SPACING AND SHADE TRIALS WITH CACAO

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INTRODUCTION

TWO of the most important factors affecting yield of cacao plantations are the spacing at which the trees are planted, and the overhead shade provided. Earlier recommendations made by the Department of Agriculture, Stock and Fisheries, such as those given by Henderson (1954), were based on observation and practical experience in cacao growing, but at the time there were few experimental data from which conclusions could be drawn. Since then, there has been considerable research, both in this country and overseas, and although results are still far from complete it has been felt desirable to review the findings for the benefit of local growers.

It must be recognized at the outset that there is no ideal spacing or shade system which can be universally applied wherever cacao is grown. There are so many different factors involved in determining what is best that the optimum must vary under different planting conditions. Because there is some interaction between shade and spacing (that is to say, the level of shade required may depend on the spacing of the trees) both are included together in this paper, although for the most part they will be discussed separately.

A. SPACING.

The optimum spacing will depend in the first place on the vigour of the trees. Thus, spacing for seedlings must be considered separately from spacing for fan cuttings, because of their different habit of growth. Different varieties of seedling cacao and different clones could also be expected to differ in their spacing requirements. Vigour of the trees will be affected by climate and soil type, so that spacing recommendations may need to be varied in different districts, and even within the same district where soil types differ. Nor is it evident from first principles whether spacing should be closer on poorer soils, because of reduced vigour, or wider to reduce competition for nutrients. Fertilizing will also affect tree vigour. The overhead shade also influences the vigour and habit of growth of the trees, while conversely the spacing affects the amount of self-shading in the cacao.

Secondly, there are economic considerations other than the production of maximum yield. Spacing influences the level of ground shade, which largely determines the amount of weed growth. Thus it has an important bearing on maintenance costs. Consideration also must be given to ease of access through the cacao stand, affecting costs of harvesting and pest and disease control operations.

Thirdly, consideration must be given to changes in the stand as the trees age. It might be expected that, as the trees grow, inter-tree competition would increase and a too dense stand would be at a disadvantage. On the other hand, there is always a proportion of trees which die out as the stand ages, and these losses might be less serious in an originally dense stand.

Overseas Experiments.

The spacings generally used vary greatly from country to country. Urquhart (1961) quotes the following as being favoured: Trinidad, 12 ft. x 12 ft.; Ceylon, New Guinea and Samoa, 15 ft. x 15 ft.; Congo, earlier 4m. x 4m., more recently 3m. x 3m.; West African peasant farmers, 3½ ft. x 4 ft. and more recently 5ft. x 5ft. The wide variation may be due in part to differences in varieties and types of planting material. Experiments in each country have tended to start from the standard for the locality, and as a result the ranges of spacings used do not always overlap.

Gordon (1954) studied 269 quarter-acre plots of farmer-planted cacao of varying density at Tafo, Ghana. He concluded that a density of 300 to 400 trees per acre might be a natural optimum for local conditions. This density was achieved by random close planting, allowing the trees to thin themselves as they matured. Between the range of 270 and 670 trees per acre there was no great variation in yield.

A trial was planted in 1947 at the West African Cacao Research Institute at Tafo (Anon., 1949) with unselected Amelonado seedlings at eight spacings ranging from 15ft. x 15ft. to 4ft. x 4ft. (200 to 2,800 trees/acre). In the first two years' bearing of these trees yields were highest at the widest spacings, but so also was

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weed growth and capsid damage (Benstead and Wickens, 1955). Published results up to 1959 (Smith, 1960) do not show any exact correlation between spacing and yield, although numbers of pods per tree have been consistently higher at wider spacings. Highest yield per acre (considering totals up to 1959) has been obtained at 7½ft. x 7½ft. (774 trees/acre), with yields falling off consistently at wider spacings though not so consistently at closer spacings. It should be noted that there has been no tendency for the optimum to move towards wider spacings as the trees age, but rather the reverse.

A second trial at Tafo, with Upper Amazonian cacao was planted in 1949-50, with three spacings (8 ft. x 8 ft., 10 ft. x 10 ft., 12 ft. x 12 ft.). Smith (1960) reported that no conclusions could yet be drawn, though the 10-foot spacing had given highest yields in the two years 1957-59.

In Nigeria, a trial was planted in 1941 with Trinitario and Amelonado cacao in alternate rows, at spacings from 5 ft. x 5 ft. up to 15 ft. x 15 ft. Kowal (1959*a*) states that the trees had fully developed eight years after planting, but the canopy was still open at 12 ft. x 12 ft. and 15 ft. x 15 ft. spacings. Trees were taller at close spacings, and capsid infestation was much lower. By 1956, 32 per cent. of the original trees were missing, but there was no clear relation between spacing and tree survival. The effect of stand density on yield per acre differed for the two varieties. With Trinitario there was a linear increase in yield with increasing density of stand, maximum yield being obtained at the closest spacing (1,020 trees/acre actual stand). Amelonado, however, showed a clear optimum at about 800 trees/acre, with yield declining at greater densities than this as well as at lower. Both varieties commenced bearing earlier at the closer spacings. The author concludes that, in Nigeria, for either variety a stand density of less than 580 trees/acre is disadvantageous in relation to health and management and uneconomic in relation to yield. He found also (Kowal, 1959*b*) that there was a strong correlation between stand density and soil moisture, soil nitrates, organic litter and soil nutrient status. This experiment was apparently conducted under rather unfavourable conditions, since the average annual yield of all plots from 7th to 14th year of age was only 160 lb. dry cocoa per acre.

In the Congo, Vallaeys (1954) noted that in an experiment at Yangambi, over a period of 14 years, the closest spacings (520 to 650 trees per acre) gave earlier bearing and sustained higher yields.

Trials in Trinidad have used clonal material, not seedlings. Up to nine years of age, higher yields were obtained at 8 ft. x 8 ft. than at 12 ft. x 12 ft. spacings (Maliphant, 1959*a* and 1959*b*).

Table I.—**Numbers of Pods Harvested in Cacao Shade—Spacing Observation Block.**

	12-FOOT TRIANGLE				15-FOOT TRIANGLE			
	SHADED		UNSHADED		SHADED		UNSHADED	
	Pods/tree	Pods/acre	Pods/tree	Pods/acre	Pods/tree	Pods/acre	Pods/tree	Pods/acre
1953-54	14.4	5,027	28.5	9,928	18.8	4,220	31.7	7,102
1954-55	28.1	9,782	47.0	16,422	26.4	5,915	58.9	13,210
1955-56	21.9	7,610	37.9	13,262	24.8	5,561	45.0	10,092
1956-57	45.5	15,840	56.5	19,757	54.8	12,286	66.5	14,915
1957-58	29.4	10,244	26.0	9,073	39.8	8,920	39.1	8,760
1958-59	44.7	15,543	34.0	11,882	65.0	14,570	57.3	12,854
1959-60*	44.9	15,628	61.2	21,403 (20,275)	70.5	15,796	68.2	15,284 (14,400)
1960-61*	36.3	12,639	39.6	13,832 (12,145)	52.8	11,842	49.9	11,175 (9,420)
TOTAL	265.2	92,313	330.7	115,559	352.9	79,110	416.6	93,392

12-ft. plots Total yield—103,936 pods/acre.
15-ft. plots Total yield—86,251 pods/acre.
Shaded plots Total yield—85,711 pods/acre.
Unshaded plots Total yield—104,475 pods/acre.

* Figures in brackets for the unshaded plots have been adjusted to remove fertilizer effects.

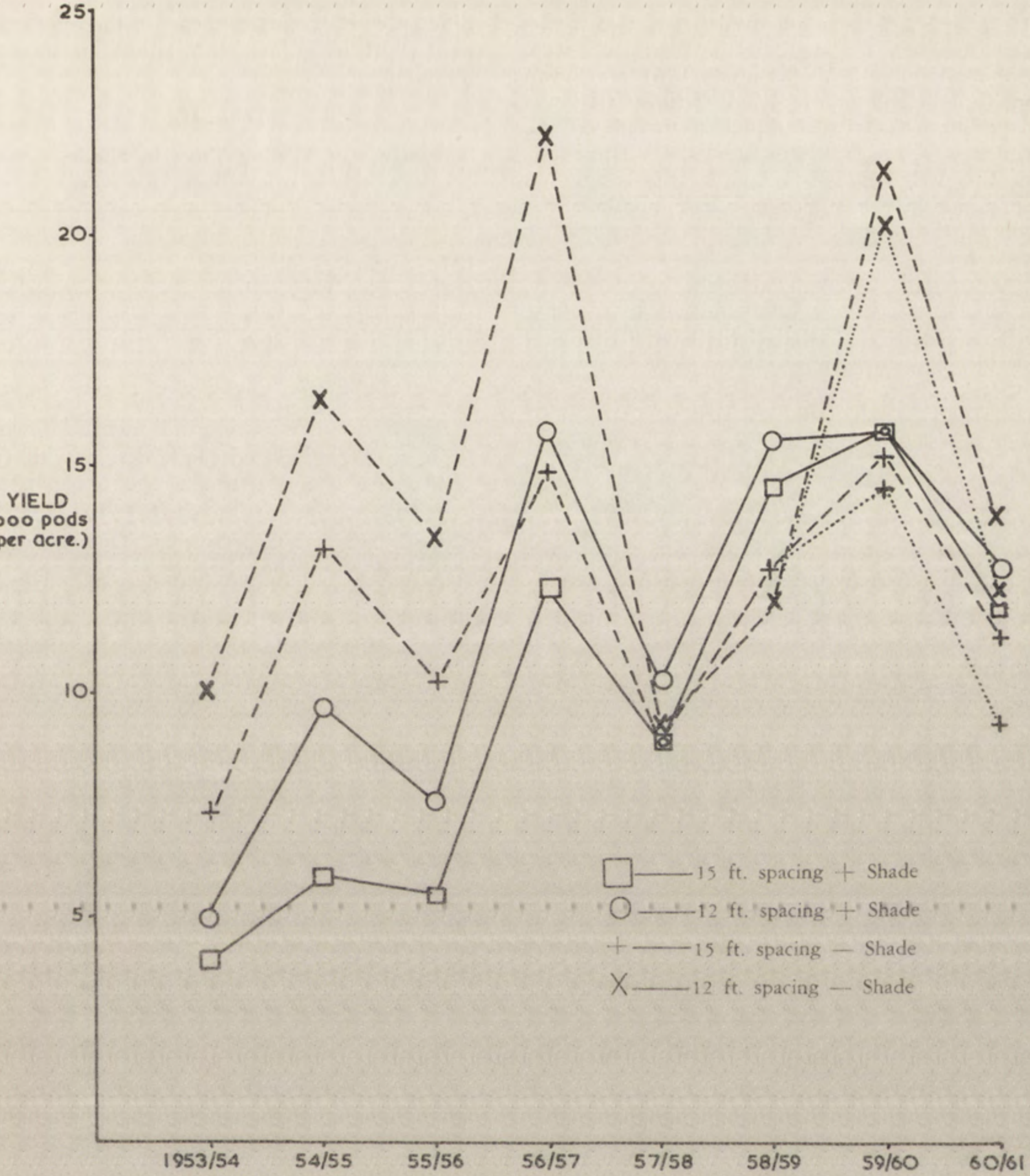

Fig. 1.—Yields in Cacao Shade—Spacing Observational Trial Block, Keravat.

Note.—Dotted lines for yields of no-shade plots 1959/61 indicated estimated yields in absence of fertilizer.

Local Experiments and Observations.

An observational block was planted at Keravat in early 1949 to compare 12 ft. triangular spacing (348 trees/acre) with the standard 15 ft. triangle (224 trees/acre) and also to compare the performance of cacao from which all permanent shade was removed at maturity with normally-shaded cacao. This block, of seven acres, contained eight replicates of a progeny trial, four spaced at 12 ft. and four at

15 ft. Shade was removed from two replicates of each spacing, but the treatments were not randomized. Yields up to 1961 are shown in Table I and Figure 1. A fertilizer trial was superimposed as a split-plot treatment on the progeny trial replicates in late 1958. The effects of this will be discussed under the section on shade as there has been no clear indication that the fertilizer would have influenced the spacing effects.

Although the trend in yield of the 12-ft. unshaded block has been somewhat irregular, it seems quite clear that yields have been better at the closer spacing. Over eight years, the 12-ft. plots have produced 17 per cent. more pods per acre than the 15-ft. plots in the presence of shade, while without shade 12 ft. yield has been 25 per cent. higher. Vigour of the trees has been sufficient for a closed canopy to be formed at both spacings, and in fact a gap of 20 ft. left between the 12-ft. and 15-ft. plots has been completely covered over. In June, 1961, approximately 10 per cent. of the original trees were missing, and there are quite marked differences between treatments in the numbers of trees which have died. Mortalities are shown in Table II.

Table **II.**

Percentages of Missing Trees in Shade—Spacing Observation Block, Keravat.

	Missing Trees
12-ft. Spacing + Shade	5 per cent.
12-ft. Spacing Unshaded	7 per cent.
15-ft. Spacing + Shade	12 per cent.
15-ft. Spacing Unshaded	18 per cent.

(Recorded as at 30.6.61—Trees 12 years old.)

A more accurate spacing trial was laid down in 1956, in a randomized block design with four replications of five triangular spacings : 12 ft., 15 ft., 17 ft. 2 in., 20 ft., 24 ft. (348, 224, 174, 126, 87 trees/acre respectively). This was extended in 1957 by the planting of a second trial with four replicates of two hedge spacings, 24 ft. x 6 ft. and 18 ft. x 8 ft. (both 303 trees/acre).

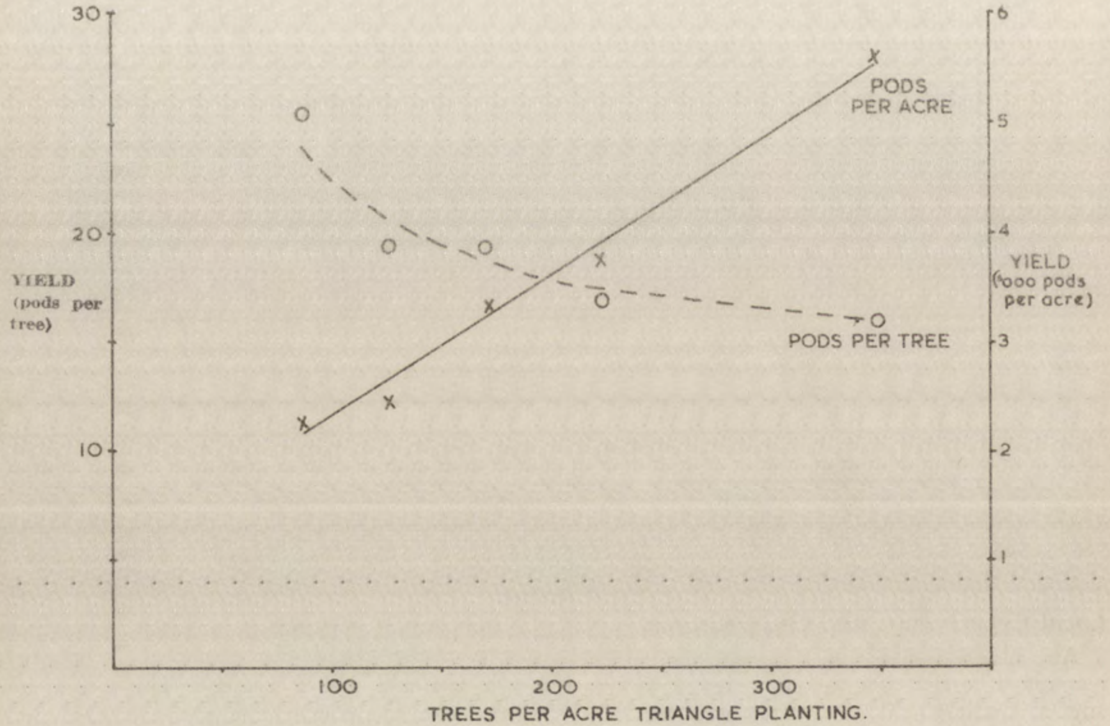

Fig. **2.—Cacao Seedling Spacing Trial. Yield to 4 years of age.**

The first year's yield records are available from the triangular plantings, and are shown in Table III and Figure 2. The relationship between yield per acre and trees per acre gives a straight line with a correlation between pods per acre and trees per acre of 0.955. Thus yields per acre increase with density of stand, although yields per tree decrease.

Table **III.**

Cacao Spacing Trial, Keravat. Pod Yields up to Four Years of Age.

Trees per acre	348	224	174	126	87
Spacing	12 ft.	15 ft.	17 ft. 2 in.	20 ft.	24 ft.
Pods per acre	5,578	3,765	3,302	2,439	2,215
Pods per tree	16	17	19	19	25

Minimum difference for significance :

5 per cent. = 1,081 pods per acre.
1 per cent. = 1,518 pods per acre.

Differences in weed growth under the different spacing were quite pronounced. At 12 ft. spacing, by the end of 1960 (four years of age) the cacao had formed a closed canopy and the ground was covered with a complete mulch of dead leaves, preventing virtually all regrowth. At 15 ft. the canopy had not closed completely by the end of June, 1961, and some weed growth was still present in the plots. At this spacing the trees would take about 12 months longer to form a closed canopy. In the wider triangle spacings the trees remained quite separate and weed growth was inhibited only in the circle directly under the trees. In the hedge spacing, still 12 months younger, the trees intermingled within the hedge rows, but a gap remained between the rows. Thus there was a line clean of weeds under the cacao but considerable growth between the rows.

Some difference was evident also in the habit of the trees. This is influenced also by the level of shade and under the fairly heavy shade level maintained for young cacao at Keravat most of the trees tended to be upright in habit even at the widest spacings. There were a few trees, however, in which the branches tended to droop to the ground, and this hinders access for harvesting. It has been observed in other plantations, particularly where cacao is grown under coconuts, that this tendency to droop is much more pronounced, and it may be that it increases with age of the trees. By contrast, in the 12-ft. plots of this trial, and generally at Keravat where the trees have formed a closed canopy, self-shading forces growth upwards and drooping is virtually eliminated. It is the practice at Keravat to prune the trees once they have reached maturity to remove any limbs which hinder access, and under the closed canopy this proves permanently effective. It has been observed on other plantations that similar pruning of trees where the canopy is open has been less effective, probably because there is not the support from intermingled branches, and regrowth at low levels is not shaded out.

In addition to these trials with seedlings, a spacing trial with cuttings was planted in 1957, with two replications of five spacings : 9 ft., 11 ft. 6 in. and 14 ft. triangular, and 18 ft. x 6 ft. and 18 ft. x 4 ft. hedge. This trial is only just coming into bearing, so that little can be said about yields, though it may be noted that in the first few months highest per acre yield has come from the closest spacing. At four years of age, in all triangular spacings the branches intermingle so that access is difficult. Even in the hedge spacings, although it is easy enough to walk between the rows, approach to the trees for harvesting is hindered by a mass of low-hanging branches. However, in another block of clonal cacao planted at 12 ft. x 12 ft., at five years of age it appears that earlier difficulty of access is now passing off. Self-shading and competition is forcing new growth upwards and causing lower branches to die, so that access is now fairly easy and seems likely to improve. This has not occurred with certain clones which have a rather straggly habit, but such clones are not likely to be used commercially.

Discussion and Recommendations.

It is significant that almost every experiment that has been conducted has shown highest yields at close spacings, usually closer than standard recommendations. The inference is that cacao probably performs best at a stand density that has the appearance of being excessively crowded. It should be remembered that most of these trials are still in their early years, and the optimum may change later. However, there is little in the results reported to suggest this. In the Tafo trial, any change in the optimum has been towards narrower rather than wider spacings. In the Keravat observation trial the initial advantage of the 12-ft. plots does seem to have declined, but there is no sign that the 15-ft. plots are likely to overtake them to the extent of ultimately giving a higher total yield.

Plate I.—**Seedling cacao, 4 years, 9 months age, 12-ft. triangle spacing.**
(The ground under the trees is completely covered with a mulch of dead leaves, and weed growth eliminated. Growth of the trees is entirely upright.)

Plate II.—**Seedling cacao, 4 years, 9 months age, 15-ft. triangle spacing.**
(Leaf mulch covers the ground only in parts of the plot. One tree in left background is drooping to the ground.)

Plate III.—**Seedling cacao, 4 years, 9 months age, 24-ft. triangle spacing.**
(Trees are quite separate, some droop to the ground and weed growth is abundant.)

Plate IV.—**Seedling cacao, 3 years, 11 months age, 18-ft. hedge spacing.**
(Trees meet within the rows but not across the rows. Leaf mulch is present only immediately under the trees.)

The results of the West African trials could not be transposed directly to Papua-New Guinea. Yields in Nigeria are low, and growth not sufficient for a closed canopy to form even at 12-ft. spacing, which indicate that the trees in this trial are much less vigorous than trees at Keravat. In Tafo, too, although yields are higher than in Nigeria the optimum yield of 4,500 lb./acre up to 12 years of age is only about half the yield of the 12-ft. plots at Keravat up to the same age. Probably growing conditions are not as good as at Keravat, and it is likely that as a general principle closer spacings are required under poorer conditions, although the experimental evidence is not yet sufficient to establish this conclusively. Kowal (1959*b*) states that it is generally accepted in Nigeria that good health, growth and performance of cacao is incompatible with the encroachment of grass/weed ground cover. The most important, or at least the easiest, method of controlling ground cover is by the establishment of a closed canopy. Thus, if Kowal is correct, this points clearly to the need for closer planting on poorer soils. There is no evidence yet from the Keravat spacing trial to support the need for a closed canopy, as trees still look quite healthy even at the widest spacings, but this is to be expected when the trees are only five years old. General observation on older cacao in New Britain does suggest that trees do not perform so well where the canopy is not closed.

Considering the factors involved as they were set out in the introduction, the following conclusions may be drawn: for productivity, 12 ft. spacing is to be preferred to 15 ft. for seedling cacao in the Gazelle Peninsula. In districts where soils are less fertile, spacings even closer than 12 ft. may be desirable. Twelve-foot spacings are to be favoured also for reduced maintenance costs, as a closed canopy is formed earlier and shades out the grass. Access is also facilitated in a stand where the canopy has closed, since lower growth is shaded out, although a tendency to taller growth of the trees may be some disadvantage for harvesting. In regard to hedge plantings, insufficient experience has been had for conclusions to be reached. However, there does seem some danger that the wide spacing between rows, through delaying the formation of a closed canopy, may allow branches to droop to the ground and thus hinder rather than assist access. Finally, considering changes in the stand as the trees age, there is some evidence from Keravat of higher mortality at 15 ft. than at 12 ft., so that again closer planting is favoured.

On present evidence, therefore, it seems clear that the recommendation for spacing of seedling cacao in the Territory should be changed to 12 ft. on the triangle, rather than 15 ft.

B. SHADE.

In the wild state, cacao is an under-story tree of dense, tropical rain forest, and is thus capable of, and adapted to, growth under heavy shade. However, like any other plant, it requires light for photosynthesis (the process by which the leaves manufacture carbohydrates, which are the main raw materials for growth and pod production). Consequently, too dense shade limits photosynthesis and thereby retards growth and reduces productivity. At the other extreme, the tree appears unable to stand full exposure to direct sunlight without ill effects. The aim in using overhead shade is to strike a balance where productivity is at a maximum but health of the tree is unimpaired.

Urquhart (1961) states that "although there is some difference of opinion as regards the extent to which the cocoa tree needs shade after it has grown and produced a canopy, there is universal agreement on the need for shade at the seedling stage and in the first few years of the life of the tree." This has been accepted without question by the Department of Agriculture, Stock and Fisheries, and is fully borne out by observations on occasional seedlings which have been seen growing without shade. However, there is still room for inquiry into the intensity of shade required in the early stages, as well as in the later stages. The changing requirement as the tree ages is probably due primarily to increase in self-shading, though other factors also may be involved.

The effects of shade are complex. Overhead shade affects not only the illumination of the cacao trees, but also such things as air temperature, soil temperature, wind and air movements (and possibly movement of pollinating agents) and humidity. Many different tree species are used for shade, and these may differ in their secondary effects if not in their primary effects. The roots of shade trees must compete with the cacao to some extent for water and nutrients, although it might be expected that a leguminous species would add nitrogen to the soil through fixation from the atmosphere. A shade tree which is deeper rooted than the cacao could perhaps bring up nutrients from lower levels and make them available through leaf fall. Because of all these things, shading will interact with such factors as spacing and fertilizing, and shade requirements will vary according to climate and weather pattern.

As with spacing, long-term effects must also be considered. Removal of shade from mature cacao generally boosts production initially, but we need to know whether this is only temporary and whether under full light the trees may "burn out" prematurely. Vallaeys (1954) quotes reports from several countries indicating that the life of the cacao tree is reduced in the absence of shade.

Overseas Experiments.

A fundamental study of shade effects on cacao was laid down at the Imperial College of Tropical Agriculture, Trinidad, in 1950 (Evans and Murray 1953). Clonal cuttings were grown under artificial shade with light intensities ranging from 15 per cent. to 100 per cent. The general conclusions from this trial were summarized by Murray (1955). Under heavy shade, plants were insecurely rooted and of spreading habit, while under little or no shade they were stronger and more bushy in habit. Under shade, total leaf area was greater and individual leaves larger. Relative growth rate of the plants, in the absence of fertilizer, was found to be highest at about 50 per cent. light, decreasing above and below this. One of the most significant features of the trial was an interaction between shade and fertilizer, particularly nitrogen, there being little fertilizer response under heavy shade but marked response under light shade. Thus, highest yields were obtained from fertilizer plots under light shade. Murray states, however, that even with high nutrition shading appears to be necessary in the early stages until the plant is big enough to provide self-shading.

A similar experiment was laid down at Yangambi, Congo, in 1955 (van Himme and Petit 1957), again using clonal material under artificial shade. Effects on early growth were similar to those at Trinidad, and it was noted that the optimum light intensity shifted from 25 per cent. in the first year to 75 per cent. in the second year of growth. This again points to the requirement of heavier shade in the early stages.

In a field experiment planted at River Estate, Trinidad, in 1949 (Havord 1953) yields up to 1958 were about 10 per cent. higher in the absence of permanent shade, and fertilizer response was greater (Maliphant 1959*b*). From West Africa, Cunningham (1959, 1960) reports a trial on 10-year-old Amelonado seedling cacao spaced at 8 ft. x 8 ft. under *Gliricidia* shade. Shade was removed from half the plots and a mixed fertilizer applied to half the plots. There was a marked response to the treatments in the first year, and even more in the second year. Response to fertilizer under shade was slight (20 per cent.) but shade removal gave an increase of 150 per cent. in yield, and shade removal plus fertilizer gave an increase of 220 per cent. with the phenomenal yield of 3,091 lb. dry cocoa per acre.

Local Experiments and Observations.

Concerning shade species, little can be added to the comments of Henderson (1954) who compared several species and listed *Leucaena glauca* and coconuts as the most satisfactory for local conditions. These two species are almost the only ones now used in this Territory. Recently some introduced strains of *Leucaena glauca* have been tested by the Department, and have proved more vigorous than the local strain in all localities so far tried. In observation plots at Keravat average height of seedling five months after transplanting were : local strain, 7.4 ft.; Peru, 8.5 ft.; El Salvador, 9.0 ft. ; Guatemala, 11.0 ft. The introduced strains are a rather darker green and do not seed as freely as the local. In another small plot about three years old, the Guatemala strain is 10 ft. to 15 ft. taller than local strain of the same age, and the trees are generally stouter and more vigorous.

The main shade experiments at Keravat have been concerned with the shade requirements of mature cacao. The observation block whose yields are shown in Table I and Figure 1 includes two plots from which all permanent shade was removed gradually as the trees approached maturity. The plots were planted early in 1949 and differential shade removal was commenced in March, 1953, and completed in May, 1954. Shade on the remaining two plots was at this time at what was then considered normal (i.e., approximately 15 ft. spacing of the *Leucaena* trees). In 1957, the shade on these plots was further thinned to about half this level.

Plate V.—Young cacao tree showing effects of too heavy shade.
(Ramification is high, branches are long and spindly and leaves large.)

Plate VI.—Young cacao tree under satisfactory shade.
(This tree is the same age as that in Plate V.)

The results indicate that shade removal caused a large initial boost in productivity, followed by a decline, evident first in 1957-58. However, the rapidity of this decline is probably exaggerated in the graph, since in the same year the yield of the control plots was boosted by shade thinning (this boost was evident through comparison with another block under normal shade, in which 57-58 yields were lower than those of 55-56). The trends since 1958 have been complicated by an apparent interaction between spacing and shade, the unshaded plots at 12-ft. spacing showing a marked burst of productivity in 1959-60 which has been only partially maintained in 1960-61. At 15 ft. spacing, the unshaded plots have continued to give lower yields. Interpretation of the trends in the past two years is not so certain, because the superimposed fertilizer trial appears to have caused yield improvement only in the unshaded plots. The response has not been consistent, and therefore not statistically significant, but by analogy with results reported from overseas it may be assumed to be valid. Accordingly, the trends without fertilizer (based on yields of the control plots) are indicated in the graph by dotted lines. It will be seen that this does not alter the general picture very significantly.

The effects of shade removal on the appearance of the trees has been reduction in leaf size but increase in leaf number, a general tendency to a paler green colour, shortening of the internodes, and some tip die-back at the tops of the trees. The overall impression is that trees with-

Plate VII.—Young cacao tree showing symptoms of insufficient shade.
(Ramification is low, growth is very bushy, leaves are small. This tree is older than those in Plates V and VI.)

Plate VIII.—Unshaded cacao in Observation Plot at Keravat.
(Some tip die-back is evident at the tops of the trees.)

out shade look appreciably less healthy than trees under shade and from their appearance it had been expected that productivity would decline earlier and more severely than it did. After seven years without shade, some trees show severe effects, being largely defoliated, but most are only mildly affected. The tendency is more pronounced at 15 ft. spacing than at 12 ft. It may be seen from Table II that there have been more deaths in the unshaded plots than in the shaded.

A more comprehensive shade trial was commenced in 1957 on another block of seedling cacao which had been planted in 1948 at 15-ft. triangle and raised under normal *Leucaena* shade. Between October, 1957, and January, 1959, shade was reduced on certain plots to give four levels—normal (15-ft. triangle spacing of *Leucaena*), half normal, quarter normal, nil. The design of the trial is a randomized block with four replications, and plot size is 130 trees including guards. Individual yield records have been kept for all trees since 1953, and the level of guarding required between plots was determined by comparing shade effects in different zones from the outside to the centre, of the 1959-1960 yields. It appeared that 30 ft. guarding might be adequate, but to be on the safe side results have been assessed on the yields of an inner plot of 35 trees surrounded by 40-ft. guards having the same shade treatment Yields for 1959-60 and 1960-61, adjusted by covariance analysis for pretreatment yield, are shown in Table IV and Figure 3. It may be seen that so far yield has been about 70 per cent. higher with no shade than with normal, with a clear negative correlation between yield and shade density.

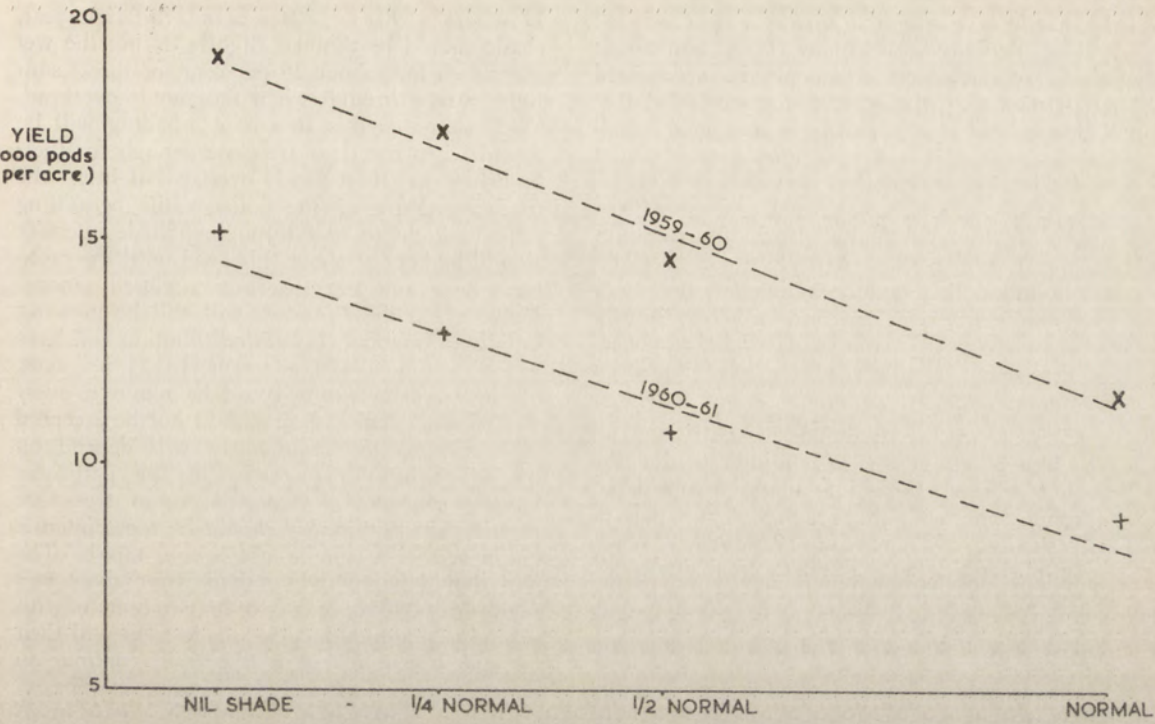

Fig. 3.—Cacao Shade Trial, Keravat, yields 1959 to 1961.

Table IV.

Pods Harvested in Cacao Shade Trial, Keravat.
Yield—Pods per acre.

	Nil shade	¼ Normal	½ Normal	Normal
1959-60	19,021	17,338	14,643	11,475
1960-61	15,194	12,941	10,714	8,794

Note.—Yield adjusted for pretreatment yield.

It should be noted that in both these trials the cacao canopy is closed, so that there is a large amount of self-shading. Observations on other cacao in New Britain indicate that where the canopy is not closed trees show more pronounced yellowing and die-back symptoms even when light shade is present. This is particularly evident in some stands of cacao growing under coconuts, where many 10- to 12-year-old trees appear to be dying. Quite spectacular improvement in appearance has been obtained on similar cacao given heavy dressings of nitrogenous fertilizer (up to 1 lb. nitrogen per tree). The effect in the Keravat fertilizer trial has been less spectacular, but perhaps mainly because the original condition of the trees was not so poor.

Discussion and Recommendations

Further information will be needed before clear-cut recommendations can be made about shade requirements of mature cacao. This applies particularly to fertilizer-shade interaction effects. There is no doubt that nitrogenous fertilizers have greater effect in the absence of shade, and the symptoms of insufficient shade seem virtually identical with the symptoms of nitrogen deficiency. It may be that the ill effects of excess sunlight result primarily from an upset in the tree's food supply. Increased photosynthesis produces more carbohydrate, and this is utilized in the production of more pods. However, although carbohydrate is the major material used in growth of pods, it has to be balanced with small quantities of nutrients, especially nitrogen. Thus the tree draws more heavily on nutrients from the soil, and deficiency symptoms may appear unless fertilizer is used. However, it is not yet established that this is a complete explanation of the harmful effects of excess sunlight. Experimental results are not sufficient to show to what extent application of nitrogen can take the place of external shade, nor whether this would be economic. Growers are cautioned against drawing conclusions from short-term effects, as early results may not be maintained later. For the present, it is recommended that light overhead shade should be maintained for all mature cacao. However, it does appear that a shade density sufficient to prevent all signs of leaf yellowing and tip die-back causes reduced yields. It may be that a stand of cacao producing at its maximum will always show slight symptoms of this type, but they do not seem to be inconsistent with continued tree health. Where such symptoms are only slight, responses to nitrogenous fertilizer so far have not been very great.

Apart from the question of nutrition, all the observations of the author indicate that the amount of external shading must be considered in conjunction with the amount of internal, or self, shading. Where the trees do not meet, it is probably that quite heavy external shade will be necessary to maintain the health and productivity of the trees. Where there is a closed canopy only light external shading is necessary.

The desirability of a closed canopy obviously points to closer spacings. However, perhaps more important, though not so obvious, is that it points to a need for fairly heavy shade in the early years. Several of the overseas experiments quoted have shown the influence of shade level on habit of growth, growth being more spreading under heavy shade. If shade is too light in the early years the trees become bushy and somewhat stunted, and therefore do not cover such a large area. Under heavier shade they grow outwards and much more quickly form a closed canopy. This may slightly retard the trees for productivity, but it has considerable economic advantage in that grass and weed growth is much reduced through the whole establishment period. Most of the difficulty growers experience with excess *Leucaena* seedling regrowth would be eliminated if the ground were kept constantly shaded in this way.

For the present, the following recommendations would be made for cacao establishment. For the first 12 to 18 months the shade canopy should be thick enough to prevent almost all direct sunlight from reaching the seedling, yet not so thick that the seedlings become leggy. Henderson (1954) sets out detailed recommendations of methods of establishment of shade of this type, which have been quoted in full by Urquhart (1961). After about the first year, shade should be thinned slightly during the wet season, so that about 25 per cent. of direct sunlight passes through when the sun is overhead. With *Leucaena* this amount of shading will be found when the trees are close enough for their branches to meet and overlap slightly, the feathery nature of the foliage still permitting some sunlight to pass through. Shade intensity should be kept at about this level until the cacao trees meet and start to form a closed canopy. However, as the *Leucaena* will still be growing rapidly throughout this period thinning will have to be continued—20 per cent. to 25 per cent. of the trees remaining could be removed every wet season. This figure should not be accepted arbitrarily, as the requirement will depend on the vigor of the *Leucaena* in the particular locality concerned. Once the cacao trees are meeting shade thinning should be more intense, but nevertheless should not be too rapid. The aim should be to reduce shade over about two years until 70 per cent. to 80 per cent. of full sunlight is admitted. The shade trees will then be quite separate, but as they will continue to expand slowly further light thinning may be required in later years, possibly in the form of removal of individual branches rather than whole trees.

CONCLUSION.

As has been stated, firm recommendations cannot yet be made, particularly in respect of shade, as the basic principles involved are not yet clear. In order to gain further information, the following trials are to be commenced at Keravat :

(*a*) a spacing trial covering spacings closer than 12-foot triangle.

(*b*) a fertilizer trial to be superimposed on the existing shade trial, to find the effect of added nitrogen at different levels of shade.

(*c*) a shade x spacing x fertilizer trial to test interaction of all three factors.

It is hoped that these trials will fill in many of the gaps in our present knowledge and ultimately enable detailed recommendations to be made for all three factors.

SUMMARY.

Spacing—West African trials have shown optimum yields at close spacing (7½ ft. or less). In an observation plot at Keravat, cacao at 12-ft. triangle outyielded acaco at 15-ft. triangle up

to 12 years of age. In a replicated trial with spacing from 12-ft. up to 24-ft. triangle, yield in the first year was highest at the closest spacing, and weed growth was much lower. It is recommended that 12-ft. spacing should be used in this Territory.

Shade—Experiments in Trinidad and West Africa have shown that the level of shade affects habit and rate of growth, and that responses to fertilizer are greater in the absence of shade. In an observation plot at Keravat, removal of shade from cacao at maturity caused greatly increased yields at first, but yield later declined to less than that of shaded plots. The effect differed at different spacings. In another trial with four levels of shade, yield in the first two years increased linearly with decreasing shade. Nitrogen fertilizer has given response only in the absence of shade. Further information will be required before definite recommendations can be made.

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