Cacao shade, spacing & fertilizing trials in Papua & New Guinea

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SUMMARY

A review is made of cacao spacing, shade and fertilizer trials conducted by the Department of Agriculture, Stock and Fisheries in Papua New Guinea. The trials showed the importance of each of these factors and their interactions in achieving high cocoa yields. More importantly they define to some extent, optimum levels for these factors for the type of planting material used and the conditions under which cacao is grown in Papua New Guinea.

The cacao of Papua New Guinea is classed as Trinitario. Amazonian material was introduced to Papua New Guinea in the early sixties. However, hybrid seed arising from crosses of Amazonian with local material has not yet been released for commercial use.

Henderson (1951) claimed there were large areas with soils and climatic conditions suitable for cacao planting in Papua New Guinea. Urquhart (1957) considered climate of the greater part of the country to be particularly well suited to cacao and as near ideal as can be found in any country. This combination of soils and climate results in a cacao tree of more vigorous habit than in many other countries and hence reaction of cacao to agronomic practices, particularly spacing, may differ from other countries.

Cacao is grown in Papua New Guinea either as a sole crop or interplanted to coconuts. Recommended planting and management practices follow Henderson (1954) with modifications dictated by research results. Earlier plantings of both sole cacao and cacao interplanted to coconuts were usually at 15-ft. triangular spacing. Interplanted cacao was planted in the same lines as, and in lines mid-way between coconut palms. This usually gave a planting density of 56 coconut palms and 168 cacao trees per acre. The most commonly used shade tree has been Leucaena leucocephala.

Since the early 1960's there has been a move to a closer spacing, a more drastic reduction in shade levels and greater use of fertilizers. Current spacing is usually a 12 ft. triangle or its equivalent but denser plantings are used, particularly where heavy losses from diseases and pests are anticipated. Leucaena has lost popularity in some areas as certain cacao flush defoliating caterpillars will feed and adults oviposit on this shade tree, Dun, (1967).

Charles (1961) reported results of spacing and shade trials to that time. These results are brought up to date and other trials, including fertilizer trials, are reported. Unfortunately most of the trials conducted on the Gazelle Peninsula of New Britain had to be prematurely terminated due to the severe effects of an epidemic of vascular streak dieback of cacao and its treatment. Because of this, most results from 1964 onwards are considered unreliable while other more recent trials had to be abandoned before any meaningful results were obtained.

With the exception of KTC 21, all spacing and shade trials have been carried out at the Lowlands Agricultural Experiment Station, Keravat on the Gazelle Peninsula of New Britain. Fertilizer trials have been carried out in the Gazelle Peninsula, New Ireland and the Northern District of Papua, where large areas are planted to cacao.

SPACING TRIALS

KTC 3

In an unreplicated spacing and shade trial, KTC 3, a comparison was made between a 12-ft. triangular spacing (348 tree/acre) and a 15-ft. triangular spacing (224 trees/acre) both with and without shade. Cacao was planted in early 1949 and shade gradually removed from the no shade plots during 1953 and 1954. Later, in 1958, a nitrogenous fertilizer treatment was superimposed. Details of planting and treatments are given by Charles (1961) who also reported this trial for the period 1953–54 to 1960–61.

Charles found that the closer spacing resulted in greater yields per unit area than the wider spacing, particularly in the earlier years. Over the period the 12-ft. plots produced 17 per cent more pods per acre than the 15-ft. plots in the presence of shade while without shade the 12-ft. plots yield was 25 per cent higher. Total combined yields for shaded and unshaded cacao were:

- 12-ft. plots: 103,936 pods/acre
- 15-ft. plots: 86,251 pods/acre
KTC 4.

In order to get more reliable data on spacing effects, a replicated spacing trial, KTC 4, was planted in October, 1956 to compare five triangular spacings ranging from 12-ft. to 24-ft. (Charles, 1961). Yields from first bearing (up to December, 1960) to December, 1963 are given in Table 1. Results after 1963 are not reported due to the effects of vascular streak dieback. Treatment differences in each year were significant. Only in the first year was the 12-ft. spacing significantly superior to all other spacings. In subsequent years there were no significant differences in the yields of the three closest spacings but these were significantly different from the two widest spacings or approached significance.

A supplementary trial comprising two hedge plantings at 24 ft. x 6 ft. and 18 ft. x 8 ft. (both 303 trees/acre) was planted in August 1957. While there was no bridging treatment to give a true comparison with the main trial, yields were not apparently as good as either the 12-ft. or 15-ft. triangular spacing. Also there was a much greater grass problem and inter-tree competition was obvious. These were discussed by Charles (1961).

KTC 50.

A second closer spacing trial, KTC 50, was planted in December, 1969. This compares 5-ft., 8-ft., 10-ft. and 12-ft. triangular and 15 ft. x 7.5 ft. and 18 ft. x 8 ft. hedge spacings. Even at age 21 months inter-tree competition was obvious in the 5-ft. triangular spacing. (O’Donohue, 1971).

KTC 6.

In a pruning and spacing trial on clonal fan cutting, KTC 6, differences never approached significance, mainly due to high variability between replicates. There were indications that the 11.5-ft triangular spacing was best; but pruning at all spacings, particularly in the early stages, appeared to depress yields (1968a). While the 11.5-ft. triangle appeared to be the best spacing, there were problems of access due to the growth habit of clones.

No formal trials on spacing for cacao interplanted to coconuts have been carried out. However, recommendations have been made based on observation and experience (Byrne, 1971). This is for two cacao trees between coconut palms in the coconut lines and at ten feet spacing in a line midway between lines of coconut

TABLE 1

KTC 4 Seedling Spacing Trial. Yields in Pods per acre.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>TRIANGULAR SPACING</th>
<th>L.S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12 ft</td>
<td>15 ft</td>
</tr>
<tr>
<td>Trees/Acre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up to 1960</td>
<td>5,578</td>
<td>3,765</td>
</tr>
<tr>
<td>1961</td>
<td>7,658</td>
<td>6,994</td>
</tr>
<tr>
<td>1962</td>
<td>13,210</td>
<td>12,535</td>
</tr>
<tr>
<td>1963</td>
<td>16,505</td>
<td>16,170</td>
</tr>
<tr>
<td>TOTAL</td>
<td>42,951</td>
<td>39,464</td>
</tr>
</tbody>
</table>

N.B. Yields connected by line are not significantly different at 5% level.

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palms. With coconut palms planted at 30-ft. triangular spacing this gives a density of 56 palms and 280 cacao trees per acre.

SHADE TRIALS

KTC 3.

The shade and spacing trial, KTC 3, already mentioned and reported by Charles (1961) showed that under local conditions removal of shade led to increased yields and there was an interaction with both spacing and fertilizer. Over the period 1953/54 to 1960/61 shaded plots yielded 85,711 pods/acre compared to 104,475 pods/acre for unshaded plots. Refer to table 2 which has been taken from Charles (1961). The effect of the interaction between shade and spacing over this period was mentioned earlier.

At both spacings there was a marked initial response to shade removal for the first four years. After a period of depressed yields for unshaded plots, the tendency was for them to again out-yield the shaded plots. As can be seen from reference to table 4 this occurred less rapidly in the case of the 15 ft spacing.

KTC 2.

In trial KTC 3 shade and spacing treatment were not replicated, and to get more precise information on shade effects a shade levels trial was superimposed on a block of mature cacao at 15-ft. triangular spacing. Shade levels consisted of no shade, ¼ normal shade (56 shade trees/acre), ½ normal shade (112 shade trees/acre) and normal shade (224 shade trees/acre). Shade consisted of well developed Leucaena trees.

Yields, adjusted by taking 1956/58 pre-treatment yields as the independent variate are given in table 3. Differences between shade levels for each year were significant.

Response to shade levels previously reported by Charles (1961) continued. There was a negative correlation between shade levels and yields with a correlation coefficient of $-0.73 \ (P<0.001)$. The fitted regression line had the formula $y = (15.483 - 26.3x)$ pods per acre where $x$ is the number of shade trees per acre. Analysis was carried out on the mean adjusted treatment yields for each year reported in table 3.

In 1963/64 there was a relative decline of no shade treatment yield. No shade plots yielded less than ¼ normal shade plots but more than either of the other two treatments. This decline of the no shade treatments paralleled the decline of yields of no shade plots in KTC 3 which also occurred in the fifth post-treatment

<table>
<thead>
<tr>
<th>YEAR</th>
<th>12-ft. Triangle</th>
<th>15-ft. Triangle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shaded</td>
<td>Unshaded</td>
</tr>
<tr>
<td>1953-54</td>
<td>5,027</td>
<td>9,928</td>
</tr>
<tr>
<td>1954-55</td>
<td>9,782</td>
<td>16,422</td>
</tr>
<tr>
<td>1955-56</td>
<td>7,610</td>
<td>13,262</td>
</tr>
<tr>
<td>1956-57</td>
<td>15,640</td>
<td>19,757</td>
</tr>
<tr>
<td>1957-58</td>
<td>10,244</td>
<td>9,073</td>
</tr>
<tr>
<td>1958-59</td>
<td>15,543</td>
<td>11,882</td>
</tr>
<tr>
<td>1959-60*</td>
<td>15,628</td>
<td>21,403</td>
</tr>
<tr>
<td></td>
<td>(20,275)</td>
<td></td>
</tr>
<tr>
<td>1960-61*</td>
<td>12,639</td>
<td>13,832</td>
</tr>
<tr>
<td></td>
<td>(12,145)</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>92,373</td>
<td>115,559</td>
</tr>
<tr>
<td></td>
<td>(112,744)</td>
<td></td>
</tr>
</tbody>
</table>

12 ft. plots Total = 103,936 (102,529)* Pods/acre
15 ft. plots Total = 86,251 (84,932)* Pods/acre.

Shaded plots Total = 85,711 pods/acre.
Unshaded Plots Total = 104,475 (101,749)* pods/acre.

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

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year. Unfortunately the epidemic of vascular streak dieback led to termination of this trial after 1963/64. It may be that this depression would have been temporary only and would have followed the same pattern as those of the unshaded fertilizer plots in KTC 3.

In June, 1963 a split plot fertilizer treatment was superimposed on this trial (1965a). However, fertilizer treatment effects were not significant in 1963/64 so that inclusion of 1963/64 yields in table 3 is valid.

**FERTILIZER TRIALS.**

**KTC 3.**

In 1958 a nitrogenous (Urea fertilizer trial was superimposed on the spacing and shade trial, KTC 3. Shade had been removed from the no shade treatment in 1953/54. Fertilizer treatments consisted of a nil control and a positive rate of 212 pounds urea per acre. In December 1960 the positive rate was changed to four pounds urea per tree so that yearly rates of urea per acre were 1392 pounds for 12-ft. spacing and 896 pounds for 15-ft. spacing (O'Donohue, 1966).

Yields in pods per acre uncorrected for pre-treatment effects are given in table 4. Assuming differences in yields were the results of the effect of the three factors of shade, spacing and fertilizing then these three factors apparently all influenced yields with the spacing x fertilizer interaction exerting the least effect.

There were apparent marked interactions —
(a) There was no fertilizer effect on shaded plots but a marked one on unshaded plots. The unshaded fertilized plots out-yielded shaded plots by 38 per cent.
(b) The unshaded fertilized plots out-yielded the unshaded unfertilized plots by 31 per cent.
(c) There possibly was an interaction between fertilizing and spacing, the closer spacing being slightly superior; but this may have been a response to different fertilizer rates per acre for spacings.
(d) While unshaded unfertilized plots was slightly better than the shaded plots yield it showed greater year to year variation than any of the other treatments.

**KTC 17.**

Compared to then reported yields of over 3,000 pounds of dry beans per acre in Ghana (Cunningham et al, 1961) trials at Keravat on unshaded fertilized cacao had been disappointing with maximum yields

**TABLE 3.**

**KTC 2. Shade levels trial. Yields in pods per acre and adjusted for pretreatment yields. Mean pretreatment yields 1956-58 was 8,550 pods/acre/year.**

<table>
<thead>
<tr>
<th>YEAR</th>
<th>SHADE TREATMENT</th>
<th>L.S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>56</td>
<td>112</td>
</tr>
<tr>
<td>Shade*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trees/Acre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1959-60</td>
<td>19,021</td>
<td>17,338</td>
</tr>
<tr>
<td>1960-61</td>
<td>15,194</td>
<td>12,941</td>
</tr>
<tr>
<td>1961-62</td>
<td>14,163</td>
<td>12,838</td>
</tr>
<tr>
<td>1962-63</td>
<td>18,067</td>
<td>15,558</td>
</tr>
<tr>
<td>1963-64</td>
<td>11,206</td>
<td>14,195</td>
</tr>
<tr>
<td>TOTAL</td>
<td>77,651</td>
<td>72,870</td>
</tr>
<tr>
<td>MEAN</td>
<td>15,530</td>
<td>14,574</td>
</tr>
</tbody>
</table>

* Well grown *Leucaena leucocephala.*

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TABLE 4.

**KTC 2. Spacing, Shade and Fertilizer Trial. Uncorrected yields in pods per acre after superimposing fertilizer treatments on spacing and shade trial.**

<table>
<thead>
<tr>
<th>YEAR</th>
<th>12 ft. SPACING</th>
<th>15 ft. SPACING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shaded</td>
<td>Unshaded</td>
</tr>
<tr>
<td></td>
<td>No N1</td>
<td>No N1</td>
</tr>
<tr>
<td>1959–60</td>
<td>15,583</td>
<td>16,333</td>
</tr>
<tr>
<td>1960–61</td>
<td>12,188</td>
<td>13,292</td>
</tr>
<tr>
<td>1962–63</td>
<td>13,665</td>
<td>15,046</td>
</tr>
<tr>
<td>1963–64</td>
<td>11,249</td>
<td>13,166</td>
</tr>
<tr>
<td>TOTAL</td>
<td>64,155</td>
<td>71,193</td>
</tr>
</tbody>
</table>

under similar conditions approaching 1,750 pounds in Trial KTC 3 in 1962/63. An observation trial, KTC 17, with a complete fertilizer treatment was started in 1963 to see if similar yields to those achieved in Ghana could be attained. KTC 17 was superimposed on mature hand-pollinated progenies planted at 15–ft. triangular spacing.

A fertilizer mixture based on nutrients removed by one ton dry beans per acre (Hardy, 1960) and characteristics of local pumice soils was applied at three-monthly intervals (1965b). Two replicates of two treatments were applied. The comparison was between shaded unfertilized plots and unshaded fertilized plots.

Numbers and weight of pods per acre are given in table 5. The unshaded fertilized cacao out-yielded the control plots by 43 per cent over a seven year period. Using an arbitrary pod value of 10.5 unshaded fertilized cacao averaged about 1,266 pounds of beans per acre with a maximum of about 1,500 pounds in 1963/64.

The start of this trial did coincide with the onset of the vascular streak dieback epidemic. This disease and its control measures would have prevented trees achieving full potential. From trial KTC 3 it is obvious that the local Trinitario material has a greater potential than the yields obtained in this trial. Tree losses did occur, many probably as a result of vascular streak dieback and its treatment.

**KTC 21.**

Results of a series of shade and fertilizer trials, KTC 21, conducted by O'Donohue at Popondetta (1966) were difficult to interpret because of the high variability between plots (1969a). There was no response to fertilizer under shaded conditions, except in one trial where a response was obtained to sulphur. On unshaded cacao fertilized plots gave higher yields than unfertilized plots. There was no consistency in relative yields of the four fertilizer treatments (N, NS, NPKS and NPKS plus minors). Results were influenced by predation of the *Pantorhytes* weevil and vascular streak dieback.

**KTC 29.**

A fertilizer trial, KTC 29, is being conducted on mature sole cacao growing on yellow-brown clay loams of coralline origin in New Ireland. Nitrogen as urea and potassium chloride being applied in four combination (control, N, K, and N + K).

In the first post-treatment year there were no significant differences but some interesting trends. Urea on its own appeared to depress yields while positive responses to potash on its own and in combination with urea were of the same order. This would indicate that the response probably was due to potash alone and a response to nitrogen could not be expected unless potash rate is increased or until the effects of shade reduction wear off.
TABLE 5.

**KTC 17. Shade-Fertilizer observation plots. Mean yields in pods per acre.**

<table>
<thead>
<tr>
<th>YEAR</th>
<th>SHADED UNFERTILIZED</th>
<th>UNSHADE FERTILIZED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1963−64</td>
<td>11,672</td>
<td>11,623</td>
</tr>
<tr>
<td>1964−65</td>
<td>9,497</td>
<td>9,033</td>
</tr>
<tr>
<td>1965−66</td>
<td>7,691</td>
<td>8,095</td>
</tr>
<tr>
<td>1966−67</td>
<td>7,966</td>
<td>8,205</td>
</tr>
<tr>
<td>1967−68</td>
<td>9,590</td>
<td>9,664</td>
</tr>
<tr>
<td>1968−69</td>
<td>10,551</td>
<td>10,069</td>
</tr>
<tr>
<td>1969−70</td>
<td>8,253</td>
<td>7,911</td>
</tr>
<tr>
<td>TOTAL</td>
<td>65,220</td>
<td>64,600</td>
</tr>
<tr>
<td>MEAN</td>
<td>9,317</td>
<td>9,229</td>
</tr>
</tbody>
</table>

**KTC 11.**

The effect of fertilizing on young shaded sole cacao has been studied in one trial only. This was one treatment in a comprehensive spacing, shade and fertilizing trial, **KTC 11.**

Cacao was planted 'at stake' in July/August 1962 and the first fertilizer application made in December, 1963, to the 'early' plots. A compound fertilizer (N:P:K. 15:15:15) was applied at two positive rates namely 87 and 174 pounds per acre.

There was no response to fertilizer as measured by girths and 'early' fertilizer treatment was discontinued after October, 1965. There was a possible yield response from first bearing to 30th June, 1960; but this was not statistically significant (1968b). The 'early' F1 treatment plots yielded 9 per cent and F2 treatment plots 15 per cent more than the control plots.

The trial was terminated later because of severe losses from vascular streak dieback and its treatment. No further results are available.

**Interplanted Cacao-Coconuts.**

**KTC 9.**

Fertilizer trials have been carried out on cacao trees interplanted to coconut palms. Of these, trial **KTC 9** is of particular interest as it has demonstrated the effect frequency of application of nitrogenous fertilizer has on yields. This trial is located on a private plantation on the typical pumice sands of the Gazelle Peninsula. Original planting densities were about 56 palms and 168 cacao trees per acre. Both coconuts and cacao were mature at the start of the trial.

Originally the trial was three replicates of a 3 x 2 factorial with nitrogen and phosphate as treatments. These treatments were subject to considerable changes which have been reported by O'Connell (1966).

Over the period 1961 to 1966 responses to nitrogen fertilizer applied every six months were:—

- N0 (Control) — 9,647 pods/acre
- N1 (1 lb urea/tree/year) — 11,797 pods/acre or 22% increase over control.
- N2 (2 lb urea/tree/year) — 12,643 pods/acre or 31% increase over control.

There were indications that more frequent applications would give a better response. In April 1966 a new fertilizer regime was started (1969b) with the higher rate of application doubled (N4) and both rates at two frequencies, viz. 6—monthly (F2) and 3—monthly (F1).

While there was some change in 1968 resulting from frequency of application it was not until 1969, the third post-treatment year, that this effect became clear cut.

Charles (1971) analysed yields according to frequency of application, using 1962−65 yields as the independent variate. He found significance for
TABLE 6.

**KTC 9. Yields of cacao pods/acre for Rate and Frequency nitrogenous fertilizer trial on interplanted cacao-coconuts.**

<table>
<thead>
<tr>
<th>TREATMENT</th>
<th>No. of pods/Acre (Unadjusted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N0F0 — Control</td>
<td></td>
</tr>
<tr>
<td>N1F2 — ½ lb. Urea every 6 months.</td>
<td>12,035</td>
</tr>
<tr>
<td>N1F1 — ¾ lb. Urea every 3 months.</td>
<td>11,277</td>
</tr>
<tr>
<td>N4F2 — 2 lb. Urea every 6 months.</td>
<td>13,273</td>
</tr>
<tr>
<td>N4F1 — 1 lb. Urea every 3 months.</td>
<td>12,833</td>
</tr>
</tbody>
</table>

frequency approached the one per cent level. He also concluded that the relative responses of the two levels of nitrogen were unchanged and frequency response was the same at both nitrogen levels.

Unadjusted plot yields are given in table 6. From this it can be seen that ¼ pound urea/tree every three months was just as effective as 2 pounds every six months. In fact, in 1970 there was a suggestion of an adverse effect from the latter. Dick (1971) from leaf and soil analyses from this trial found an affect on other nutrients from the continual application of urea, particularly at the higher rate and six-monthly frequency. Handreck (1971) also reported a similar reaction to continued application of urea in KTC 3.

The marked response to the three-monthly frequency indicates that a greater response may result from even more frequent applications. It is planned to start a new trial to test this possibility. This trial probably will be on a mature but younger stand of sole cacao.

**KTC 37.**

A types and rates fertilizer trial on interplanted cacao-coconuts, KTC 37, is also being conducted in New Ireland on yellow-brown clay loams of coralline origin. These soils are typical of large areas of the coastal regions of Papua New Guinea which have been interplanted to cacao-coconuts.

TABLE 7.

**KTC 37. Cacao yields in pods/acre for interplanted cacao-coconuts rates x type of fertilizer trial, New Ireland.**


<table>
<thead>
<tr>
<th>POTASH</th>
<th>NITROGEN</th>
<th>MEAN POTASH</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>N0</td>
<td>N1</td>
</tr>
<tr>
<td>K0</td>
<td>10,596</td>
<td>9,190</td>
</tr>
<tr>
<td>K1</td>
<td>10,288</td>
<td>11,187</td>
</tr>
<tr>
<td>K2</td>
<td>10,273</td>
<td>11,548</td>
</tr>
<tr>
<td>MEAN</td>
<td>10,384</td>
<td>10,642</td>
</tr>
</tbody>
</table>

NITROGEN
The trial is of three replicates with all combinations of two fertilizers at three rates, giving nine treatments. Nitrogen is applied at zero, 224 pounds and 448 pounds of urea per acre per year. Originally this was applied in two six-monthly applications but changed to four three-monthly applications in February, 1970. Potash is applied as muriate in one application at the rate of zero, 140 pounds and 280 pounds KCl per acre.

Plots consist of a nominal nine coconut palm and twenty seven cacao trees (0.16 acres) with a double guard between plots. Leucaena shade was removed at the end of the pre-treatment yield recording period in July, 1969 and the first fertilizer treatments were applied at the same time. A basal dressing of 4oz. industrial sulphur per tree was applied to the whole area in March/May, 1971, as leaf analyses had shown a marked drop in levels of this nutrient.

Yields in pods per acre adjusted for pre-treatment variability are given for the first post-treatment year in table 7.

<table>
<thead>
<tr>
<th>L.S.D.</th>
<th>N x K</th>
<th>N</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>P = 0.05</td>
<td>504</td>
<td>274</td>
<td>274</td>
</tr>
<tr>
<td>P = 0.01</td>
<td>709</td>
<td>392</td>
<td>392</td>
</tr>
</tbody>
</table>

Mean yields for both potash and nitrogen showed increases with increasing rates. These were significant at the one per cent level except for the difference between N0 and N1 which only approached the five per cent level.

In the absence of potash, nitrogen gave a variable response with depression of N1 relative to both N0 and N2. It is possible, as occurred in KTC 29 that increased rates of nitrogen in the absence of potash may have depressed yields and N2 should have been depressed also. In the presence of K1 there was no response to the increase of nitrogen from N1 to N2 but there was an increase in the presence of K2, i.e. in the former case potash was limiting.

In the absence of nitrogen there was no response to increasing rates of potash. In the presence of N1 there was no increase from K1 to K2 but a response in the presence of the higher nitrogen level, i.e. nitrogen in the former case was limiting.

From this it would appear that when one fertilizer was at the lower level it limited the response to the other fertilizer. It would also appear that the highest level was below the optimum.

There would have been an overall response to removal of shade which probably reduced the response to fertilizing treatments. As the effect of shade removal wears off, differences between these treatments may become more marked.

DISCUSSION

While it is clear from cacao trials carried out in Papua New Guinea that there is an interaction between spacing, shade and fertilizer, these mainly will be discussed at separate factors.

With the exception of KTC 21, trials on both spacing and shade have been restricted to the Lowlands Agricultural Experiment Station, Keravat. Soils at Keravat are representative of only one of the soil types on which cacao is grown in this country. However, from observation on cacao growing in other areas, results of spacing and shade trials are generally applicable to all cacao growing areas.

Fertilizer trials have been conducted on soils representative of substantial areas planted to cacao but, while results are applicable to a greater or lesser extent to other areas, it would be desirable to extend the range of soil types on which fertilizer trials are conducted.

Spacing.

For the two spacing trials on seedling cacao which reached the yield recording stage (KTC 3 and KTC 4), the closest spacings under test gave both the highest early and total yields per unit area. In both cases the best spacing was 12-ft triangle (348 trees/acre).

Observations on closer spacing, 5-ft. and 8-ft. triangle, indicated that inter-tree competition under this country's conditions would have limited yields (O'Donohue, 1971). There are as yet only limited yield data to support this observation. In view of higher yields per acre from closer spacing reported from overseas (e.g. Maliphant, 1964), it is possible that a greater yield per unit area would be obtained with a closer spacing. This possibility is being tested in trial KTC 50.

At this stage all that can be said is that the optimum spacing for Papua New Guinea conditions would be 12-ft. triangular or less but greater than 8-ft. triangular spacing. However, if it is less, from observations it would approach the 12-ft spacing. Should Amazonian hybrids show expected vigour, the 12-ft spacing possibly would be the optimum.

While results of clonal (cuttings) cacao spacing and pruning trial were inconclusive, it would appear that optimum spacing is about the same as for seedlings, but would require some adjustment to take into
account varying vigour between clones. Difficulty of
access, particularly for a young stand, has already been
mentioned and should a modified hedge planting of
15–ft x 12–ft. be adopted and hedged planted to
single clones or clones of equal vigour, both the access
problem and inter-tree competition would be over-
come to some extent. However, advantage of higher
early yields would be lost. A spacing x vigour trial on
cuttings (KTC 46) will give information on effect of
this interaction on yields.

Charles (1961) has already mentioned other
advantages of close spacing in its effects on weed
growth; also, advantage can be taken of early reduction
or complete removal of shade.

Shade

It is generally accepted, and for good practical
reasons, that shade is required for cacao establishment
in Papua New Guinea. Cacao can be and has been
established without shade, but not as a commercial
practice. A compromise often is practiced where cacao
is interplanted to coconut palms with coconuts providing
less shade than is generally accepted but with
fertilizing to compensate for higher light intensity.

The response of young bearing cacao to shade
removal has been established by trial KTC 3 (table 2).
Shade was removed in the cacao’s fifth year and, while
this was not a replicated trial, there is no doubt that a
true response was obtained. Cacao in the KTC 21
series of trials had shade removed at about the same
age as for KTC 3 and a marked yield response was
recorded.

A response also was obtained by removal of shade
from mature cacao in trial KTC 2. Over a five year
period there was highly significant inverse correlation of
\(-0.73\) \((P \leq 0.01)\) between number of shade trees and
yields of pods/acre. The fitted regression line was \(y = \)
\((15.483 - 26.3 \times x)\) pods per acre where \(x\) was the
number of shade trees/acre.

The straight line relationship obtained at Keravat is
not inconsistent with the curvilinear relationships
reported by Murray (1964) and Vernon (1967). At
Keravat the number of shade trees per acre was used as
an indirect measure of light intensity, whereas Murray
used controlled shade conditions and direct light
measurements and Vernon direct light measurements.

In the fifth post-treatment year the no shade treat-
ments plots yielded less than the quarter shade treatment
plots but more than the other treatments. The same
thing also occurred to the no shade treatments in trial
KTC 3 in the fifth post-treatment year, but to a greater
extent. However, this trend was subsequently reversed
and it is possible that yields of the KTC 2 no shade
treatment plots would have recovered eventually.

In KTC 3 there was a very marked response by
unshaded plots to fertilizer. This also occurred in New
Ireland KTC 37).

The general conclusion to be drawn from shade
trials carried out in Papua New Guinea is that provided
other factors are not limiting, cacao which has formed a
complete canopy will respond to reduction of shade
levels, with response having an inverse relationship to
the number of remaining shade trees per acre. Under
conditions of high light intensities this response eventu-
ally will decline, unless the factor or factors which
eventually become limiting, are replenished.

While the above does present a fairly clear cut case
for shade per se other considerations do enter into the
levels and types of shade used. Bonaparte (1967)
reported interspecific competition limiting yields. The
role of shade trees as alternate hosts for pests and
diseases has been long recognized, and Papua New
Guinea is no exception. On the other hand, the choice of
the right shade tree and/or shade levels can be used as a
pest or disease control measure. An example of the
former in Papua New Guinea is the waning popularity of
Leucaena leucocephala because certain cacao flush
defoliating caterpillars feed and adults oviposit on this
shade tree (Dun, 1976). An example of the use of
shade for pest control is that the entomologists now
specify a high canopied shade for Pantorhytes weevil
control (Bourke, 1971). The potential danger from this
pest is greatly increased under conditions of low
canopied and light or no shade.

Fertilizing

From limited experimental data and observation it is
apparent that under conditions of ‘normal’ shade,
growth of cacao during establishment is not limited by
nitrogen in Papua New Guinea. However, it is known
from observation to be limiting under high light intens-
ities. Other nutrients, where a deficiency exists, can
be limiting even under ‘normal’ shade.

On pumice sands in trial KTC 11 at Keravat, there
was no response by establishing cacao to an N:P:K
compound fertilizer under ‘normal’ shade. On the
other hand, experience shows that a potash fertilizer is
required on mature soils of coralline origin.

Apart from a factorial trial on shaded cacao at
Keravat by Charles (unpublished data), the KTC 21
series of trials by O’Donohue (1961) and the original
KTC 9 treatments, fertilizer trials on bearing cacao
have been restricted to nitrogen and potash treatments.
The only responses demonstrated have been to
nitrogen in all cases under conditions of little or no
shade, potash on coralline soils in New Ireland, and in some instances at Popondetta an additional response from other fertilizers.

In general therefore, it can be said for cacao in Papua New Guinea that nitrogen is limiting under conditions of little or no shade and other nutrients can be limiting. No experimental data are available to support a claim that the latter will occur under relatively heavy shade conditions, but observations does support his statement.

Trial KTC 3 indicated an interaction between spacing and fertilizing of unshaded cacao. This statement is made with some reservations as fertilizer treatments for most of the period reported on, were applied at an annual rate of four pounds per tree giving per acre rates of 896 and 1392 pounds urea at 15-ft. and 12-ft. spacing respectively. Both rates could have been excessive and even depressed yields.

The frequency of nitrogen application effect has been well established by trial KTC 9 where quarter of a pound of urea every three months was just as effective as two pounds every six months but neither was as effective as one pound every three months. However, there are indications from KTC 3, KTC 9 and KTC 37 that continued application of nitrogen as urea does effect availability of other nutrients (Dick, 1971 and Handreck, 1971). This aspect required further investigation.

Frequency of potash application has not been investigated. Charles and Douglas (1965) found that for coconuts grown on coralline soils, potash applied every two years was just as effective as yearly applications. It is unlikely that cacao would require more frequent applications than once a year.

Comparison of rates of application for various nitrogenous fertilizer trials show some interesting trends. If KTC 37 is excluded from considerations leaving only fertilizer trials for which results are available for a number of years, the relatively high rates per acre with three-monthly applications have very little additional effect on yields compared to the lowest rates. This is illustrated by table 8. This would indicate that 672 pounds per acre of urea either is the optimum or, more probably, above the optimum rate. The optimum rate probably lies somewhere between 168 and 672 pounds urea per acre. Maliphant (1964) had maximum response by unshaded cacao to split application at the lowest rates of N, P, and K, with N as 450 pounds ammonium sulphate.

Fertilizer treatments discussed above were applied some years after complete shade removal for KTC 3 and partial shade removal for KTC 9. In the case of the latter, coconuts provided shade, probably at levels somewhere between the ¼ and ½ normal levels of KTC 2. Thus the initial ‘boost’ resulting from increased light intensity would have worn off. On the other hand KTC 37 probably still was at the initial ‘boost’ stage and either or both nitrogen and potash were limiting at that stage. Future results will resolve this question.

| TABLE 8. |

Comparative response of various fertilizer trials to nitrogenous fertilizers. Rates in pound of Urea. All three-monthly applications except for trial marked with asterisk*.

<table>
<thead>
<tr>
<th>TRIAL</th>
<th>RATE/TREE PER YEAR</th>
<th>RATE/ACRE PER YEAR</th>
<th>INCREASE OVER CONTROL PLOTS</th>
<th>MEAN OF YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb.</td>
<td>lb.</td>
<td>Pods/Acre</td>
<td>No.</td>
</tr>
<tr>
<td>KTC 3</td>
<td>4</td>
<td>896</td>
<td>4,146</td>
<td>5</td>
</tr>
<tr>
<td>KTC 3</td>
<td>4</td>
<td>1392</td>
<td>4,548</td>
<td>5</td>
</tr>
<tr>
<td>KTC 9</td>
<td>1</td>
<td>168</td>
<td>3,459</td>
<td>4</td>
</tr>
<tr>
<td>KTC 9</td>
<td>4*</td>
<td>672*</td>
<td>3,412</td>
<td>4</td>
</tr>
<tr>
<td>KTC 9</td>
<td>4</td>
<td>672</td>
<td>4,125</td>
<td>4</td>
</tr>
<tr>
<td>KTC 37</td>
<td>1.33</td>
<td>224</td>
<td>591</td>
<td>1</td>
</tr>
<tr>
<td>KTC 37</td>
<td>2.67</td>
<td>448</td>
<td>2,769</td>
<td>1</td>
</tr>
</tbody>
</table>
Current Departmental recommendation is for the equivalent of ¾ pound urea per tree every three months for a 12-ft. triangular spacing or 348 pounds urea per acre per year. In some cases it is also recommended that Ammonium sulphate, at double this rate, be substituted for urea for one in four applications.

At this stage little can be said about potash rates where this nutrient is deficient. KTC 37 did indicate that the higher (2½ cwt/acre) level was too low. This was doubled the optimum rate for coconuts (Charles and Douglas, 1965) but slightly less than the equivalent of the lowest rate used at the River Estate, Trinidad (Maliphant, 1964).

Deficiencies of other nutrients do occur to some extent as judged by visual symptoms and from reports on foliar analyses. These deficiencies apparently do respond to corrective measures. However, there are no data on the economic importance of these other deficiencies apart from a double economic response to copper found by Charles in his unpublished data on shaded cacao.

The possible detrimental effects of continued use of urea reported by both Dick and Handreck have already been noted. These effects and means of remediating are to be investigated.

Work is Papua New Guinea on other nutrients is lacking and is planned for the near future.

**Interaction of Spacing, Shade and Fertilizing.**

Running through this discussion have been references to the interaction of these three factors but, of necessity, mainly confined to trials conducted at Keravat. However, results are generally applicable to recognised cacao growing areas of Papua New Guinea.

It is quite well established that nitrogen does not lead to increased yields at low light intensities, but it does at higher light intensities. On the limited evidence available it would be quite reasonable to assume that response to nitrogen above a certain level of light would be proportional to light intensity.

The evidence from Papua New Guinea trials of an interaction of spacing with shade and fertilizing is not clear, mainly because fertilizer rates varied between spacing. However, because of the advantages of closer spacing, particularly in the first few years of bearing and no obvious disadvantage in subsequent years, a closer spacing is recommended, viz. 12-ft. triangle.

It is recognised that a major deficiency in the agronomic investigations in Papua New Guinea is lack of precise information on interaction of spacing, shade and fertilizing. A trial was laid down in the early sixties but was prematurely terminated due to vascular streak dieback with the development of vascular streak dieback resistant material by O'Donohue (Unpublished) another trial on the interaction of these three factors has been planned for the near future.

**ACKNOWLEDGEMENTS**

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