition implies that the development of average growing space in time is proportional to the squared dominant height.

Assuming that $a$ is constant over a relatively short period, the $s\%$ decreases with time because of increasing $h_{dom}$. Now a stand may be grown with a fixed $s\%$. This implies that periodic thinnings must take place in order to increase $a$ and so to restore the required $s\%$. Consequently, the relation between $s\%$ and time is a saw-tooth line. The length of the period between two successive thinnings depends on how far one allows the $s\%$ to sink below its required value. The faster height growth in the moist tropics causes a higher rate of decrease in the $s\%$ than in temperate regions, so that thinnings will have to be more frequent under tropical conditions. In order to avoid that the $s$-percentages of a series of experimental plots with different thinning intensities (characterized by their $s\%$) sink too far within each other's 'saw-tooth ranges' during the time interval between two successive thinnings, either this interval may be shortened, or the interval between the required $s$-percentages of the plots may be increased, or both. Incorporating experience in temperate regions into the above reasoning, the required $s$-percentages to be applied in the experiment at issue were tentatively put at 17% (Z-degree), 22% (M-degree) and 27% (S-degree), assuming a thinning cycle of 3 years.

In 1972 only 12 out of the 36 plots were up to the first thinning to the required $s\%$, viz. the 4 plots in each of the AS, AM and BS treatments.

In 1975 the previously thinned plots were thinned again. In addition, now the AZ, BM and CS plots were up to their first thinning. As the S-degree of 27% was considered too high, it was changed to 25%. The Z-degree was kept unchanged, so that from 1975 onwards the thinning series will consist of the intensities: Z = 17%, M = 21% and S = 25%.

By means of the $s\%$ the number of trees can be calculated that has to be removed from each EP to give it the required thinning degree. Trees qualifying for being thinned are first selected on vitality and stem form criteria. At increasing $s\%$-values however, trees selected on competition criteria, as judged ocularly, are increasingly included in the thinnings.

In view of obtaining remaining EP stands of as uniform a stem distribution as possible, the mean number of remaining stems per ESP is calculated. Then by successively marking the thinnings in each of these 16 subplots, it is tried to approach this mean number as closely as possible.

## 2.2. Computations, Analyses and Results

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### 2.2.1. *Processing of Field Data*

The 16 to 24 observations of dominant tree heights per EP are averaged to the value $h_{dom}$.

Girth measurements are condensed per EP to *DBHOB* frequency lists with 1-cm class intervals.

From the combined height and diameter measurements of about 30 trees per EP, a regression of height on diameter is computed for each EP, using Henriksen's model: $h = a + b.\log DBHOB$.

From these data, stand volume per EP before thinning is computed, per *DBHOB*-class, using Voorhoeve and Bower's (1971) volume regressions for total stem volume o.b. and i.b., and for commercial stem volumes i.b. to top diameters i.b. of 7½ and 15 cm respectively. The volume of the thinnings is computed similarly; stand volume after thinning then is known also.

Basal areas of the stands before and after thinning, as well as for the thinnings are computed per diameter class. From the total basal areas and numbers of stems, diameters of mean basal area o.b. follow for entire stand, remaining stand and thinnings. Mean height of the stands before and after thinning are estimated as regression values at the respective diameters of mean basal area, in HENRIKSEN's model. For the thinnings however, mean height is computed as the LOREY mean.

Finally, total, mean annual and current annual increments are computed for the various types of stand volume.

As far as applicable, the above stand values are converted to a one-hectar basis.

### 2.2.2. *Yield Tables*

From the processed field data separate yield tables were constructed (App. 1, 2, 3) for each combination of spacing and thinning intensity, so each table is based on the means of four plots. The symbols in the heads of these tables denote:

$t$ = stand age in years from germination;
$H$ = dominant height in meters;
s% = stemdistance percent, i.e. HART's thinning degree;
$N$ = number of stems per hectar;
$G$ = stand basal area o.b. in $m^2$ per hectar;
$d$ = diameter of mean basal area o.b. in centimeters;
$h$ = mean stand height in meters;
Volume or Increment O.B.: total stem volume over bark in $m^3$ per hectar;
do., IB: total stem volume inside bark in $m^3$ per hectar;
do., C1: commercial stem volume inside bark, to a top diameter of 7.5 cm i.b., exclusive of 10 cm stump, in $m^3$ per hectar;
do., C2: commercial stem volume inside bark, to a top diameter of 15 cm i.b., exclusive of 10 cm stump, in stems with *DBHOB* of 20 cm and up, in $m^3$/ha.

Further on differences between these tables will be tested on their statistical significance by applying analysis of variance to the 36 individual plot values of a number of mayor stand characteristics.

### 2.2.3. *Analysis of the Spacing Experiment*

At he age of 8, reached in 1972 a number of plots were up to first thinning to the required *s*%. Till that moment the experiment was a spacing experiment, laid-out as a four times replicated Latin Square with 3 square spacings, viz. A = 2½, B = 3, and C = 3½ meter. The effect of spacing on a number of characteristics of the stands before thinning was investigated by analysis of variance on the basis of this design. Significant row- or column effects appeared in the analysis of only very few characteristics.

As an illustration, the 36 observations of stem volume o.b. in $m^3$/ha at age 8 are given in Appendix 4, and analysed in App. 5, 6, and 7.

The quantities $s_i^2/s_{81}^2$ used in the LSQ analysis point at the existence, on the 95%-significance level, of differences between blocks and between spacings. The latter differences are explained by the presence of a significant linear effect due to spacing, which is clearly suggested by the values $\bar{\bar{a}} = 141$, $\bar{\bar{b}} = 113$, and $\bar{\bar{c}} = 89$ in App. 4. These three means, each from 12 plots, possess accidental variances of $s_{81}^2/12 = 7.96$ with 14 degrees of freedom. Then the significant studentized ranges are 3.18 and 3.03 for series of three and two means respectively, so that in DUNCAN's Multiple Range Test the least significant ranges are 9.0 and 8.5 respectively. Hence the conclusion is justified that the three means have significant mutual differences. This result, together with the results of a similar analysis of other stand characteristics, is included in table 5.

TABLE 5. Caribbean Pine – Coebiti Experiment – Surinam.
Characteristics (means of 12 plots) of unthinned stands of different initial spacing at the age of 8 years.

| Characteristic | Spacing | | |
|---|---|---|---|
| | 2½ × 2½ | 3 × 3 | 3½ × 3½ |
| Mortality percentage[1] | 4.7 | 4.8 | 4.4 |
| Number of stems per ha[2] | 1525 | 1058 | 780 |
| Dominant height in m | 13.5 | 13.4 | 13.0 |
| Mean stand height in m | 11.5 | 11.6 | 11.3 |
| Basal area o.b. in $m^2$/ha | 24.2 | 19.4 | 15.7 |
| Diameter o.b. of m.b.a. in cm | 14.2 | 15.3 | 16.0 |
| Total stem volume o.b. in $m^3$/ha | 141 | 113 | 89 |
| M.A.I. (o.b.) in $m^3$/ha/year | 17.6 | 14.1 | 11.1 |
| Number of stems/ha with *DBHOB* of 20 cm and up | 90 | 113 | 128 |
| Percentage of stems with *DBHOB* of 20 cm and up | 5.9 | 10.7 | 16.4 |
| Percentage of crooked stems | 13 | 14 | 15 |
| Percentage of stems forked ⩽ 6 m | 13 | 16 | 16 |
| Percentage of stems forked ⩾ 6 m | 11 | 12 | 12 |
| Total percentage of forked stems | 24 | 28 | 28 |
| Total percentage of defective stems, inclusive of foxtails | 40 | 43 | 43 |

[1] Values connected by underlining do not differ significantly by DUNCAN's Multiple Range Test. Absence of line denotes significant difference with underlined values, if any.
[2] All values differ significantly at the 5%-level by DUNCAN's Multiple Range Test.

From table 5 it is evident that no significant differences due to spacing are found in mortality percentages (mean 4.6%) and mean stand height (average 11.5 m). The same holds for the percentage of stems showing distinct crook (mean 14%), and those with a fork above 6 meter (mean 12%) or one below 6 meter (mean 15%). However, the latter data suggest slightly lower percentages in the narrowest spacing. Disregarding fork height above ground level, the percentage of forked stems is 26.7% on an average; the lowest value of 24%, found in spacing A, differs significantly from the 28% found in C. A similar situation exists in respect of total percentage of defective stems, where stems with multiple defects count only once of course and in which foxtails are included. We have the impression that foxtails were very scarce in this experiment as compared with the number in nearby plantations. Needless to state that in subsequent thinnings defective stems were among the first to be selected for removal.

Dominant height shows a trend to decrease with increasing spacing, most probably because of more severe weed competition. Mean stand height on the other hand does not appear to be influenced to the same extent.

Mean stand diameter at breast height increases significantly and linearly with spacing: from 14.2 cm in A to 16.0 cm in C. The reverse holds for total stem volume o.b. per hectar and, of course, for mean annual volume increment per hectar, the latter being 17.6 $m^3$/ha in spacing A and only 11.1 $m^3$/ha in spacing C.

The number of stems per ha that posses a *DBHOB* of 20 cm and up, is lowest in spacing A (90) and differs significantly from that in C (128), but the increase from B to C (15) is less than that from A to B (23). However, if this number is expressed as a percentage of total number of stems per hectar, these percentages rise significantly and linearly from about 6% in A to about 16% in C.

We note that in the Latin Square analysis of appendix 5, row- and column effects are non-significant. If for this reason the LSQ design computationally is made to collapse into a randomized block design (RRB-I), the residual variance increases from $s^2_{81} = 95.51$ to $s^2_{82} = 102.23$. Yet block and spacing effects that were significant under the LSQ analysis, remain so under the RRB-I analysis.

In App. 7 a summary is given of the average composition of unthinned stands in spacings A, B and C at the age of 8. This table shows the average diameter frequencies per hectar in 2-cm *DBHOB* classes, as well as the distribution of total stem volume inside bark in $m^3$/ha over these classes. Moreover, for each diameter class a percentage is given indicating the fraction of total number of stems, resp. total volume inside bark, cumulatively contained in this class and the following thicker ones.

### 2.2.4. *Analysis of the Spacing-Thinning Experiment*

In order to obtain a Graeco-Latin Square design at stand age 8, the three thinning intensities were randomly, but orthogonally allocated to the 9 plots within each block. For each series of 12 plots of identical initial spacing, this implied the restricted choice of three sets of 4 plots (one plot per block), in view of subjecting each set to a different thinning intensity.

The three sets of 4 plots within a specific spacing preferably should be as uniform as possible, in order not to complicate future comparisons between different thinning intensities within identical initial spacings. The extent of uniformity can be investigated by analysing the observations in unthinned stands of identical spacing, after the allocation (pseudo-treatment) of thinning intensities. This type of analysis is illustrated in Appendix 8. Thinning effects within identical spacing are partly confounded with row- and column effects, which by themselves might give rise to a pseudo-effect. To compensate for this we used the quantity $s_{84}^2$ (see App. 5) in the analysis of App. 8, instead of $s_{83}^2$.

From the analysis in App. 8 it is evident that there is a significant linear pseudo-thinning effect in spacing A. Application of DUNCAN's Test (App. 8, bottom) demonstrates more specifically that there is a significant difference between the mean of the four AZ-plots and that of the AS-plots (about 15 m$^3$/ha), and further between the AZ-plots and the AM-plots (about 18 m$^3$/ha). The AM and AS differ only by a nonsignificant 3 m$^3$/ha. There are no significant pseudo-effects in the B and C plots. In App. 4 all values can be inspected. The above pseudo-effect exists in spite of its failing to be detected by the GLSQ analysis ($s_i^2/s_{83}^2$) or by the RRB-II analysis ($s_i^2/s_{84}^2$) in App. 5. We conclude here that the allocation of thinning intensities did not result in significant pseudothinning effects as a whole, but it did so within spacing A. In future comparisons the deviating initial situation in the AZ-plots should be given due attention.

In 1972 a number of plots were thinned (see App. 1, 2, 3), and in 1975, at stand age 11, the second complete enumeration was executed, followed by a thinning. The necessity of re-scaling the range of thinning intensities on that occasion was already mentioned in section 2.1.6. A slight anomaly in the $s\%$ of AS could not be avoided.

The values of relevant current characteristics of the 11-year-old stands before thinning, and measures for total production were analysed by the GLSQ design. In App. 9 through 12 an illustration of this analysis is given, using as an input current annual increment in m$^3$/ha of total stem volume o.b., computed as a periodic mean from the difference in total production at the ages of 11 and 8 years. From App. 10 it appears that, besides a significant block effect, there are significant effects due to spacing, thinning and interaction between these two main factors.

The spacing effect (irrespective of thinning intensity) is significantly linear. The lowest c.a.i., occurring in spacing C, differs significantly from that in A and B. The difference between the latter two however does not qualify as significant in this experiment. Closer investigation of the phenomenon in the anova table of App. 11 shows that there are significant linear spacing effects within the Z and M-plots, but not in the S-plots, though DUNCAN's test reveals a small one in the latter, viz. between CS and BS. We conclude that c.a.i. at $t = 11$ in the widest spacing C is significantly lower than in the two other spacings, and further, that within the Z-plots the A-spacing shows the highest c.a.i., while both in the M and S-plots spacings A and B have non-significant differences.

In the anova table of App. 10 we further note significant linear and quadratic effects due to thinning intensity. The S-plots as a whole grow significantly less than the Z and M-plots, which mutually differ only slightly. A closer analysis in App. 12 shows that the A-plots are responsible for this difference, as there the S-plots produce substantially less than the M and Z-plots. From this result it is evident that the S-degree of 27% is too severe for Caribbean Pine in Surinam. This observation constituted the reason to reconsider the *s*%-intervals in 1975 as mentioned earlier.

App. 10 also reveals a significant interaction effect, indicating that within A the difference between the Z- and S-degree is much larger than between the same degrees in C. As c.a.i. in AS is smaller than that in AZ, we concluded that by heavy thinning in spacing A too many productive trees are removed, and that the stand remaining after thinning cannot take over the latter's contribution to the current increment.

The results from the multiple range tests in App. 10, 11, 12 are summarized in table 6, together with the results of a similar analysis of other stand characteristics. In this table, inequalities, resp. equalities, denote significant, resp. non-significant differences. As in table 5, values connected by underlining do not differ significantly.

The values of characteristics in different thinning intensities within identical spacing can also be found in the yield tables (App. 1, 2, 3). The same holds of course for values of characteristics in different spacings within the same thinning intensity.

TABLE 6. Caribbean Pine – Coebiti Experiment – Surinam.
Characteristics at the age of *11* years of stands of different initial square spacings (A = 2½, B = 3, C = 3½ m), subjected to different thinning intensities (Z = low, M = medium, S = heavy).

| Characteristic at t = 11 | Treatment Spacing | | | Treatment Thinning | | |
|---|---|---|---|---|---|---|
| | A | B | C | Z | M | S |
| Dominant height (m) | 17.4 | 17.4 | 17.0 | 17.1 | 17.2 | 17.3 |
| | in Z: C < B, B = A, C = A<br>in M and S: A = B = C | | | in A, B and C: Z = M = S | | |
| Mean height (m) | 15.4 | 15.3 | 14.8 | 14.8 | 15.3 | 15.4 |
| | in Z: A = B = C<br>in M: C<A, B = A, B = C<br>in S: C<A, C<B, B = A | | | in A: Z<S, Z<M, M = S<br>in B and C: Z = M = S | | |
| Basal area ($m^2$/ha) | 27.8 | 25.8 | 21.9 | 26.5 | 26.4 | 22.6 |
| | in Z: C<B<A<br>in M: C<A, C<B, B = A<br>in S: A = B = C | | | in A and B: S<Z, S<M, M = Z<br>in C: Z = M = S | | |
| *DBHOB* (cm) | 17.2 | 18.2 | 18.9 | 17.6 | 18.1 | 18.5 |
| | in Z: A<B<C<br>in M: A<C, B<C, A = B<br>in S: A = B = C | | | in A: Z<S, Z<M, M = S<br>in B and C: Z = M = S | | |

| | A | B | C | S | Z | M |
|---|---|---|---|---|---|---|
| C.A.I. (total stem volume o.b. in $m^3$/ha/y) | 30.4 | 28.4 | 23.6 | 25.4 | 28.1 | 28.9 |
| | in Z: C<B<A<br>in M: C<A, C<B, A = B<br>in S: C<B, C = A, A = B | | | in A: S<M, S<Z, Z = M<br>in B and C: Z = M = S | | |
| M.A.I. (total stem volume o.b. in $m^3$/ha/y) | 21.1 | 18.0 | 14.5 | 17.4 | 17.7 | 18.6 |
| | in Z, M and S: C<B<A | | | in A: S<M, S = Z, Z = M<br>in B and C: Z = M = S | | |
| M.A.I. (total stem volume i.b. in $m^3$/ha/y) | 14.5 | 12.4 | 10.0 | 11.9 | 12.2 | 12.8 |
| | in Z, M and S: C<B<A | | | in A, B and C: Z = M = S | | |
| M.A.I. (comm. volume i.b. to top 7.5 cm i.b. in $m^3$/ha/y) | 12.7 | 11.1 | 9.1 | 10.5 | 10.8 | 11.4 |
| | in Z, M and S: C<B<A | | | in A: S<M, S = Z, Z = M<br>in B and C: Z = M = S | | |
| M.A.I. (comm. volume i.b. to top 15 cm i.b. in $m^3$/ha/y) | 3.1 | 3.6 | 3.9 | 3.4 | 3.5 | 3.7 |
| | in Z, M and S: A = B = C | | | in A, B and C: Z = M = S | | |
| Total standing volume o.b. before thinning in $m^3$/ha | 211 | 194 | 160 | 170 | 195 | 199 |
| | in Z and M: C<B<A<br>in S: C<B, C = A, A = B | | | in A and B: S<M, S<Z, Z = M<br>in C: Z = M = S | | |

| | A | C | B | S | Z | M |
|---|---|---|---|---|---|---|
| Total number of stems with *DBHOB* of 20 cm and up, produced till t = 11 per ha. | 309 | 346 | 373 | 335 | 339 | 354 |
| | in Z and S: A = B = C<br>in M: A<B, A = C, C = B | | | in A, B and C: Z = M = S | | |

| | A | B | C | S | Z | M |
|---|---|---|---|---|---|---|
| Total number of stems with *DBHOB* of 20 cm and up, produced till t = 11, in % of initial number of stems | 19.1 | 33.6 | 41.8 | 30.8 | 31.3 | 32.4 |
| | in Z and M: A < B < C<br>in S: A<C, A<B, B = C | | | in A, B and C: Z = M = S | | |

# DISCUSSION

Although the experiment is still too young to permit final conclusions as to the effects of spacing and thinning combinations, and especially as too short a time has elapsed yet to enable thinning effects making themselves clearly manifest, the results obtained in the foregoing already allow some interesting preliminary qualitative and quantitative conclusions to be drawn.

Considering the result obtained in stands before thinning, i.e. till the age of 8 (table 5), mortality is the same (some 5%) in square spacings ranging from A = 2½ through B = 3 to C = 3½ m. Probably because of more severe weed competition there, dominant height in spacing C is a significant .5 meter smaller than in A and B, which circumstance tends to put spacing C in a lower site class.

There is a considerable, almost linear increase in stand diameter o.b. from 14 cm in A to 16 cm in C. Total number of stems with *DBHOB* of 20 cm and up, per ha, increases from 90 in A to 128 in C, though not significantly over the entire range. However, the 40% higher number in C relative to A, is significant. If this number of stems is expressed as a percentage of total number of stems per hectar, the increase from 6% in A to 16% in C is significant and linear.

The percentage of defective stems (e.g. crooks, forked stems and foxtails) has a slight trend to be lowest in A, but this phenomenon is scarcely significant. On the other hand, in all spacings there are some 40% stems showing distinct qualitative defects. It is evident that the majority of these stems will quality for removal in subsequent thinnings. However, as the number of stems per area unit in A is more than twice that in C, spacing A offers considerably larger selection possibilities in view of obtaining future stands of good quality.

Regarding the production of total stem volume, spacing A, which made a very dense impression at the age of 8 and contained a number of dying suppressed trees, exploited the environment to a maximum, resulting in 141 $m^3$ of standing volume o.b. per hectar. Spacings B and C had 113 and 89 $m^3$/ha respectively, which points at an almost linear decrease with the (almost linearly) increasing growing space. Obviously, in B and C part of the biomass production potential went to the weed vegetation, the latter being less dense in A.

As to comparisons of stand characteristics at the age of 11 (see table 6), it should be borne in mind that at the age of 8 only part of the plots had reached a relative density that necessitated a first thinning to the required *s*%. At the age of 11 the latter received their second thinning, others their first, while the BZ and CZ plots still remained unthinned (see yield tables in App. 1, 2, 3).

Thinning of a stand causes the values of the latter's mean diameter and height to shift arithmetically upwards relative to their values before thinning. Consequently, growth of these parameters over a period can be assessed only by comparing their value in the remaining stand at the beginning of the period, with their value in the unthinned stand at the end. This circumstance also implies the impossibility of interpreting in the sense of a growth difference, any difference between the values of these characteristics in thinned and unthinned stands. On the other hand, valid comparisons between these fundamentally heterogeneous elements can be obtained on the basis of cumulative quantities, such as dominant height and total (or mean annual) volume production.

Table 6 shows that till the age of 11 thinnings, as far as applied, have had no effect on dominant height. Contrarily, the trend of smaller dominant heights in wider spacings as already demonstrated at age 8, is continued.

Mean annual increments in the three spacings differ significantly as regards total stem volume over bark, total stem volume inside bark, and commercial stem volume i.b. to a top diameter of 7.5 cm.i.b., exclusive of a 10-cm stump (C1). Apart from its being a rather doubtful characteristic at the early age of 11, less significance can be attributed to the difference in production of C2, the commercial stem volume i.b. to a top diameter of 15 cm i.b., as far as this is contained in the *DBHOB* classes of 20 cm and up.

It can be concluded that, irrespective of thinning intensity, most timber i.b. is cumulatively produced in the narrowest spacing A, and that production linearly decreases with increasing spacing. However, this production is irrespective of stem quality. The degree to which the latter can be improved by selective thinning depends on the total number of trees present per area unit.

The next item to be considered then is, to what degree selective thinnings can be applied without considerable loss of total volume production. We note first of all, that irrespective of spacing, there are some significant differences in m.a.i. between the thinning intensities. The lowest values are found in the S-plots, the highest values remarkably in the M-plots. Especially in the A-spacing the S-plots show two m.a.i.'s that are significantly lower than in M. The S-plots moreover, did not produce a significantly higher absolute or procentual number of stems with *DBHOB* of 20 cm and over. So it is concluded that the S-degree of 27% is too heavy.

We also may conclude that the C-spacing is too wide because of its lower total volume production, its lower c.a.i., its lower effective site class, its more severe weed growth, and the restricted possibility for stand improvement by selective thinning.

Hence, the combinations of spacings A and B with thinning intensities Z and M remain to be compared. Irrespective of spacing, there is no significant difference in m.a.i. between the Z- and M-intensities, though the trend is towards highest production in the M-plots (see table 7). The same holds for absolute and relative total production of stems having over 20 cm *DBHOB*.

Current annual volume o.b. increment is highest in A, but it does not differ significantly from that in B. Moreover there is no significant difference in c.a.i.

TABLE 7. DUNCAN's Test applied to M.A.I.-values of total stem volume o.b. at age 11. s = 0.44; d.o.f. = 24.

| CS | CZ | CM | BS | BZ | BM | AS | AZ | AM | SSR5% | LSR |
|---|---|---|---|---|---|---|---|---|---|---|
| 9.8 | 9.8 | 10.4 | 12.0 | 12.5 | 12.6 | 13.9 | 14.2 | 15.2 | 3.37 | 1.48 |
| 9.8 | 9.8 | 10.4 | 12.0 | 12.5 | 12.6 | 13.9 | 14.2 | | 3.34 | 1.47 |
| 9.8 | 9.8 | 10.4 | 12.0 | 12.5 | 12.6 | 13.9 | | | 3.31 | 1.46 |
| 9.8 | 9.8 | 10.4 | 12.0 | 12.5 | 12.6 | | | | 3.28 | 1.44 |
| 9.8 | 9.8 | 10.4 | 12.0 | 12.5 | | | | | 3.22 | 1.42 |
| 9.8 | 9.8 | 10.4 | 12.0 | | | | | | 3.15 | 1.39 |
| 9.8 | 9.8 | 10.4 | | | | | | | 3.07 | 1.35 |
| 9.8 | 9.8 | | | | | | | | 2.92 | 1.28 |

between the Z- and M-degrees in these two spacings.

If at present a choice had to be made from the 9 treatments contained in the experiment, we would suggest:

A. for *maximum wood fiber production:* AM or AZ. It is reminded that the AZ-plots showed a pseudo-thinning effect at age 8, of 13 $m^3$ i.b. per hectar as compared with the AM-plots. This discrepancy might be accounted for by adding 1.2 $m^3$/ha to the m.a.i.(i.b.) of 14.2 $m^3$/ha at age 11. There is no significant difference between the AM and AZ-plots as to the production of stems with *DBHOB* of 20 cm and up. Treatment AZ has the advantage that thinnings can be postponed till after stand age 8 on sites comparable to the experimental one. Weed growth in the Z-degree, though less prolific than in the M or S-degree, is by no means completely suppressed. The pine stand in Z gives a very dense impression and shows small crowns which in our opinion do not react much to thinning anymore. So AM, or the M-degree of $s = 21-22\%$ in the growing-space equivalent of A (6.25 $m^2$) might be advisable.

B. for *supplying a more diversified demand* at an earlier age than A does: BM. The BM combination, though less productive than AM as regards total quantity of wood fiber, yields significantly more stems with *DBHOB* of 20 cm and up. Treatment BZ will probably suffer from crowding though at a later stage than A. However, we have not yet executed thinnings in BZ, so there is little point in speculations about the behaviour of the Z-degree.

The spacing of 3.50 by 2.20 meter used in Surinam at present comes to a growing-space of 7.7 $m^2$, which is about halfway in between that of A (6.25 $m^2$) and B (9.0 $m^2$), so that it combines properties of the latter two. On the basis of our preliminary results, we recommend a thinning intensity of $s = 21\%$ for this spacing.

Finally, the following remarks as to the initial pseudo-thinning effect on volume o.b. in the A-spacing can be made. From App. 1 we have for total production o.b.:

at age 8: AS − AZ = 145 − 130 = 15 $m^3$/ha (pseudo-effect)
AM − AZ = 147 − 130 = 17 $m^3$/ha (do.)

at age 11: AS $-$ AZ $= 224 - 227 = -3$ $m^3$/ha (pseudo- and real effect)
AM $-$ AZ $= 245 - 227 = 18$ $m^3$/ha (do.)

This illustrates that heavy thinning in the A-spacing leads to a loss of increment that cannot be compensated by increased growth of the remaining stand. Contrary to this, in moderate thinning where the remaining stand can compensate this loss, an initial difference (pseudo-effect) is maintained.

# SUMMARY

The paper is intended as a contribution to the knowledge about stand characteristics of *Pinus caribaea hondurensis* grown under different sylvicultural conditions in Surinam. In a general introduction a brief account is given of the ecology of the species, the history of its introduction into Surinam, and the techniques used in establishing plantations. Then follows a description of the spacing-thinning experiment established in 1965 by the Forest Mensuration Department of the Agricultural University of Wageningen, at the request of and in cooperation with the Surinam Government Forest Service. The experiment was designed as a four times replicated Latin Square with three square spacings, viz. A = 2½, B = 3 and C = 3½ meters. In 1972, at stand age 8 three different thinning intensities, viz. Z = low, M = medium and S = heavy, were orthogonally superimposed onto spacings, which extension changed the design into a four times replicated Graeco-Latin Square. A number of forestry students, both from Surinam and The Netherlands made measurements in the early stages; complete enumerations and thinnings were executed at stand ages of 8 and 11 years. In addition, detailed sectional measurements of about 300 stems were collected in 1965, as a basis for the first volume table for Caribbean Pine in Surinam, published in the same year. The results of these measurements are given, and compared with a volume table published by the Surinam Forest Service in 1971.

The statistical basis of the experimental analysis is given. The observational data are summarized in yields tables per spacing and thinning intensity, and tested on significance of differences. Though the experiment is still young and final conclusions cannot yet be drawn, the more so as thinning effects cannot make themselves manifest in a short period, the AM and BM combinations provisionally can be recommended as the sylviculturally justified, best ones for maximum volume production and a more diversified production respectively.

# SAMENVATTING

Het artikel beoogt een bijdrage te leveren tot de kennis van de groei van *Pinus caribaea hondurensis* onder verschillende teeltmethoden in Suriname. In een algemene inleiding worden in het kort de ecologie van deze houtsoort, alsmede de geschiedenis en de techniek van zijn aanplant in Suriname behandeld. Daarna volgt een beschrijving van het gecombineerd plantverband-dunningsonderzoek, dat in 1965 op verzoek van en in samenwerking met de Dienst Landsbosbeheer Suriname, door de Sectie Houtmeetkunde en Bosinventarisatie van de Vakgroep Bosbedrijfsregeling, Houtmeetkunde en Bosinventarisatie, Tropische Houtteelt van de Landbouwhogeschool werd geentameerd. Er werden drie vierkante plantverbanden ($A = 2\frac{1}{2}$, $B = 3$ en $C = 3\frac{1}{2}$ m) opgenomen in het als 4 maal herhaald Latijns Vierkant opgezette proefschema. Op achtjarige leeftijd werden daarop drie verschillende dunningsgraden (Z = zwak, M = matig en S = sterk) gesuperponeerd, waardoor het schema overging in een vier maal herhaald Grieks-Latijns Vierkant. Verscheidene Surinaamse en Nederlandse bosbouwstudenten verrichtten tijdens hun practijktijd metingen. Volledige houtmeetkundige opnamen en dunningen vonden plaats op 8- en 11-jarige leeftijd. In 1965 werden tevens nauwkeurige gegevens van bijna 300 stammen verzameld voor de constructie van de eerste, in hetzelfde jaar gepubliceerde, en voor de proef noodzakelijke massatabel voor *Pinus caribaea* in Suriname. De resultaten van deze metingen worden vermeld, en vergeleken met een in 1971 door LBB gepubliceerde massatabel.

Na behandeling van de wiskundig-statistische achtergrond van de proefanalyse, worden de in gedetailleerde opbrengsttabellen samengevatte proefresultaten op significante verschillen getoetst. Hoewel het jonge experiment nog geen definitieve conclusies toelaat, temeer daar dunningsinvloeden zich nog onvoldoende hebben kunnen manifesteren, kunnen de AM, resp. BM combinaties voorlopig als de houtteeltkundig verantwoorde beste worden aangenomen voor resp. de productie van maximaal houtvolume, en die van een meer gevarieerd sortiment.

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APPENDIX 1

SPACING A = 2½ × 2½ m

*Pinus caribaea hondurensis*
Coebiti Experiment – Surinam
Plots: I–2; II–6; III–4; IV–8

Thinning Intensity: Z = LOW

| | | | Remaining Stand | | | | | | | | Thinnings | | | | | | | | Volume Increment | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Volume | | | | | | | | Volume | | | | Total | | | | Current | | | Mean | | | |
| *t* | *H* | *s*% | *N* | *G* | *d* | *h* | *OB* | *IB* | *C1* | *C2* | *N* | *G* | *d* | *h* | *OB* | *IB* | *C1* | *C2* | *OB* | *IB* | *C1* | *C2* | *OB* | *IB* | *C2* | *OB* | *IB* | *C1* | *C2* |
| .8 | | | 1600 | | | | | | | | – | | | | | | | | | | | | | | | | | | |
| 2.3 | | | 1553 | | | 1.5 | | | | | 43 | | | | | | | | | | | | | | | | | | |
| 3.3 | 4.8 | 57.3 | 1531 | | | 3.2 | | | | | 22 | | | | | | | | | | | | | | | | | | |
| 5.3 | 9.6 | 28.7 | 1519 | 13.4 | 10.6 | 6.6 | 47 | 31 | 10 | | 12 | | | | | | | | 47 | 31 | 10 | | 31.1 | 21.4 | | 8.8 | 5.8 | 1.9 | |
| 8 | 13.2 | 21.0 | 1506 | 23.0 | 13.9 | 11.0 | 130 | 88 | 67 | 4 | 13 | | | | | | | | 130 | 88 | 67 | 4 | 32.3 | 22.7 | 10.0 | 16.2 | 11.0 | 8.4 | 0.5 |
| 11 | 17.2 | 17.2 | 1314 | 29.1 | 16.8 | 14.9 | 214 | 147 | 129 | 34 | 192 | 2.0 | 11.5 | 13.3 | 13 | 9 | 6 | – | 227 | 156 | 135 | 34 | | | | 20.6 | 14.2 | 12.3 | 3.1 |

Thinning Intensity: M = MEDIUM

Plots I–4; II–9; III–8; IV–3

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .8 | | | 1600 | | | | | | | | – | | | | | | | | | | | | | | | | | | |
| 2.3 | | | 1572 | | | 1.5 | | | | | 28 | | | | | | | | | | | | | | | | | | |
| 3.3 | 5.0 | 54.6 | 1550 | | | 3.4 | | | | | 22 | | | | | | | | | | | | | | | | | | |
| 5.3 | 10.1 | 27.0 | 1544 | 14.1 | 10.8 | 7.2 | 54 | 36 | 14 | | 6 | | | | | | | | 54 | 36 | 14 | | 34.9 | 24.4 | | 10.1 | 6.7 | 2.6 | |
| 8 | 13.7 | 22.0 | 1267 | 22.1 | 14.9 | 12.1 | 132 | 91 | 73 | 4 | 266 | 2.7 | 11.3 | 11.0 | 15 | 10 | 6 | – | 147 | 101 | 79 | 4 | 32.7 | 22.3 | 11.0 | 18.4 | 12.6 | 9.9 | 0.5 |
| 11 | 17.6 | 20.7 | 869 | 23.1 | 18.4 | 16.2 | 181 | 125 | 113 | 35 | 398 | 6.7 | 14.6 | 15.1 | 49 | 33 | 28 | 2 | 245 | 168 | 147 | 37 | | | | 22.3 | 15.3 | 13.4 | 3.4 |

Thinning Intensity: S = HEAVY

Plots: I–7; II–2; III–1; IV–6

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .8 | | | 1600 | | | | | | | | – | | | | | | | | | | | | | | | | | | |
| 2.3 | | | 1570 | | | 1.5 | | | | | 30 | | | | | | | | | | | | | | | | | | |
| 3.3 | 5.1 | 53.3 | 1562 | | | 3.5 | | | | | 8 | | | | | | | | | | | | | | | | | | |
| 5.3 | 9.8 | 27.9 | 1547 | 15.2 | 11.2 | 7.1 | 57 | 38 | 16 | | 15 | | | | | | | | 57 | 38 | 16 | | 33.0 | 22.5 | | 10.7 | 7.1 | 3.0 | |
| 8 | 13.5 | 27.0 | 884 | 16.3 | 15.3 | 11.9 | 95 | 65 | 53 | 3 | 652 | 8.6 | 13.0 | 11.5 | 50 | 33 | 24 | 1 | 145 | 98 | 77 | 4 | 26.3 | 18.3 | 10.0 | 18.1 | 12.3 | 9.6 | 0.5 |
| 11 | 17.4 | 23.8 | 674 | 18.6 | 18.8 | 16.0 | 145 | 100 | 91 | 31 | 210 | 4.0 | 15.6 | 15.0 | 29 | 20 | 17 | 2 | 224 | 153 | 132 | 34 | | | | 20.4 | 13.9 | 12.0 | 3.1 |

APPENDIX 2

SPACING B = 3 × 3 m

*Pinus caribaea hondurensis*
Coebiti Experiment – Surinam

Thinning Intensity: Z = LOW
Plots: I–6; II–8; III–7; IV–1

| | | | Remaining Stand | | | | | | | | Thinnings | | | | | | | | Volume Increment | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Volume | | | | | | | | Volume | | | | Total | | | | Current | | | Mean | | | |
| *t* | *H* | *s*% | *N* | *G* | *d* | *h* | *OB* | *IB* | *C1* | *C2* | *N* | *G* | *d* | *h* | *OB* | *IB* | *C1* | *C2* | *OB* | *IB* | *C1* | *C2* | *OB* | *IB* | *C2* | *OB* | *IB* | *C1* | *C2* |
| .8 | | | 1111 | | | | | | | | – | | | | | | | | | | | | | | | | | | |
| 2.3 | | | 1092 | | | 1.5 | | | | | 19 | | | | | | | | | | | | | | | | | | |
| 3.3 | 4.8 | 68.3 | 1072 | | | 3.2 | | | | | 20 | | | | | | | | | | | | | | | | | | |
| 5.3 | 9.6 | 34.2 | 1067 | 10.5 | 11.2 | 6.8 | 38 | 25 | 10 | | 5 | | | | | | | | 38 | 25 | 10 | | 28.5 | 19.9 | | 7.1 | 4.7 | 1.9 | |
| 8 | 13.7 | 24.1 | 1062 | 19.3 | 15.2 | 11.7 | 114 | 78 | 63 | 6 | 5 | | | | | | | | 114 | 78 | 63 | 6 | 28.7 | 20.0 | 12.3 | 14.3 | 9.8 | 7.9 | 0.8 |
| 11 | 17.5 | 18.8 | 1060 | 26.6 | 17.9 | 15.2 | 200 | 138 | 123 | 43 | 2 | | | | | | | | 200 | 138 | 123 | 43 | | | | 18.2 | 12.5 | 11.2 | 3.9 |
| Thinning Intensity: M = MEDIUM | | | | | | | | | | | | | | | | | | | | | | | | | | Plots: I–8; II–1; III–3; IV–5 | | | |
| .8 | | | 1111 | | | | | | | | – | | | | | | | | | | | | | | | | | | |
| 2.3 | | | 1091 | | | 1.6 | | | | | 20 | | | | | | | | | | | | | | | | | | |
| 3.3 | 4.7 | 69.8 | 1072 | | | 3.2 | | | | | 19 | | | | | | | | | | | | | | | | | | |
| 5.3 | 9.4 | 34.8 | 1071 | 10.9 | 11.4 | 6.8 | 39 | 26 | 11 | | 1 | | | | | | | | 39 | 26 | 11 | | 27.8 | 19.3 | | 7.3 | 4.8 | 2.0 | |
| 8 | 13.2 | 25.0 | 1063 | 19.7 | 15.4 | 11.5 | 113 | 77 | 62 | 5 | 8 | | | | | | | | 113 | 77 | 62 | 5 | 29.3 | 20.7 | 12.3 | 14.1 | 9.6 | 7.8 | 0.6 |
| 11 | 17.1 | 21.3 | 873 | 24.1 | 18.8 | 15.4 | 181 | 125 | 113 | 41 | 189 | 3.0 | 14.2 | 13.6 | 20 | 14 | 11 | 1 | 201 | 139 | 123 | 42 | | | | 18.3 | 12.7 | 11.2 | 3.8 |
| Thinning Intensity: S = HEAVY | | | | | | | | | | | | | | | | | | | | | | | | | | Plots: I–3; II–4; III–5; IV–9 | | | |
| .8 | | | 1111 | | | | | | | | – | | | | | | | | | | | | | | | | | | |
| 2.3 | | | 1077 | | | 1.5 | | | | | 34 | | | | | | | | | | | | | | | | | | |
| 3.3 | 4.7 | 70.4 | 1054 | | | 3.2 | | | | | 23 | | | | | | | | | | | | | | | | | | |
| 5.3 | 9.4 | 35.2 | 1054 | 10.6 | 11.3 | 6.8 | 38 | 25 | 10 | | – | | | | | | | | 38 | 25 | 10 | | 27.8 | 19.5 | | 7.1 | 4.7 | 1.9 | |
| 8 | 13.4 | 27.2 | 883 | 17.0 | 15.7 | 11.7 | 99 | 68 | 55 | 5 | 165 | 2.3 | 13.2 | 11.4 | 13 | 9 | 6 | – | 112 | 77 | 61 | 5 | 26.7 | 18.7 | 12.0 | 14.0 | 9.6 | 7.6 | 0.6 |
| 11 | 17.5 | 24.7 | 619 | 18.6 | 19.6 | 15.9 | 143 | 99 | 90 | 37 | 264 | 5.1 | 15.8 | 14.7 | 36 | 25 | 21 | 4 | 192 | 133 | 117 | 41 | | | | 17.5 | 12.1 | 10.6 | 3.7 |

APPENDIX 3

SPACING C = 3½ × 3½

*Pinus caribaea hondurensis*
Coebiti Experiment – Surinam
Plots: I–9; II–3; III–2; IV–4

Thinning Intensity: Z = LOW

| | | | Remaining Stand | | | | | | | | Thinnings | | | | | | | | Volume Increment | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Volume | | | | | | | | Volume | | | | Total | | | | Current | | | Mean | | | |
| *t* | *H* | *s*% | *N* | *G* | *d* | *h* | *OB* | *IB* | *C1* | *C2* | *N* | *G* | *d* | *h* | *OB* | *IB* | *C1* | *C2* | *OB* | *IB* | *C1* | *C2* | *OB* | *IB* | *C2* | *OB* | *IB* | *C1* | *C2* |
| .8 | | | 816 | | | | | | | | – | | | | | | | | | | | | | | | | | | |
| 2.3 | | | 799 | | | 1.5 | | | | | 17 | | | | | | | | | | | | | | | | | | |
| 3.3 | 4.6 | 83.4 | 782 | | | 3.3 | | | | | 17 | | | | | | | | | | | | | | | | | | |
| 5.3 | 9.1 | 42.3 | 779 | 8.2 | 11.6 | 6.8 | 29 | 19 | 8 | | 3 | | | | | | | | 29 | 19 | 8 | | 21.7 | 15.0 | | 5.4 | 3.6 | 1.5 | |
| 8 | 12.8 | 30.0 | 774 | 15.6 | 16.0 | 11.2 | 87 | 59 | 49 | 5 | 5 | | | | | | | | 87 | 59 | 49 | 5 | 23.0 | 16.3 | 11.0 | 10.9 | 7.4 | 6.1 | 0.6 |
| 11 | 16.7 | 23.1 | 772 | 21.7 | 18.9 | 14.7 | 156 | 108 | 97 | 38 | 2 | | | | | | | | 156 | 108 | 97 | 38 | | | | 14.2 | 9.8 | 8.8 | 3.4 |

Thinning Intensity: M = MEDIUM

Plots: I–1; II–5; III–6; IV–7

| *t* | *H* | *s*% | *N* | *G* | *d* | *h* | *OB* | *IB* | *C1* | *C2* | *N* | *G* | *d* | *h* | *OB* | *IB* | *C1* | *C2* | *OB* | *IB* | *C1* | *C2* | *OB* | *IB* | *C2* | *OB* | *IB* | *C1* | *C2* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .8 | | | 816 | | | | | | | | – | | | | | | | | | | | | | | | | | | |
| 2.3 | | | 795 | | | 1.6 | | | | | 21 | | | | | | | | | | | | | | | | | | |
| 3.3 | 4.4 | 86.8 | 790 | | | 3.1 | | | | | 5 | | | | | | | | | | | | | | | | | | |
| 5.3 | 9.1 | 42.0 | 790 | 8.6 | 11.8 | 6.7 | 30 | 20 | 9 | | – | | | | | | | | 30 | 20 | 9 | | 20.7 | 16.1 | | 5.6 | 3.7 | 1.7 | |
| 8 | 13.2 | 29.1 | 782 | 16.1 | 16.2 | 11.4 | 92 | 63 | 52 | 6 | 7 | | | | | | | | 92 | 63 | 52 | 6 | 24.7 | 17.0 | 12.3 | 11.5 | 7.9 | 6.5 | 0.8 |
| 11 | 17.0 | 22.8 | 768 | 22.2 | 19.2 | 15.1 | 164 | 113 | 102 | 43 | 15 | 0.2 | 14.5 | 13.8 | 2 | 1 | 1 | – | 166 | 114 | 103 | 43 | | | | 15.1 | 10.4 | 9.4 | 3.9 |

Thinning Intensity: S = HEAVY

Plots: I–5; II–7; III–9; IV–2

| *t* | *H* | *s*% | *N* | *G* | *d* | *h* | *OB* | *IB* | *C1* | *C2* | *N* | *G* | *d* | *h* | *OB* | *IB* | *C1* | *C2* | *OB* | *IB* | *C1* | *C2* | *OB* | *IB* | *C2* | *OB* | *IB* | *C1* | *C2* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .8 | | | 816 | | | | | | | | – | | | | | | | | | | | | | | | | | | |
| 2.3 | | | 796 | | | 1.5 | | | | | 20 | | | | | | | | | | | | | | | | | | |
| 3.3 | 4.7 | 81.3 | 788 | | | 3.3 | | | | | 8 | | | | | | | | | | | | | | | | | | |
| 5.3 | 9.2 | 41.6 | 788 | 8.3 | 11.6 | 6.8 | 30 | 20 | 9 | | – | | | | | | | | 30 | 20 | 9 | | 21.7 | 15.4 | | 5.6 | 3.7 | 1.6 | |
| 8 | 13.0 | 29.7 | 783 | 15.4 | 15.8 | 11.3 | 88 | 61 | 50 | 5 | 5 | | | | | | | | 88 | 61 | 50 | 5 | 23.0 | 15.6 | 10.7 | 11.0 | 7.6 | 6.2 | 0.6 |
| 11 | 17.1 | 24.6 | 653 | 19.2 | 19.3 | 15.0 | 141 | 97 | 88 | 35 | 130 | 2.3 | 15.1 | 13.8 | 16 | 11 | 9 | 2 | 157 | 108 | 97 | 37 | | | | 14.2 | 9.8 | 8.8 | 3.4 |

APPENDIX 4

Caribbean Pine – Coebiti Experiment – Surinam.

Total stem volume o.b. in $m^3$/ha in unthinned stands at age 8 (all values reduced by 70 $m^3$).

| I | | | | II | | | | III | | | | IV | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 91.0 | 59.4 | 34.6 | 185.0 | 18.6 | 45.4 | 77.5 | 141.5 | 42.1 | 74.7 | 8.9 | 125.7 | 9.9 | 36.7 | 22.7 | 69.3 |
| AS | BM | CZ | | CS | BZ | AM | | BZ | AM | CS | | CM | AZ | BS | |
| 53.7 | 36.9 | 89.1 | 179.7 | 43.8 | 18.3 | 45.0 | 107.1 | 22.7 | 41.7 | 63.7 | 128.1 | 49.9 | 29.1 | 0.6 | 79.6 |
| BZ | CS | AM | | AZ | CM | BS | | CM | BS | AZ | | AS | BM | CZ | |
| 37.8 | 95.3 | 57.6 | 190.7 | 43.0 | 52.7 | 11.0 | 106.7 | 104.9 | 21.9 | 41.0 | 167.8 | 34.9 | 6.0 | 68.3 | 109.2 |
| CM | AZ | BS | | BM | AS | CZ | | AS | CZ | BM | | BZ | CS | AM | |
| 182.5 | 191.6 | 181.3 | 555.4 | 105.4 | 116.4 | 133.5 | 355.3 | 169.7 | 138.3 | 113.6 | 421.6 | 94.7 | 71.8 | 91.6 | 258.1 |
| ΣA = 275.4 | | $\bar{a}$ = 91.8 | | | 174.0 | | 58.0 | | 243.3 | | 81.1 | | 154.9 | | 51.6 |
| ΣB = 170.7 | | $\bar{b}$ = 56.9 | | | 133.4 | | 44.5 | | 124.8 | | 41.6 | | 86.7 | | 28.9 |
| ΣC = 109.3 | | $\bar{c}$ = 36.4 | | | 47.9 | | 16.0 | | 53.5 | | 17.8 | | 16.5 | | 5.5 |
| ΣΣx = 555.4 | | $\bar{x}$ = 61.7 | | | 355.3 | | 39.5 | | 421.6 | | 46.8 | | 258.1 | | 28.7 |

| | | | |
|---|---|---|---|
| ΣΣΣx = 1590.4 | ΣΣA = 847.6 | ΣΣB = 515.6 | ΣΣC = 227.2 |
| $\bar{\bar{x}}$ = 44.2 | $\bar{\bar{a}}$ = 70.6 + 70 ≐ 141 | $\bar{\bar{b}}$ = 43.0 + 70 ≐ 113 | $\bar{\bar{c}}$ = 18.9 + 70 ≐ 89 |

| | | | | | |
|---|---|---|---|---|---|
| ΣAZ = 239.5 | $\overline{az}$ = 59.9 | ΣAM = 309.6 | $\overline{am}$ = 77.4 | ΣAS = 298.5 | $\overline{as}$ = 74.6 |
| ΣBZ = 176.1 | $\overline{bz}$ = 44.0 | ΣBM = 172.5 | $\overline{bm}$ = 43.1 | ΣBS = 167.0 | $\overline{bs}$ = 41.8 |
| ΣCZ = 68.1 | $\overline{cz}$ = 17.0 | ΣCM = 88.7 | $\overline{cm}$ = 22.2 | ΣCS = 70.4 | $\overline{cs}$ = 17.6 |
| ΣΣZ = 483.7 | $\bar{z}$ = 40.3 | ΣΣM = 570.8 | $\bar{m}$ = 47.6 | ΣΣS = 535.9 | $\bar{s}$ = 44.7 |

APPENDIX 5

ANOVA table for a four times Replicated (Graeco-)Latin Square and Randomized Block Design.
Data: Total stem volume o.b. in $m^3$/ha (minus 70) of unthinned plots at age 8, Caribbean Pine, Coebiti Experiment, Surinam.

| SOURCE | SPACE | DIM | SS | $s_i^2$ = SS/DIM | $s_i^2/s_{81}^2$ | $s_i^2/s_{82}^2$ | $s_i^2/s_{83}^2$ | $s_i^2/s_{84}^2$ |
|---|---|---|---|---|---|---|---|---|
| BLOCKS | | | | | | | | |
| I–III | $f_1'$ | 1 | 994.58 | $s_{11}^2$ = do. | 10.41* | 9.73* | 11.74* | 10.46* |
| II–IV | $f_2'$ | 1 | 524.88 | $s_{12}^2$ = do. | 5.50* | 5.13* | 6.19* | 5.25* |
| (I+III) – (II+IV) | $f_3'$ | 1 | 3672.36 | $s_{13}^2$ = do. | 38.45* | 35.92* | 43.34* | 38.61* |
| Total Blocks | F* | 3 | 5191.82 | $s_1^2$ = 1730.61 | 18.12* | 16.93* | 20.42* | 18.19* |
| SPACINGS | | | | | | | | |
| Lin. Eff. A – C | $p_1'$ | 1 | 16037.34 | $s_{21}^2$ = do. | 167.91* | 156.88* | 189.25* | 168.60* |
| Quad. Eff. A+C – 2B | $p_2'$ | 1 | 26.40 | $s_{22}^2$ = do. | 0.28 | 0.26 | 0.31 | 0.28 |
| Total Spacings | P* | 2 | 16063.74 | $s_2^2$ = 8031.87 | 84.09* | 78.57* | 94.78* | 84.44 |
| THINNING DEGREES | | | | | | | | |
| Lin. Eff. Z – S | $d_1'$ | 1 | 113.54 | $s_{31}^2$ = do. | | | 1.34 | 1.19 |
| Quad. Eff. Z+S – 2M | $d_2'$ | 1 | 206.72 | $s_{32}^2$ = do. | | | 2.44 | 2.17 |
| Total Thinnings | D* | 2 | 320.26 | $s_3^2$ = 160.13 | | | 1.89 | 1.68 |
| ROWS (Total) | W* | 8 | 944.96 | $s_4^2$ = 118.12 | 1.24 | | 1.39 | |
| COLUMNS (Total) | Y* | 8 | 784.74 | $s_5^2$ = 98.09 | 1.03 | | 1.16 | |
| Total Rows + Col. | W*+Y* | 16 | 1729.70 | $s_{45}^2$ = 108.11 | 1.13 | | 1.28 | |
| INTERACTION P × D | | | | | | | | |
| Lin. Effect | $u_1'$ | 1 | 200.93 | $s_{61}^2$ = do. | | | 2.37 | 2.11 |
| Quad. Effect | $u_{234}'$ | 3 | 262.87 | $s_{62}^2$ = 87.62 | | | 1.03 | 0.92 |
| Total Interaction | PD* | 4 | 463.80 | $s_6^2$ = 115.95 | | | 1.37 | 1.22 |
| ROWS + COLUMNS (Partial Total) | WY* | 12 | 1265.90 | $s_7^2$ = 105.49 | | | 1.24 | |
| RESIDUALS | | | | | | | | |
| LSQ | T1 | 14 | 1337.18 | $s_{81}^2$ = 95.51 | | | | |
| RRB – I | T2 | 30 | 3066.88 | $s_{82}^2$ = 102.23 | | | | |
| GLSQ | T3 | 12 | 1016.92 | $s_{83}^2$ = 84.74 | | | | |
| RRB–II | T4 | 24 | 2282.82 | $s_{84}^2$ = 95.12 | | | | |
| TOTAL | R–N | 35 | 24322.44 | $s_9^2$ = 694.93 | | | | |

## APPENDIX 6

### Computational Formulas to ANOVA Table of Appendix 5

$$X^2 = \Sigma_m \Sigma_i \Sigma_j \, x^2_{ijm}$$
$$X^2_N = (\Sigma_i \Sigma_j \Sigma_m \, x_{ijm})^2/36$$
$$X^2_F = \Sigma_m (\Sigma_i \Sigma_j \, x_{ijm})^2/9$$
$$X^2_W = \Sigma_m \Sigma_i (\Sigma_j \, x_{ijm})^2/3$$
$$X^2_Y = \Sigma_m \Sigma_j (\Sigma_i \, x_{ijm})^2/3$$
$$X^2_P = \Sigma_p (\Sigma_m \Sigma_i \, x_{ipm})^2/12$$
$$X^2_D = \Sigma_d (\Sigma_m \Sigma_i \, x_{idm})^2/12$$
$$X^2_{PD} = \Sigma_p \Sigma_d (\Sigma_m \, x_{pdm})^2/4$$

$$X^2_{R-N} = X^2 - X^2_N$$
$$X^2_{F*} = X^2_F - X^2_N$$
$$X^2_{W*} = X^2_W - X^2{}_F$$
$$X^2_{Y*} = X^2{}_Y - X^2_F$$
$$X^2_{P*} = X^2_P - X^2_N$$
$$X^2_{D*} = X^2_D - X^2_N$$
$$X^2_{PD*} = X^2_{PD} - (X^2_N + X^2_{P*} + X^2_{D*})$$
$$X^2_{WY*} = X^2_{W*} + X^2_{Y*} - X^2_{PD*}$$

BLOCKS F*

$$X^2_{f'1} = (\Sigma\Sigma \, x_I - \Sigma\Sigma \, x_{III})^2/18 \qquad X^2_{f'2} = (\Sigma\Sigma \, x_{II} - \Sigma\Sigma \, x_{IV})^2/18$$
$$X^2_{f'3} = (\Sigma\Sigma \, x_I + \Sigma\Sigma \, x_{III} - \Sigma\Sigma \, x_{II} - \Sigma\Sigma \, x_{IV})^2/36$$

SPACINGS P*

$$X^2_{p'1} = (\Sigma\Sigma \, A - \Sigma\Sigma \, C)^2/24$$
$$X^2_{p'2} = (\Sigma\Sigma \, A + \Sigma\Sigma \, C - 2\Sigma\Sigma \, B)^2/72$$

THINNING INTENSITIES D*

$$X^2_{d'1} = (\Sigma\Sigma \, Z - \Sigma\Sigma \, S)^2/24$$
$$X^2_{d'2} = (\Sigma\Sigma \, Z + \Sigma\Sigma \, S - 2\Sigma\Sigma \, M)^2/72$$

INTERACTION PD*

$$X^2_{u'1} = (\Sigma \, AZ - \Sigma \, AS + \Sigma \, CS - \Sigma \, CZ)^2/16 \qquad X^2_{u'234} = X^2_{PD*} - X^2_{u'1}$$

RESIDUALS

LSQ: $X^2_{T1} = (X^2 - X^2_N) - (X^2_{F*} + X^2_{W*} + X^2_{Y*} + X^2_{P*})$ GLSQ: $X^2_{T3} = X^2_{T1} - X^2_{D*}$

RRB–I: $X^2_{T2} = X^2_{T1} + X^2_{W*} + X^2_{Y*}$ RRB–II: $X^2_{T4} = X^2_{T3} + X^2_{WY*}$

*Pinus caribaea hondurensis*
Coebiti Experiment – Surinam

Average Composition at Age 8 of Unthinned Stands with Different Initial Spacing
Total height is mean of 36 plots, other values are means of 12 plots

| *DBHOB* in cm | Spacing | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total height in m | | 0.5 | 3.5 | 6.0 | 7.5 | 9.0 | 10.0 | 11.0 | 12.0 | 12.5 | 13.0 | 13.5 | 14.0 | 14.5 | 15.0 | |
| Number of stems per hectar | $2\frac{1}{2}$ | 3 | 14 | 36 | 78 | 169 | 301 | 358 | 303 | 171 | 65 | 21 | 4 | 2 | – | 1525 |
| | 3 | 2 | 5 | 12 | 34 | 79 | 160 | 240 | 234 | 174 | 77 | 33 | 8 | – | – | 1058 |
| | $3\frac{1}{2}$ | – | 4 | 5 | 16 | 42 | 105 | 157 | 180 | 141 | 80 | 35 | 11 | 3 | 1 | 780 |
| % of stems in and above *DBHOB*-class | $2\frac{1}{2}$ | 100 | 99.8 | 98.9 | 96.5 | 91.4 | 80.3 | 60.6 | 37.1 | 17.3 | 6.0 | 1.8 | 0.4 | 0.1 | – | |
| | 3 | 100 | 99.8 | 99.3 | 98.2 | 95.0 | 87.5 | 72.4 | 49.7 | 27.6 | 11.2 | 3.9 | 0.8 | – | – | |
| | $3\frac{1}{2}$ | – | 100 | 99.5 | 98.9 | 96.8 | 91.4 | 78.0 | 57.8 | 34.8 | 16.7 | 6.4 | 1.9 | 0.5 | 0.1 | |
| Total stem volume i.b. in $m^3$ per hectar | $2\frac{1}{2}$ | – | – | 0.1 | 1.2 | 4.4 | 12.2 | 21.0 | 24.5 | 18.4 | 9.0 | 3.7 | 0.9 | 0.5 | – | 96 |
| | 3 | – | – | 0.1 | 0.5 | 1.9 | 6.2 | 13.6 | 18.6 | 18.5 | 10.5 | 5.7 | 1.7 | – | – | 77 |
| | $3\frac{1}{2}$ | – | – | – | 0.2 | 1.0 | 3.9 | 8.5 | 13.6 | 14.3 | 10.4 | 5.8 | 2.2 | 0.7 | 0.3 | 61 |
| % of total stand i.b. volume in and above *DBHOB*-class | $2\frac{1}{2}$ | 100 | 100 | 100 | 99.9 | 99.6 | 94.1 | 81.3 | 59.4 | 33.9 | 14.8 | 5.3 | 1.5 | 0.5 | – | |
| | 3 | 100 | 100 | 100 | 99.9 | 99.2 | 96.8 | 88.8 | 71.2 | 47.1 | 23.2 | 9.6 | 2.2 | – | – | |
| | $3\frac{1}{2}$ | – | 100 | 100 | 100 | 99.7 | 98.0 | 91.6 | 77.7 | 55.3 | 31.9 | 14.8 | 5.2 | 1.6 | 0.5 | |

APPENDIX 8

ANOVA table: Thinning Effects Within Identical Initial Spacings. Pseudo-thinning effects after allocation of thinning intensities at stand age 8. Data: Total stem volume o.b. (minus 70) in $m^3$/ha in unthinned stands.

| SOURCE | SPACE | DIM | SS | $s_i^2 = SS/DIM$ | $s_i^2/s_{84}^2$ | $f_i; f_{84}$ | $F_{95}(f_i; f_{84})$ |
|---|---|---|---|---|---|---|---|
| AS – AZ | a′ | 1 | 435.13 | $s_{11}^2 =$ do. | 4.75* | 1; 24 | 4.26 |
| AS + AZ – 2AM | a″ | 1 | 274.74 | $s_{12}^2 =$ do. | 2.89 | | |
| Thinn. Effect within A | A* | 2 | 709.86 | $s_1^2 = 354.93$ | 3.73* | 2; 24 | 3.40 |
| Level of A | $p_a$ | 1 | 59868.81 | | | | |
| Total A | A | 3 | 60578.67 | | | | |
| BS – BZ | b′ | 1 | 10.35 | $s_{21}^2 =$ do. | 0.11 | | |
| BS + BZ – 2BM | b″ | 1 | 0.16 | $s_{22}^2 =$ do. | 0.00 | | |
| Thinn. Effect within B | B* | 2 | 10.51 | $s_2^2 = 5.26$ | 0.06 | | |
| Level of B | $p_b$ | 1 | 22153.61 | | | | |
| Total B | B | 3 | 22164.12 | | | | |
| CS – CZ | c′ | 1 | 0.66 | $s_{31}^2 =$ do. | 0.01 | | |
| CS + CZ – 2CM | c″ | 1 | 63.03 | $s_{32}^2 =$ do. | 0.66 | | |
| Thinn. Effect within C | C* | 2 | 63.72 | $s_3^2 = 31.86$ | 0.33 | | |
| Level of C | $p_c$ | 1 | 4301.65 | | | | |
| Total C | C | 3 | 4365.37 | | | | |
| RESIDUAL RRB–II | T4 | 24 | 2282.82 | $s_{84}^2 = 95.12$ | | | |

Computational Formulas

$X_A^2 = (1/4)((\Sigma AZ)^2 + (\Sigma AM)^2 + (\Sigma AS)^2)$

$X_{pa}^2 = (\Sigma\Sigma A)^2/12 \quad X_{A*}^2 = X_A^2 - X_{pa}^2$

$X_{a'}^2 = (\Sigma AS - \Sigma AZ)^2/8 \quad X_{a''}^2 = X_{A*}^2 - X_{a'}^2$

Similar formulas hold for spacings B and C

DUNCAN's Multiple Range Test

$s^2 = s_{84}^2/4 = 23.78$ d.o.f. = 24

| AZ | AS | AM | SSR5% | LSR = s.SSR |
|---|---|---|---|---|
| 59.9 | 74.6 | 77.4 | 3.07 | 15.0 |
| 59.9 | 74.6 | | 2.92 | 14.2 |

Appendix 9

Caribbean Pine – Coebiti Experiment – Surinam

Current Annual Increment of Total Stem Volume o.b. in $m^3$/ha at age 11.

| I | | | | II | | | | III | | | | IV | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24.4 | 27.9 | 24.3 | 76.6 | 19.9 | 27.5 | 31.9 | 79.3 | 28.2 | 27.0 | 20.9 | 76.1 | 22.6 | 31.8 | 26.7 | 81.1 |
| AS | BM | CZ | | CS | BZ | AM | | BZ | AM | CS | | CM | AZ | BS | |
| 28.9 | 27.3 | 36.7 | 92.9 | 30.1 | 25.1 | 28.3 | 83.5 | 24.5 | 25.4 | 30.8 | 80.7 | 27.1 | 28.2 | 22.7 | 78.0 |
| BZ | CS | AM | | AZ | CM | BS | | CM | BS | AZ | | AS | BM | CZ | |
| 25.7 | 37.6 | 27.5 | 90.8 | 33.6 | 26.7 | 21.2 | 81.5 | 26.8 | 24.5 | 28.4 | 79.7 | 29.9 | 24.1 | 34.9 | 88.9 |
| CM | AZ | BS | | BM | AS | CZ | | AS | CZ | BM | | BZ | CS | AM | |
| 79.0 | 92.8 | 88.5 | 260.3 | 83.6 | 79.3 | 81.4 | 244.3 | 79.5 | 76.9 | 80.1 | 236.5 | 79.6 | 84.1 | 84.3 | 248.0 |
| $\Sigma A = 98.7$ | | $\bar{a} = 32.9$ | | | 88.7 | | 29.6 | | 84.6 | | 28.2 | | 93.8 | | 31.3 |
| $\Sigma B = 84.3$ | | $\bar{b} = 28.1$ | | | 89.4 | | 29.8 | | 82.0 | | 27.3 | | 84.8 | | 28.3 |
| $\Sigma C = 77.3$ | | $\bar{c} = 25.8$ | | | 66.2 | | 22.1 | | 69.9 | | 23.3 | | 69.4 | | 23.1 |
| $\Sigma\Sigma\ x = 260.3$ | | $\bar{x} = 28.9$ | | | 244.3 | | 27.1 | | 236.5 | | 26.3 | | 248.0 | | 27.6 |
| $\Sigma\Sigma\Sigma\ x = 989.1$ | | | | $\Sigma\Sigma\ A = 365.8$ | | | | $\Sigma\Sigma\ B = 340.5$ | | | | $\Sigma\Sigma\ C = 282.8$ | | | |
| $\bar{\bar{x}} = 27.5$ | | | | $\bar{\bar{a}} = 30.4$ | | | | $\bar{\bar{b}} = 28.4$ | | | | $\bar{\bar{c}} = 23.6$ | | | |
| $\Sigma AZ = 130.3$ | | | | $\overline{az} = 32.6$ | | $\Sigma AM = 130.5$ | | | $\overline{am} = 32.6$ | | | $\Sigma AS = 105.0$ | | $\overline{as} = 26.2$ | |
| $\Sigma BZ = 114.5$ | | | | $\overline{bz} = 28.6$ | | $\Sigma BM = 118.1$ | | | $\overline{bm} = 29.5$ | | | $\Sigma BS = 107.9$ | | $\overline{bs} = 27.0$ | |
| $\Sigma CZ = 92.7$ | | | | $\overline{cz} = 23.1$ | | $\Sigma CM = 97.9$ | | | $\overline{cm} = 24.5$ | | | $\Sigma CS = 92.2$ | | $\overline{cs} = 23.0$ | |
| $\Sigma\Sigma Z = 337.5$ | | | | $\bar{z} = 28.1$ | | $\Sigma\Sigma M = 346.5$ | | | $\bar{m} = 28.9$ | | | $\Sigma\Sigma S = 305.1$ | | $\bar{s} = 25.4$ | |

APPENDIX 10

ANOVA table for a 4 times Replicated Graeco-Latin in Square and Randomized Block Design II.

Data: C.A.I. of Total Stem Volume o.b. between ages 8 and 11. Caribbean Pine, Coebiti Experiment, Surinam.

| SOURCE | SPACE | DIM | SS | $s_i^2 = SS/DIM$ | $s_i^2/s_{83}^2$ | $s_i^2/s_{84}^2$ |
|---|---|---|---|---|---|---|
| BLOCKS | | | | | | |
| I–III | $f_1'$ | 1 | 31.47 | $s_{11}^2 =$ do. | 6.21* | 5.50* |
| II–IV | $f_2'$ | 1 | 0.76 | $s_{12}^2 =$ do. | 0.15 | 0.13 |
| (I+III) – (II+IV) | $f_3'$ | 1 | 0.56 | $s_{13}^2 =$ do. | 0.11 | 0.10 |
| Total Blocks | F* | 3 | 32.79 | $s_1^2 = 10.93$ | 2.16 | 1.91 |
| SPACINGS | | | | | | |
| Lin. Eff. A – C | $p_1'$ | 1 | 287.04 | $s_{21}^2 =$ do. | 56.62* | 50.18* |
| Quad. Eff. A + C – 2B | $p_2'$ | 1 | 14.58 | $s_{22}^2 =$ do. | 2.88 | 2.55 |
| Total Spacings | P* | 2 | 301.62 | $s_2^2 = 150.81$ | 29.75* | 26.37* |
| THINNING DEGREES | | | | | | |
| Lin. Eff. Z – S | $d_1'$ | 1 | 43.74 | $s_{31}^2 =$ do. | 8.63* | 7.65* |
| Quad. Eff. Z + S – 2M | $d_2'$ | 1 | 35.28 | $s_{32}^2 =$ do. | 6.96* | 6.17* |
| Total Thinnings | D* | 2 | 79.02 | $s_3^2 = 39.51$ | 7.79* | 6.91* |
| Rows (Total) | W* | 8 | 80.29 | $s_4^2 = 10.04$ | 1.98 | |
| COLUMNS (Total) | Y* | 8 | 42.97 | $s_5^2 = 5.37$ | 1.06 | |
| Total Rows + Col. | W* + Y* | 16 | 123.26 | $s_{45}^2 = 7.70$ | 1.52 | |
| INTERACTION P × D | | | | | | |
| Lin. Effect | $u_1'$ | 1 | 38.44 | $s_{61}^2 =$ do. | 7.58* | 6.72* |
| Quad. Effect | $u_{234}'$ | 3 | 8.44 | $s_{62}^2 = 2.81$ | 0.55 | 0.49 |
| Total Interaction | PD* | 4 | 46.88 | $s_6^2 = 11.72$ | 2.31 | 2.05 |
| ROWS + COLUMNS (Partial Total) | WY* | 12 | 76.38 | $s_7^2 = 6.37$ | 1.26 | |
| RESIDUALS | | | | | | |
| GLSQ | T3 | 12 | 60.82 | $s_{83}^2 = 5.07$ | | |
| RRB-II | T4 | 24 | 137.20 | $s_{84}^2 = 5.72$ | | |
| TOTAL | R–N | 35 | 597.51 | $s_9^2 = 17.07$ | | |

DUNCAN's Multiple Range Test . $s^2 = s_{83}^2/12 = 0.4225$; d.o.f. = 12.

| C | B | A | S | Z | M | SSR5% | LSR = s.SSR |
|---|---|---|---|---|---|---|---|
| 23.6 | 28.4 | 30.4 | 25.4 | 28.1 | 28.9 | 3.23 | 2.09 |
| 23.6 | 28.4 | | 25.4 | 28.1 | | 3.08 | 2.00 |

APPENDIX 11

ANOVA table: Spacing Effects Within Identical Thinning Intensities.

Data: C.A.I. in Total Stem Volume o.b. in $m^3$/ha at age 11. Caribbean Pine, Coebiti Experiment, Surinam.

| SOURCE | SPACE | DIM | SS | $s_i^2 = SS/DIM$ | $s_i^2/s_{84}^2$ | $f_i; f_{84}$ | $F_{95}(f_i; f_{84})$ |
|---|---|---|---|---|---|---|---|
| AZ – CZ | z′ | 1 | 176.72 | $s_{11}^2$ = do. | 30.90* | 1; 24 | 4.26 |
| AZ + CZ – 2BZ | z″ | 1 | 1.50 | $s_{12}^2$ = do. | 0.26 | | |
| Spacing Effect within Z | Z* | 2 | 178.22 | $s_1^2$ = 89.11 | 15.58* | 2; 24 | 3.40 |
| Level of Z | $d_z$ | 1 | 9492.19 | | | | |
| Total Z | Z | 3 | 9670.41 | | | | |
| AM – CM | m′ | 1 | 132.85 | $s_{21}^2$ = do. | 23.22* | | |
| AM + CM – 2BM | m″ | 1 | 2.53 | $s_{22}^2$ do. | 0.44 | | |
| Spacing Effect within M | M* | 2 | 135.38 | $s_2^2$ = 67.69 | 11.83* | | |
| Level of M | $d_m$ | 1 | 10005.19 | | | | |
| Total M | M | 3 | 10140.57 | | | | |
| AS – CS | s′ | 1 | 20.48 | $s_{31}^2$ = do. | 3.58 | | |
| AS + CS – 2BS | s″ | 1 | 14.41 | $s_{32}^2$ = do. | 2.52 | | |
| Spacing Effect within S | S* | 2 | 34.89 | $s_3^2$ = 17.45 | 3.05 | | |
| Level of S | $d_s$ | 1 | 7757.17 | | | | |
| Total S | S | 3 | 7792.06 | | | | |
| RESIDUAL RRB–II | T4 | 24 | 60.82 | $s_{84}^2$ = 5.72 | | | |

Computational Formulas

$X_Z^2 = (1/4)((\Sigma AZ)^2 + (\Sigma BZ)^2 + (\Sigma CZ)^2)$

$X_{dz}^2 = (\Sigma\Sigma Z)^2/12 \qquad X_{Z*}^2 = X_Z^2 - X_{dz}^2$

$X_{z'}^2 = (\Sigma AZ - \Sigma CZ)^2/8 \quad X_{z''}^2 = X_{Z*}^2 - X_{z'}^2$

Similar formulas hold for M and S degrees.

DUNCAN's Multiple Range Test. $s^2 = s_{84}^2/4 = 1.43$; d.o.f. = 24

| CZ | BZ | AZ | CM | BM | AM | CS | AS | BS | SSR5% | LSR = s.SSR |
|---|---|---|---|---|---|---|---|---|---|---|
| 23.1 | 28.6 | 32.6 | 24.5 | 29.5 | 32.6 | 23.0 | 26.2 | 27.0 | 3.07 | 3.7 |
| 23.1 | 28.6 | | 24.5 | 29.5 | | 23.0 | 26.2 | | 2.92 | 3.5 |

APPENDIX 12
ANOVA table: Thinning Effects Within Identical Initial Spacings.
Data: C.A.I. in Total Stem Volume o.b. in $m^3$/ha at age 11. Caribbean Pine, Coebiti Experiment, Surinam.

| SOURCE | SPACE | DIM | SS | $s_i^2 = SS/DIM$ | $s_i^2/s_{84}^2$ | $f_i; f_{84}$ | $F_{95}(f_i; f_{84})$ |
|---|---|---|---|---|---|---|---|
| AS − AZ | a′ | 1 | 80.01 | $s_{11}^2$ = do. | 13.99* | 1; 24 | 4.26 |
| AS + AZ − 2AM | a″ | 1 | 27.53 | $s_{12}^2$ = do. | 4.81* | | |
| Thinn. Eff. within A | A* | 2 | 107.54 | $s_1^2$ = 53.77 | 9.40* | 2; 24 | 3.40 |
| Level of A | $p_a$ | 1 | 11150.80 | | | | |
| Total A | A | 3 | 11258.34 | | | | |
| BS − BZ | b′ | 1 | 5.45 | $s_{21}^2$ = do. | 0.95 | | |
| BS + BZ − 2BM | b″ | 1 | 7.93 | $s_{22}^2$ = do. | 1.39 | | |
| Thinn. Eff. within B | B* | 2 | 13.38 | $s_2^2$ = 6.69 | 1.17 | | |
| Level of B | $p_b$ | 1 | 9661.69 | | | | |
| Total B | B | 3 | 9675.07 | | | | |
| CS − CZ | c′ | 1 | 0.03 | $s_{31}^2$ = do. | 0.00 | | |
| CS + CZ − 2CM | c″ | 1 | 4.96 | $s_{32}^2$ = do. | 0.87 | | |
| Thinn. Eff. within C | C* | 2 | 4.99 | $s_3^2$ = 2.50 | 0.44 | | |
| Level of C | $p_c$ | 1 | 6664.65 | | | | |
| Total C | C | 3 | 6669.64 | | | | |
| RESIDUAL RRB–II | T4 | 24 | 137.20 | $s_{84}^2$ = 5.72 | | | |

DUNCAN's Multiple Range Test. $s^2 = s_{84}^2/4 = 1.43$; d.o.f. = 24

| AS | AZ | AM | BS | BZ | BM | CS | CZ | CM | SSR5% | LSR = s.SSR |
|---|---|---|---|---|---|---|---|---|---|---|
| 26.2 | 32.6 | 32.6 | 27.0 | 28.6 | 29.5 | 23.0 | 23.1 | 24.5 | 3.07 | 3.7 |
| 26.2 | 32.6 | | 27.0 | 28.6 | | 23.0 | 23.1 | | 2.92 | 3.5 |

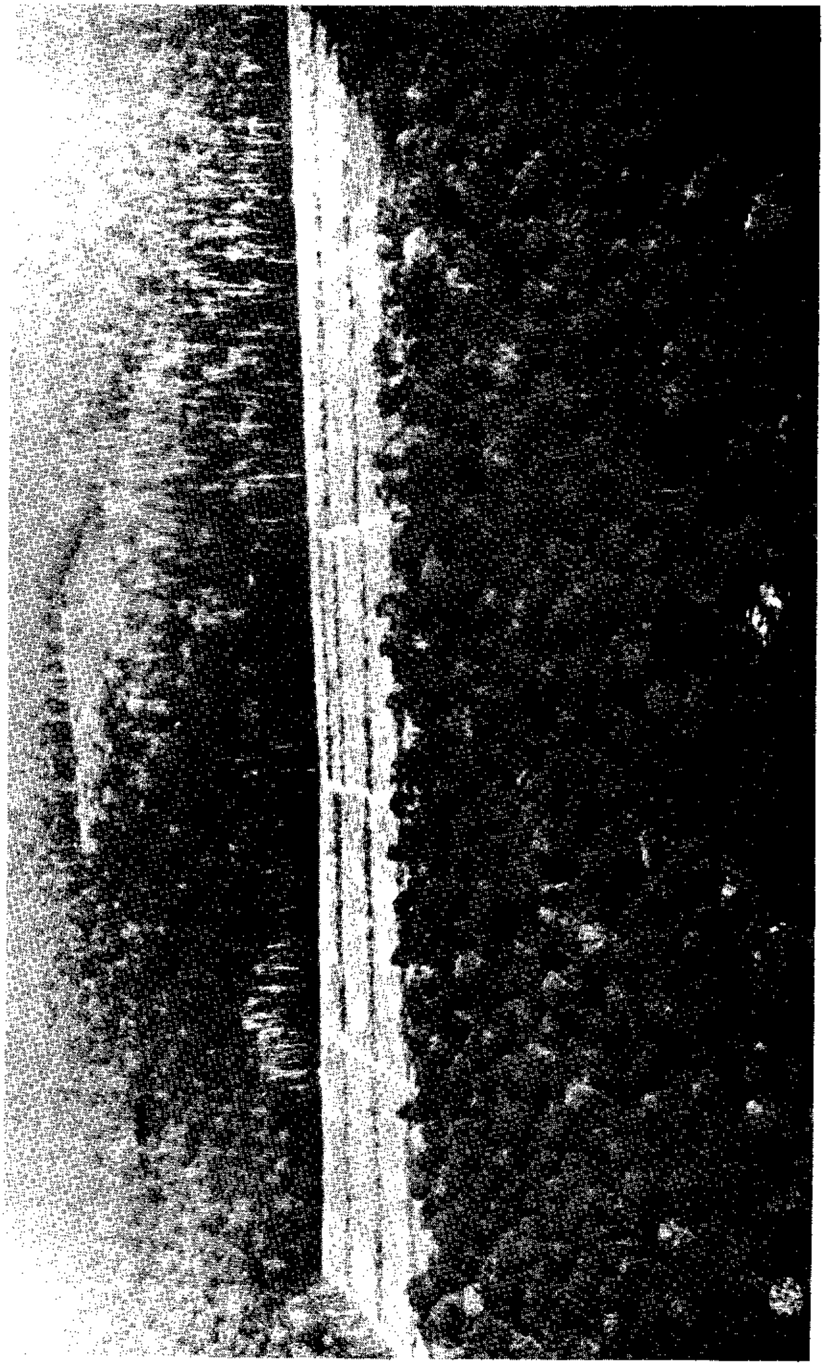

PHOTO 1. Aerial view of experimental area in 1965 (Compare fig. 1).

PHOTO 2. Experimental area just before planting in 1965.

PHOTO 3. Spacing A = $2^1/_2$ at age 2 in block IV.

PHOTO 4. Two-year-old foxtails in windrow in block III.

PHOTO 5. Collecting stem data in Blakawatra district, 1965.

PHOTO 6. View of road between blocks III and IV, at age 8.

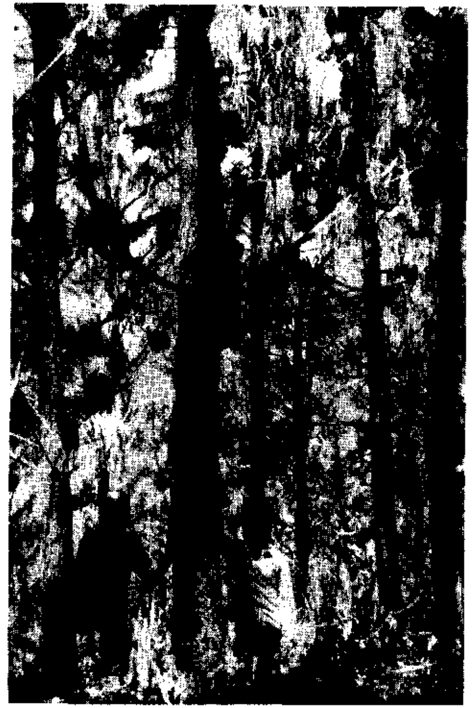

PHOTO 7. Largest pine on 13 hectar. Age = 8 years, DBHOB = 33 cm, h = 19.2 m. Location: Block III in windrow between plots 2 and 3.

PHOTO 8. Spacing A = $2^1/_2$ at age 8, before thinning.

PHOTO 9. Spacing B = 3 at age 8, before thinning.

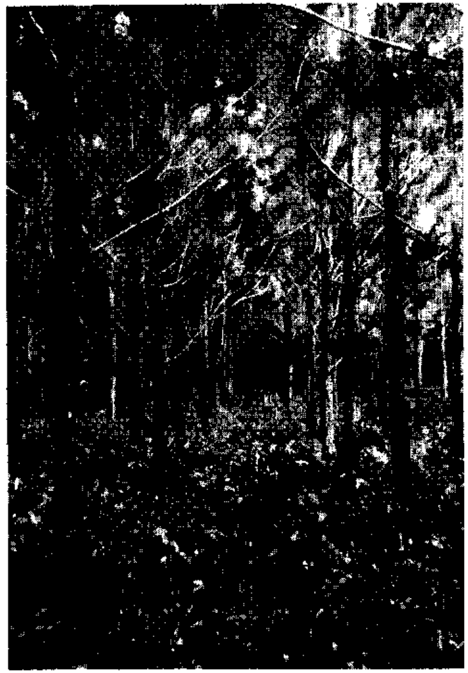

PHOTO 10. Spacing C = $3^1/_2$ at age 8 , before thinning.