PLATE 1.—*Open-pollinated spacing. Pruning trial at 11 years old, planted 12 feet on the triangle.*

CACAO IMPROVEMENT PROGRAMME, KERAVAT

L. A. BRIDGLAND.

The thriving cacao industry in Papua and New Guinea has drawn all its planting material from the comparatively few trees of varied stock which survived the war. In this paper, Mr. Bridgland, until recently Agronomist-in-Charge at the Lowlands Agricultural Experiment Station at Keravat, near Rabaul, discusses the origin of the Trinitario complex in New Guinea, the scope for improvement and the objects and methods of the development programme at Keravat. Mr. Bridgland also discusses the "clonal seed" production programme, the development of clones for commercial use and the methods being used for the development of uniform hybrids through seed.

ORIGIN OF NEW GUINEA CACAO.

THE present cacao population in Papua and New Guinea probably came from stock introduced from Trinidad by way of Java, Ceylon and Samoa (Green, 1938). There is also some evidence to suggest a direct introduction from Venezuela at one stage (Henderson, 1951). These introductions began at about the turn of the century and continued until 1907. The only subsequent introduction was from Java in 1932. The New Guinea Department of Agriculture assembled planting material from certain known sources, and some of this stock was used for plantings at the then Demonstration Plantation at Keravat during the 1930's. No systematic breeding was carried out and different types became thoroughly mixed through inter-crossing. The original parent trees in the Rabaul Botanic Gardens were completely destroyed during the war and the plantings at Keravat were decimated.

In the immediate postwar years, Keravat became the major experiment station for lowlands crops in the Territory and a collection of cocoas was re-established by F. C. Henderson. These early postwar plantings were in the form of progeny trials from open-pollinated selected trees covering an extremely wide range from near Amelonado and Calabacillo types to pure Criollo. The parent trees were selected by Henderson from the remnants of cacao surviving at Keravat and various plantations near Rabaul. Taking the cacao in all parts of the Territory, the sum total is a Trinitario type.

The present programme is based almost entirely on Henderson's progeny trials which have provided a large variable population growing under the best plantation conditions at wide spacings and for which individual tree yield records have been kept from first bearing.

The early open-pollinated progeny trials had great value, quite apart from supplying a useful cacao population. Henderson's original parent trees were selected on the basis of vigour, disease and pest resistance, apparent yielding ability and pod and bean characters. Indeed, anything which survived the war must have possessed remarkable vigour. However, the performance of the parent trees over their lifetime must unfortunately remain unknown.

It soon became apparent that the progenies from the different parent trees showed a wide variation in performance. Certain trees gave early and high-bearing progenies, but, since the male parentage was unknown, this information could not be put to direct practical use beyond indicating that, with control of male parentage, clonal seed of a high order of performance could be produced. This is an objective worth working for. These trials provided some information on the general combining ability of a large number of trees and this information is of great value.

Certain parent trees yielded extremely poor progenies. One tree in particular gave a completely defective progeny, although normal itself except for the presence of what we have tentatively termed "embryo failure". "Embryo failure" is referred to again in greater detail later in this paper. Such information formed the basis of the Department's recommendation to planters that where tree selection is practised on the plantation—

1. At least 20 trees should be selected ;
2. The seed of these selected trees be bulked and three seeds planted per point with subsequent removal of the two least vigorous ; and
3. Where cacao is planted out from a nursery, any seedlings lacking in normal vigour be discarded.

SCOPE FOR IMPROVEMENT

Observations and measurement indicate that cacao is capable of radical improvement in every respect, including earliness of bearing, yielding ability, cocoa butter content of bean, bean size and flavour. There is also a big variation between trees in susceptibility to Black Pod Disease, although no really serious diseases of cacao have appeared yet in the Territory.

To indicate the potential improvement in yielding ability the field figures for Area 405 are quoted. Area 405 was one of Henderson's progeny trials planted in July, 1948. It covers an area of approximately 10 acres. A severe drought in 1950 caused complete defoliation, and a very heavy capsid attack in 1951-52 largely destroyed the early crop, so that yield recording did not commence until 1953. The figures in Table I cover the total yield from 1953 to 1958, excluding edge trees and excluding 20 of the highest yielding trees, which were selected in 1954 and subsequently butchered for cuttings.

The percentage of yield contributed by the upper bracket of trees is illustrated by the graph in Fig. I. The yield increase which would theoretically result from entire plantings of a narrower or wider proportion of the highest yielding trees is illustrated by the graph in Fig. II.

The figures from Area 405 give some idea of the variation in yield performance of individual trees in a block of seedling cacao. If it could be assumed that there is no reason why all the trees should not yield as well as the best, and having regard to the fact that if all the trees yielded as well as the best five per cent. there would be an increase in yield of the order of 140 per cent., it would appear to be possible to attain yields of 2,000 lb. dry beans per acre per annum by vegetative propagation of the best trees in our existing seedling population.

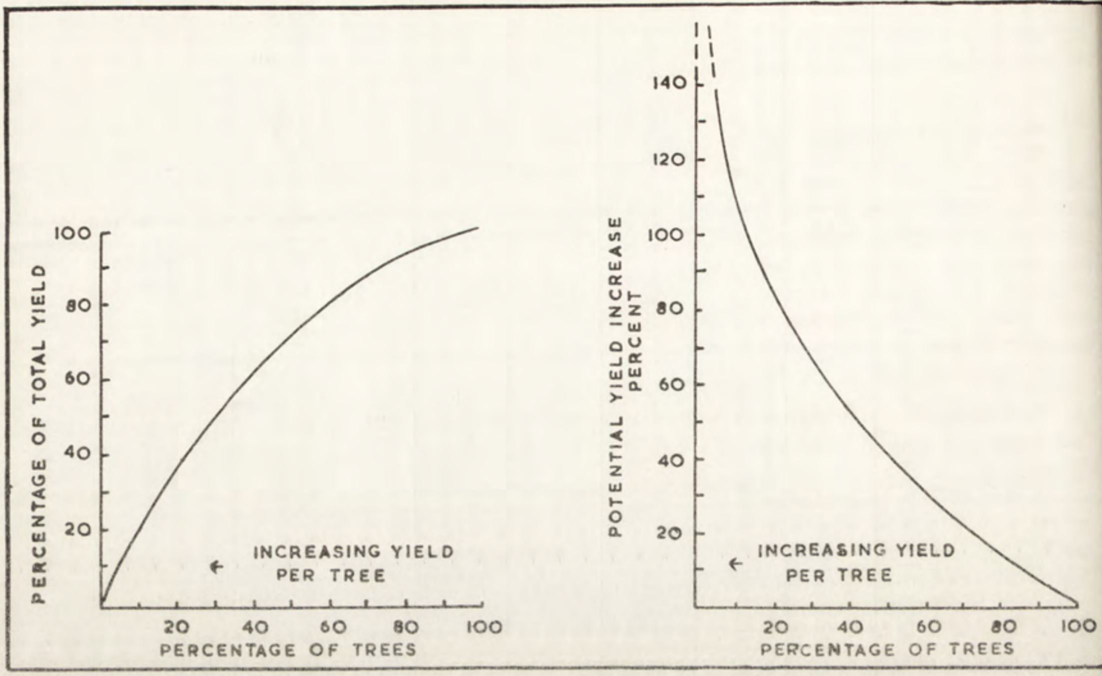
A criticism which may be levelled at the above deductions is on the basis of our calculation of yield of dry beans by using the conversion factor of 10.5 pods/lb. dry beans for all yield classes. Taken over all, the conversion factor is accurate for the trial, but it might be expected that there

Table I.

Area 405—Frequency Distribution—Pods Per Tree Yearly Average over Period 1953-1958.

Yield Class Pods/Tree.	131 to 140	121 to 130	111 to 120	101 to 110	91 to 100	81 to 90	71 to 80	61 to 70	51 to 60	41 to 50	31 to 40	21 to 30	11 to 20	0 to 10
Number of Trees	1	0	3	10	17	31	64	105	199	284	375	357	214	126
Running Total .... (Trees)	1	1	4	14	31	62	126	231	430	714	1089	1446	1660	1786
Percentage of Total	0.05	0.05	0.2	0.8	1.7	3.5	7.1	12.9	24.1	40.0	61.0	81.0	93.0	100.0
Number of Pods	135	0	377	1055	1624	2651	4832	6878	11045	12922	13313	9104	3317	693
Running Total .... (Pods)	135	135	512	1567	3191	5842	10674	17552	28597	41519	54832	63936	67253	67946
Per cent. of Grand Total	0.2	0.2	0.8	2.3	4.7	8.6	15.7	25.8	42.1	61.1	80.7	94.1	99.0	100.0

Mean = 38.044 + or — 12.006.



FIGS. I *and* II.

would be a decrease in pod value with increasing pod yield. Naturally, the trees in the highest-yield classes have received closest attention and our measurements indicate that the conversion factor is accurate for the trees with high pod yields.

The selections made in the particular trial are listed in Table II with their pod values :

selected, have pod values which do not differ significantly from the pod value for the trial as a whole.

Objects

In the first instance our aim is to produce early-bearing, high-yielding types without weakening other desirable characters such as high fat content, flavour, vigour and disease resistance.

TABLE II.

Pod Values of Trees Selected in Area 405.

Selected Tree.	Pod Value.	Selected Tree.	Pod Value.	Selected Tree.	Pod Value.
K5.101	9.8	K17.101	9.2	K23.102	9.6
K6.101	8.4	K19.101	11.3	K23.103	10.6
K11.101	7.6	K19.102	11.0	K23.104	12.4
K12.101	10.3	K22.101	9.1	K23.105	10.9
K15.101	10.5	K22.102	7.5	K23.106	9.7
K16.101	10.5	K23.101	11.8	K23.107	12.3
K27.101	11.7	K27.102	8.8		

Mean Pod Value = 10.15.

The above pod values are based on determinations from 30 to 50 pods measured at three or four different times of the year.

Examination of the other trees with high pod yields, which for various reasons were not

For the present, it is our intention to retain the Trinitario character and, in actual fact, in the short term we have no other alternative without large-scale introductions and this we will not do. Our first aim is to meet the above requirements on a broad base of genetic material and as times goes on the emphasis can be swung closer to the Forastero type if this is what the market demands. Meanwhile, we aim at considerably less variation in nearly all characters than exists in our present cacao population.

When yield requirements are met, the emphasis of our breeding programme will shift to cocoa butter content and flavour characters, provided that no other serious problems arise in the meantime.

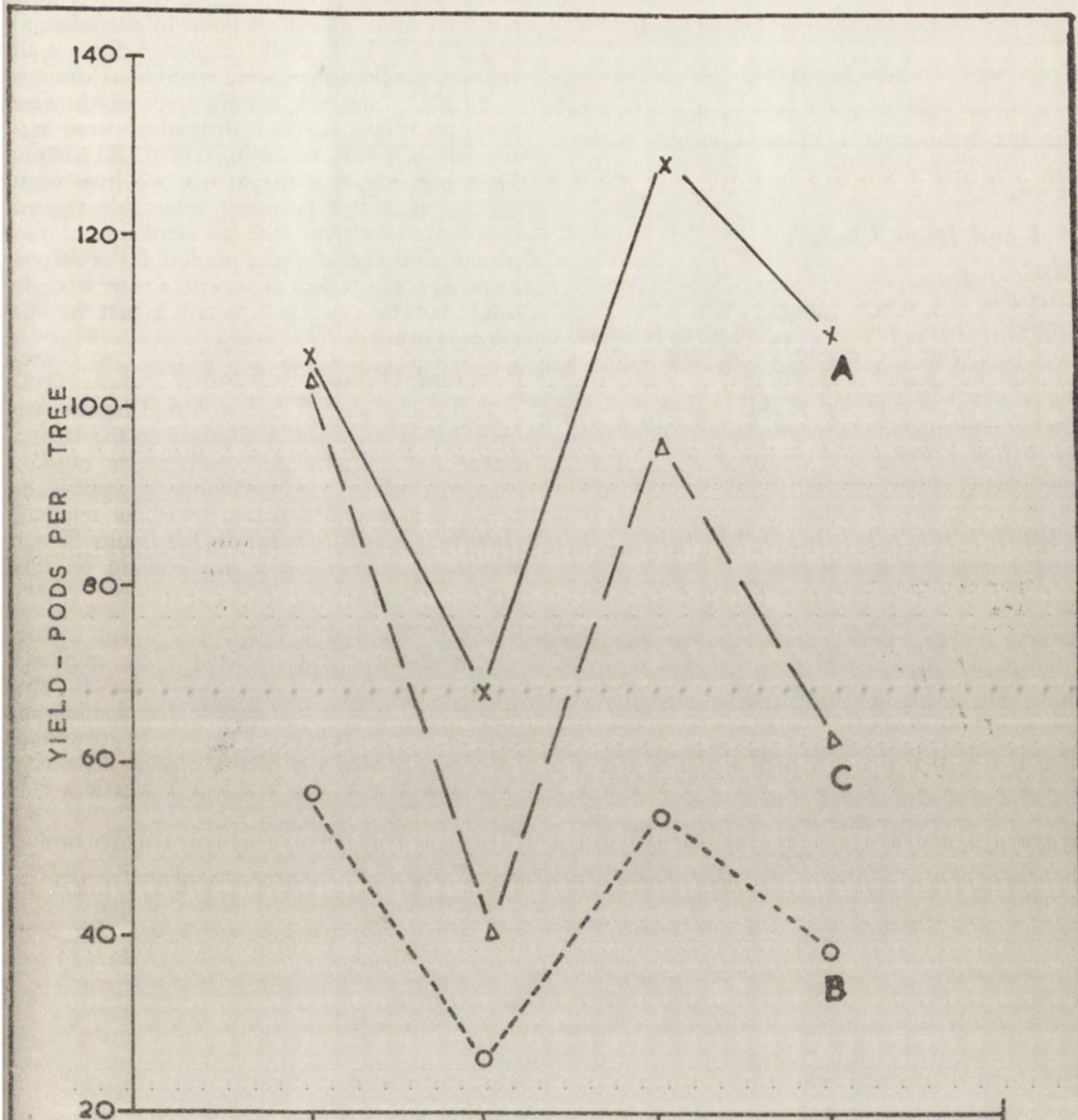


FIG. III.

In translating these objects into an actual programme, three separate avenues have been followed concurrently :—

(1) The development of "clonal seed".

(2) The development of clones for commercial use as such.

(3) The development of hybrid seed.

SELECTION

Each of the above avenues is dependent in the first instance on selection of suitable parent material. The bases for such selection are given below.

Pod and Bean Characters

Selection on the basis of pod and bean characters is a simple and straightforward matter. We have not placed the same emphasis on "pod value" (the number of pods required to make one pound of dry beans) as workers in many other parts of the world, because we can see no particular objection to somewhat smaller pods if bean characters and yielding ability are satisfactory. In fact, to overemphasize pod value would mean discarding a great deal of our highest-yielding material. However, anything with a pod value higher than 12 has not been selected. Most of the selections have a pod value of eight to ten although a few are as low as seven.

Minimum standards of bean size have generally been laid down by manufacturers at 450 beans per lb. Most of our selections have a bean value of 300 to 400, but it is as low as 250 in some cases.

Flavour and cocoa butter content were disregarded in the early stages of our selection work for the reason that the nib belongs to the second generation and both characters are therefore likely to be influenced by male parentage. However, any selected tree with a particularly low cocoa butter content was discarded. Further culling will be carried out on the basis of clone testing trials (see page 158) which have been designed to throw light on the influence of male parentage on nib characters.

Shell Percentage

Any tentative selections found to have a particularly high shell percentage were also discarded. The average shell percentage of New Guinea beans is some three to four per cent. higher than in West African beans and is therefore a point of some importance in our breeding programme.

Vegetative Characters

For the most part, vegetative characters have not been made a cardinal point in our selection programme. Early results suggested that not all vigorous seedling trees were vigorous as cuttings (e.g., K24) and that certain trees which were not particularly vigorous themselves were surprisingly vigorous as cuttings (e.g., K17.101). Therefore, in selecting parents, we have been satisfied if a tree possessed reasonable vigour. It appears that trees with an erect type of fan growth from the jorquette produce better-shaped plants as cuttings than those with a more straggly habit, but this has not played a part in our selection work.

Pest and Disease Resistance

This could scarcely be considered because we have no serious pests or diseases on the station except for "Black Pod" and a few capsids. Any tree which was noticeably susceptible to Black Pod or capsid damage was not selected. However, we will depend on the results of our clone-testing trials for a final culling on this basis.

Early Bearing

This character has received great emphasis because of its practical importance to the grower. Due to a favourable combination of type and conditions, cacao appears to come into significant bearing considerably earlier here than overseas. This is illustrated in Table III.

TABLE III.

Area 304 *—*Planted March,* 1948.

Age.	Yield Dry Beans/Acre (lb).
To 3 years	281
3-4 years	503
4-5 years	627
5-6 years	976
6-7 years	1,147
7-8 years	607
8-9 years	1,268
TOTAL	5,409

(* Open-pollinated progeny trial involving 10 acres, approximately.)

Notwithstanding the above, individual trees have shown a far greater tendency to early bearing and the most vigorous of these have been selected where pod and bean characters were also satisfactory. As an indication of the effect of the early high yielders on the early yield pattern, a frequency distribution was drawn up for the total yield to the age of four years and six months for the area of cacao referred to in Table III. In the high-yielding bracket of trees, this showed that 10 per cent. of the trees produced 30 per cent. of the yield and at the other end of the scale, that is, the low-yielding bracket, 30 per cent. of the trees contributed only 6 per cent. of the total yield.

Risks are involved in selecting for precocity. It is likely that high-yielding, precocious types may have a shorter economic life span, although this has not been proved. Not all selections made at Keravat are precocious and we have deliberately selected a proportion of " later " maturing trees, although even these are by no means " late " by most overseas standards.

Selecting for Yielding Ability

The yield of any tree is influenced by many factors apart from its inherent yielding ability. Locational factors involving soil fertility, water relations, exposure to wind and level of maturation, presence or absence of shade and competition effects for nutrients, water and light may flatter or obscure the true inherent yielding ability of a tree. Thus the scientific basis for selecting on inherent yielding ability is not particularly sound. The general performance of the Trinidad selections caused us to give careful consideration to the question of minimizing the effect of factors which tend to obscure the inherent yielding ability of individual trees. Thus, in planting up areas for selection work, attention was paid to the following points :—

(1) Only areas without significant topographical irregularities and where any pretreatment was uniform were chosen for planting. The " soil " at Keravat is an immature volcanic ash and, while there may be minor variations in water relations, the soil type does not vary greatly in nutrient status over short distances.

(2) A uniform shade canopy was established.

(3) Comparatively wide spacings were used.

(4) Edge trees, which we have shown to yield some 50 per cent. higher (at 10 years old) than inside trees, were ignored.

(5) Age at which selection was carried out was between the fifth and seventh year, with emphasis on the period of fifth to sixth years. At this stage many precocious types are selected and also later maturing trees—but competition effects have not assumed great importance.

The importance of competitive effects is not well understood, but is likely to be a major determinant of individual tree performance.

Effects of Competition and Tree Size

Measurements of girth have been recorded on a random sample of 26 cacao trees in Area 304 at different stages of growth and these have been correlated with current yield at the time of measurement.

The first girth measurements in 1952 were made at ground level but because of the distortion caused by the tendency of some trees to " buttress " at ground level, subsequent measurements were taken half-way between ground level and the jorquette. Results are as follows :—

Correlation between girth in 1952 and total yield up to 17.9.52, $r = 0.240$ (Trees four years old).

Correlation between girth in 1955 and yield for 12 months ended 30.6.55, $r = 0.531^{**}$ (Trees seven years old).

Correlation between girth in 1958 and yield for 12 months ended 20.6.58, $r = 0.714^{***}$ (Trees ten years old).

It is clear, therefore, that the vegetative vigour of a cacao tree becomes increasingly important as a determinant of its yield as the tree ages. This might be due to two factors :—

(1) Yield in the early years may be determined by genetic factors for precocity independent of the factors controlling vegetative vigour. The ultimate yielding capacity of the tree, however, is largely dependent on its size.

(2) Inherent yielding capacity of the tree may be largely independent of its vegetative vigour, but as the tree grows older the bigger trees have a competitive advantage over the smaller ones, which tend to become suppressed and outyielded.

In an attempt to assess the importance of competition against tree size as such, the following groups were selected from a sample on which girth measurements were made in 1954. This gave a rough measure of individual tree vigour. The relative vigour of individual trees was calculated by dividing their girth by the mean girth of the four surrounding trees, which, when multiplied by 100, gives a " relative vigour index ".

A. Trees bigger than those surrounding them—i.e., Relative Vigour Index greater than 100 (11 trees).

B. Trees smaller than those surrounding them—i.e., Relative Vigour Index less than 100 (23 trees).

C. Trees about the same size as those surrounding them—i.e., Relative Vigour Index about 100 (nine trees).

The girth of trees in group (C) was approximately the same as those in Group A.

Average girths in 1954 were :—

Group (A), 17.1 inches.
Group (B), 13.1 inches.
Group (C), 16.7 inches.

It was not possible to find another group similar in girth to Group B with equally sized surround trees.

TABLE IV.

Increase—girth 1954-58.

	Girth in inches.		Per cent. Increase
	1954	1958.	
Group A	17.1	20.9	22
Group B	13.1	14.5	11
Group C	16.7	19.4	16

This suggests that differences in size become accentuated as the plantation ages and that these differences may be to some considerable extent due to differential competition.

TABLE V.

Change in Relative Vigour Index.

	R.V.I. 1954.	R.V.I. 1958.
Group A	114.0	122.6
Group B	82.1	76.6
Group C	100.8	98.7

This result gives further support to the above conclusion.

Yield Trends

The yields of the trees involved for the four years are shown in the graph (Fig. III). This indicates that there is a marked correlation between size and yield in the early stages, and that competition becomes increasingly important as the trees grow older, particularly among the larger trees.

TABLE VI.

Yield and Vigour Correlations.

	Corr. Coeff.—Yield and Girth, 1958.	Corr. Coeff.—Yield and R.V.I., 1958.
A	0.011	0.235
B	0.352	0.689***
C	- - - 0.145	- - - 0.009
A + B	0.606***	0.790***
A + C	0.321	0.610**
A + B + C	0.484	0.721***

The consistently higher correlations for relative vigour index indicate that competition is probably important, although the differences between the correlation coefficients are not statistically significant.

Thus, it would appear possible and likely that selection at too early an age would differentiate only precocious types and selection at too late an age would select to a greater or lesser degree for competitive ability than for inherent yielding ability. Such trees would not necessarily reproduce a respectable yield per acre when grown as clones under equal conditions of competition.

Taking all the above considerations into account as far as possible, some 60 trees have been selected and propagated for clone testing.

Future Selection Work

When the progeny of clonal and hybrid seed gardens come into bearing, further selection work will be carried out. The possibilities of our existing population have been largely exhausted. Meanwhile, a trial has been laid down designed to provide more accurate information on the relationship between earliness of bearing, vegetative vigour and inherent yielding ability. This trial is in the form of a randomized block with four replications of plots of random cacao seedlings at spacings of 12 feet, 15 feet, 17 feet 2 inches, 20 feet and 24 feet. This trial is now two years old. Individual tree yields and vigour are to be measured—yield at every harvest and vigour at 12-monthly intervals.

DEVELOPMENT OF CLONAL SEED

The term " clonal seed " is used here to denote the progeny of the crossing of two clones. Although this is not an exact usage, it has become a generally accepted term.

For the past few years, Keravat has been called on to supply 60,000 to 80,000 pods per annum for planting. Having no alternative, we have been compelled to distribute open-pollinated material from high-yielding blocks. Our clones are not yet ready for distribution and even if they were the size of the Territory and the scattering of our cocoa-growing areas around a huge coastline and throughout a large number of small islands makes the distribution of clonal material extremely difficult. Under the circumstances we have looked for methods of improving the stock through seed. Our long-term approach to this is through the hybrid seed programme discussed below, but in the meantime it was thought probable, from the results of Henderson's open-pollinated progeny trials, that the crossing of certain selected clones would yield a reasonably uniform and improved progeny. Figures indicating the variation in yield performance of progenies from the different parent trees from one such progeny trial are set out below :—

TABLE VII.

Area 405—*Planted July,* 1948.

(10 acres approximately)

(4 Replications of the progeny of 18 Selected Trees—Randomized Block)

PROGENY Descending Merit	YIELD—lb. Dry Beans/Acre 1953-1954	1954-1955	1955-1956	1956-1957	1957-1958	MEAN
K6	830	1,548	970	1,885	900	1,227
K23	1,023	1,667	878	1,555	824	1,189
K25	785	1,389	766	1,420	648	1,002
K12	809	1,293	745	1,434	690	994
K5	767	1,214	743	1,468	800	978
K17	762	1,265	814	1,291	646	956
K20	754	1,170	678	1,404	640	929
K19	626	996	694	1,447	803	913
K11	673	1,093	767	1,271	613	883
K13	514	1,052	629	1,467	716	876
K26	715	1,127	603	1,263	449	831
K16	662	1,103	621	1,130	550	813
K21	614	1,051	579	1,045	437	745
K14	712	1,069	585	873	408	729
K24	414	842	414	1,287	521	696
K27	475	778	482	887	531	631
K9	390	762	406	917	345	564
K10	189	518	378	475	251	362
Mean	651	1,108	653	1,253	594	852

Analysis of Variance

Differences between—

(*a*) Parents.

(*b*) Years.

(*c*) Replications.

Significant at 0.1 per cent. level.

(Difference for significance between parents at 5 per cent. level = 150 lb. dry cacao/acre.)

It will be seen from the above figures that the best progenies yielded at a rate of some 40 per cent. to 44 per cent. better than the mean. In the nature of Henderson's early selection work, many more or less isolated trees or at least trees, the pollination of which would have come from a restricted source, were selected. This applies particularly in the case of K23 which is self-incompatible. There seems to be no reason why the chance male parentage of this tree cannot be improved on by deliberate selection and, naturally, this number has been used with a variety of male parents in clonal seed gardens.

At all events, the likelihood of a cross of two selected clones giving seed of poorer potential than bulk unselected seed is remote and there is a likelihood of substantial gain in a proportion of the crosses. Pairing a self-incompatible with a self-compatible parent in seed gardens and using the incompatible clone as a source of seed for planting may provide the quickest way of producing improved seed in commercial quantities. Insufficient is known regarding the existence of cross-compatibility between self-incompatible clones in our population to make use of this for the present.

Some 65 seed gardens have been planted at Keravat. The method is empirical, seed gardens being established as the parent trees were propagated. It would of course be desirable to plant all seed gardens in isolation, but this is impracticable. In the first gardens established there was a scarcity of self-compatible clones. Gardens took the form of a single line of a self-compatible clone with two surround lines of the self-incompatible parent. Two lines of robusta coffee were planted between seed gardens to form a rough barrier. This design is hardly satisfactory. As material from self-compatible clones became available in greater quantity, the gardens were designed with self-incompatible plots with a triple compatible surround.

The pairing of clones was highly empirical. Pairings between both similar and divergent types have been made. Where a clone appeared to be weak on a particular point it was paired with a clone in that point.

The clonal seed gardens are now coming into bearing and at a later date each one will be progeny-tested. As the results of progeny testing come to hand, gardens yielding unimproved seed will be discarded and those showing promise will be extended. In the meantime, seed is already being distributed from the seed gardens in small quantities. Our planting recommendations for this seed remain the same. Plant three seeds per point and cull the two weaker ones.

CLONE DEVELOPMENT

(See plates 2-8.)

The vegetative propagation of desirable types is the most straightforward approach to improvement. Its possibilities are limited only by the variability of the seedling population on which it is based. Our primary object is to develop desirable types through seed, and vegetative propagation of clonal material is regarded as a means to an end, although a useful and indispensable expedient in the meantime.

This being the case and having regard to the amount of research work carried out on the subject, we determined to use cuttings rather than other forms of vegetative propagation. Satisfactory methods for the striking of cuttings and field establishment have been worked out by Mr. I. L. Edward of this Station. A paper by Mr. Edward will appear in a later issue of *The Papua and New Guinea Agricultural Journal*.

The problems associated with the use of rooted cuttings include cost, difficulty in transportation and weakness in the early stages of growth. The method of Nichols (1958) which has been tried successfully here, considerably reduces cost and goes a long way to solving the transport problem. Some years ago, stagnation of cuttings after planting out in the field was a problem of major importance, but the methods of propagation used by Mr. Edward have overcome this problem. Nevertheless, the young cutting at best is not nearly as hardy as the young seedlings and requires "nursing" in its early stages of growth.

Clone Testing

Of the 60 clones to be tested, 20 are self-compatibles and 40 are self-incompatibles. Clones are tested in series of 13 on a modified randomized block design which eliminates any possibility of fertilization of incompatible clones becoming a limiting factor in yield (see Plate 10). Nine self-incompatible clones occur in 3 x 2 plots, with a double self-compatible surround. There are four replicates and a different self-compatible clone is used as the pollen source in each of the four replicates. This has been repeated five times and a single self-compatible clone forms a bridge between all series.

In addition to testing the yielding ability of the clones involved, these trials will provide information on the influence of male parentage on flavour and cocoa butter content by comparison of the same self-incompatible clones from each replicate. Furthermore, 36 different lines of clonal seed will be produced.

Self-compatible clones not accommodated by the above trial are to be tested in a separate randomized block and will include the same bridging clone.

The first of the above series is now coming into bearing (three years old) and only the last-mentioned randomized block for self-compatible clones remains to be planted.

Field Use of Clonal Material

(see Plates 9 and 11.)

It is not proposed that clonal material be used in the form of large mono-clonal blocks. There are advantages and disadvantages in complete genetical uniformity and while uniform high-yielding ability and uniform bean characters in respect of bean size, strength and flavour and cocoa butter content are valuable, a degree of variability in other characters may be a distinct advantage.

For commercial use it is our intention to recommend the establishment of poly-clonal blocks using mixtures of 10-12 clones. In the absence of precise information on pollen movement within a block, these clones will be equally divided between self-compatible and self-incompatible clones.

In the meantime, trials have been laid down to give better information on pollen movement. These take the form of three isolated blocks—21 x 21 trees (approximately).

PLATE 2.—*Weak clone showing splitting of branch.*

PLATE 3.—*Clone testing, planted March-June, 1956. Photograph taken at three-year-old stage.*

Trial A—where the centre line of the block is planted with a self-compatible clone (KT82) with a uniform dark purple break and the surround lines are planted with a self-compatible clone (KT14) with a uniform pure white break.

Trial B—where the centre line of the block is planted with a self-compatible clone (KT14) with a uniform pure white break and the surround lines are planted with a self-compatible clone (KT82) with a uniform dark purple break.

PLATE 4.—*Upright growth with desirable, well-developed form.*

PLATE 5.—*Cutting in clone testing block, photographed at three years old.*

PLATE 6.—*Clone testing. Three-year-old trees showing profuse fan branching at base.*

PLANT 7.—*Clone testing cutting, showing three-year-old tree, demonstrating inverted clone development.*

Trial C—where the centre line of the block is planted with a self-compatible clone (KT82) with a uniform dark purple break and the surround lines are planted with a self-incompatible clone (KT8) with a uniform pure white break.

PLATE 8.—*Hedge planting of clonal material, pruning and spacing trial. Clones planted 18 feet by 16 feet in mid-1957.*

PLATE 9.—*Older clones in observation block, showing effects of pruning.*

The break of the pods set in the surrounds and setting and "break" in Trial C should enable us to trace pollen movement with reasonable accuracy. By cutting beans in the pods set on the surround trees, it will be a simple matter to determine the pollen source. Such observations will be made six months after the two clones in each block have been observed to be flowering in phase.

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HYBRID SEED DEVELOPMENT

Background

Little precise information on hybrid vigour in *Theobroma cacao* has emerged but there seems to be no doubt as to its existence. The performance of ICS x SCA crosses in Trinidad reported by Bartley (1957) support this conclusion.

The nature and performance of cacao in Papua and New Guinea suggests that there is already in our population a hybrid vigour component. This is illustrated by the fact that all of our outstanding mother trees are distinctly hybrid in most characters.

PLATE 10.—*Clonal block of 12-foot triangle plantings in pruning and spacing trial, planted mid-1957.*

The occasional appearance in Henderson's open-pollinated progeny trials of certain weedy, abnormal progenies with a variety of genetical defects and lacking vigour led us to suspect that natural inbreeding may occur. Observations indicate that any self-compatible tree is, in fact, usually *selfed* to the extent of 50 per cent. or higher and, under these circumstances, natural inbreeding from generation to generation is almost inevitable in some small degree.

The early open-pollinated progeny trials were planted in pod rows and it is noticeable that for a particular progeny, while certain "pod-rows" are defective, others are normal (see Plate 12). It was this state of affairs which caused us in the first instance to consider the possibilities of a deliberate programme of inbreeding followed by selection and crossing of divergent types, with a view to producing uniform F_1's with maximum hybrid vigour combined with desirable agronomic characters.

PLATE 11.—*Pruning and spacing trial in clonal block. Planting 12 feet on triangle.*

Hybrid Programme

Generally speaking, the development of specific breeding techniques for the maximum utilization of heterosis in tree crops has been neglected. This is somewhat surprising since, although the results may take considerably longer to achieve, perpetuation may be a much simpler matter than with annual crops.

Under the circumstances, it is impossible to lay down a firm, long-range breeding programme. A tentative programme can be planned and this will require modification as preliminary results and problems

PLATE 13.—*Hand pollinated selfed progeny of* K10. *Trees are five years old.*

PLATE 12.—*Open-pollinated seedling cacao at* 11 *years old. Note dwarf progeny of* K10, *probably due to in-breeding The same effect has been obtained by hand pollinating* K10 *to obtain selfed seed.*

emerge. The period between generations, compatibility effects and the period of seed viability and other factors will require departures from the methods used for annual crops. In broad principle, however, we propose to follow the method of Comstock *et al* to make use of both general and specific combining ability.

(1) Parent trees with desirable agronomic characters have been selected within two groups (see Plates 18, 19 and 20) :—

A. Criollo or near Criollo.

B. Forastero or near Forastero.

The compatibility of all such trees has been determined.

(2) Self-compatible parent trees in Groups A and B have been self-pollinated and the S_1's planted out in a block set aside for this purpose.

(3) Further selections in Groups A and B have been made in

PLATE 14.—*Loss of vigor in* S_1 *generation. Tree is eight years old.*

PLATE 15.—*High ramifications occurring in some selfed progeny.*

LATE 16.—F_1 *showing vigour of* F_1 *cross at approximately eight years of age.*

PLATE 18.—*Criollo-type tree.*

LATE 17.—*Material nursery, source of cutting material for clones. Trees planted nine feet by four feet.*

the S_1's and the compatibility of these selections has been determined.

(4) Selections in the S_1's have been self-pollinated and the S_2's have been planted in a block set aside for this purpose. These S_2's are still at the seedling stage and further selections will be made in this progeny when they come into bearing.

(5) Forty-eight trees have been selected from the S_0 and S_1 generations as follows :—

Group A.—

12 Self-compatible Parents.
12 Self-incompatible Parents.

Group B.—

12 Self-compatible Parents.
12 Self-incompatible Parents.

PLATE 19.—*Criollo-type pod.*

(6) Using the Self-incompatible selections as the female parents and the self-compatible selections as male parents, 48 crosses have been made—24 like crosses and 24 unlike crosses. Thus, this trial will provide information on the specific combining in each of 48 crosses, but little or no information will be obtained on general combining ability.

The progeny of these crosses are to be tested in a trial using a triple rectangular lattice design (Cochran and Cox, 1950) involving 12 groups of three replicates, each group consisting of four crosses (two like and two unlike). Plot size is 4 x 4 trees, 15-foot-square spacing and the whole trial is suitably guarded.

Discussion

The specific objects of the above trial are therefore—

(*a*) To test 48 specific crosses.

(*b*) To test the generalization that unlike or divergent crosses are generally superior to like crosses.

The next steps in the programme will depend on results of the programme as it has been planned so far. Already some interesting points have emerged from the inbreeding :

(*a*) *Vigour* (see Plates 13, 14 and 15).

S_1's show a considerable loss of vigour compared with the S_0's. No actual measurements on this have been carried out, but there is no doubt that the first generation of inbreds falls far short of the vigour of trees in our main plantings. Certain crosses were planted side by side with the S_1's and although these are in no way outstanding they are about half as big again as the selfs. Certain parent trees have thrown a highly uniform progeny indicating possibly a high level of homozygosity to begin with. Such progenies show a considerably greater loss of vigour than parents which yielded very variable S_1's indicating a high level of heterozygosity in the parent. Certain progenies (e.g., K10), and individuals within other progenies grew to a height of three to four feet and then stopped (see Plate 13). Such plants produce a profusion of chupons from the jorquette and below. These chupons expand slightly and stop growing. As would be expected the S_2 seedlings show promise of being less vigorous than the S_1's.

PLATE 20.—*Forastero type obtained from selfing* K4-101. *Trees are six years old.*

(*b*) *Defects*

A variety of defects has appeared in the S_1's and S_2's. These include—

Viability. There is a considerable drop in the viability of seed produced by the selfing of S_1's. This seems to be related to "embryo failure" noted below.

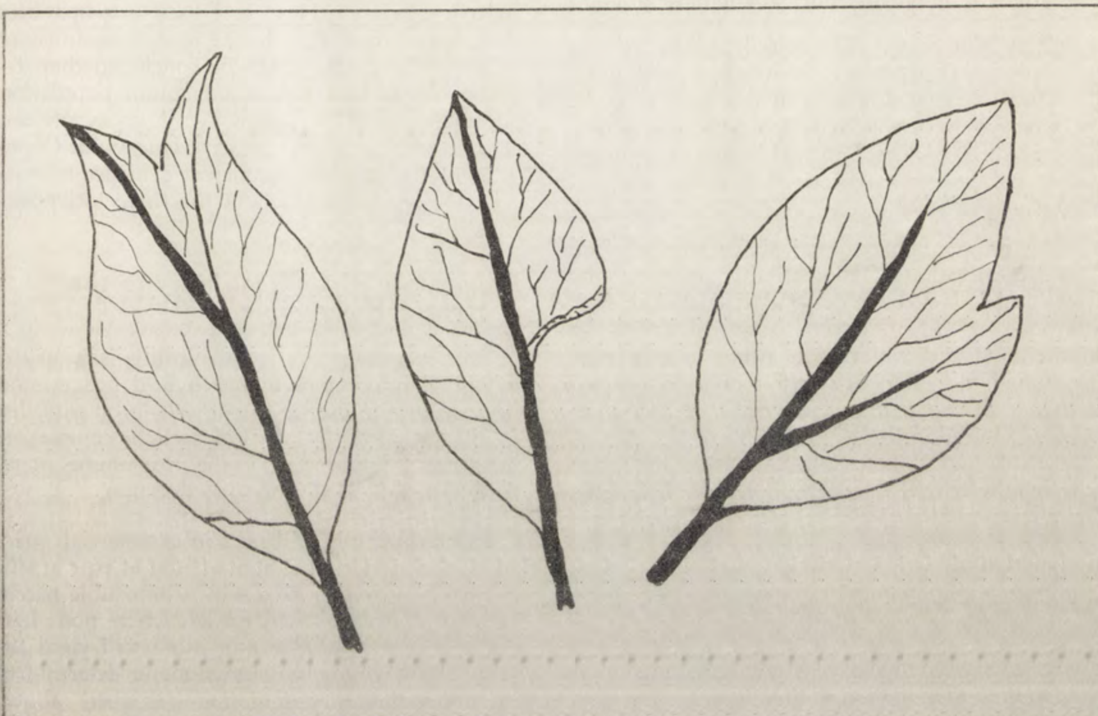

FIG. IV.—*Deformed leaves noticed on in-bred trees.*

Leaf Form. Some S_1's and many S_2's show leaf deformities in the first leaves to emerge above the cotyledons. These deformities are illustrated in Fig. IV. Seedlings appear to grow away from such deformities within the first 6-8 weeks of growth.

Cotyledon Scorch. The cotyledons of some S_1's and many S_2's show a marked scorch along the inner face. Such a bean cut across shows a brown "centre breakdown".

"*Embryo failure*". This term is used for want of a better one. The beans of certain S_1's and many S_2's often show varying degrees of incomplete development. These differ from the few undeveloped seeds which are frequently found in pods from any population. The seed appears to develop normally for some time. The testas are expanded to full size or nearly full size and, although no cytological studies have been carried out, the endosperm appears to be normal. Cotyledon growth, however, is abnormal. At one extreme there is no visible cotyledon development. In other cases the cotyledon develops to about three-quarters of normal size. In these beans the cotyledons are very loosely arranged within the testa and the viability of such beans is low. When germinated, the resultant plants are completely lacking vigour. It is noticeable that embryo failure seems to be associated with the Criollo rather than the Forastero type. The extent of embryo failure within a pod varies considerably from tree to tree. It is sometimes difficult to find a normal bean in a pod and in other cases the extent of embryo failure is slight. On trees where the selfed pods show embryo failure crossing from a divergent source causes complete disappearance of embryo failure, but crossing from a close source leaves embryo failure unchanged.

Chupon Growth. Certain S_1's produce such a profusion of chupon growth from below the jorquette that this can be put in the "defective" class. The vigour of such trees is frequently normal for most inbreds.

Crazy Flowering. The selfed progeny of one parent (KA2.103) produced a great number of crazy flowerers in the ratio of eight crazy flowerers to 12 normal flowerers. KA2.103 is itself normal in flowering habit.

(*c*) *Compatibility*

The programme outlined above has involved the determination of compatibility of about 300 trees and it is at once evident that existing field methods of identification leave much to be desired. Hand pollination using the covered tube method will clearly differentiate a proportion of self-compatible clones with 12-24 pollinations. It cannot be assumed, however, that all the remainder, where "takes" have not been obtained, are self-incompatible. It has been found repeatedly that it is difficult to self-fertilize self-compatibles at certain times of the year. Following the initial separation from selfing, at the suggestion of Dr. Posnette, we therefore selfed and crossed undetermined trees at the same time, using a known self-compatible as the male parent for the cross. By doing this, it is possible to identify positively a bracket of self-incompatible trees.

This still leaves a proportion of trees unidentified—those which set neither from selfing or crossing. This group frequently includes "crazy flowerers" which carry almost no crop and whose setting ability under any circumstances is extremely poor. It also includes a number of trees carrying a normal crop which for one reason or another are not setting at the time of pollination. To identify these it is necessary to carry on selfing and crossing over a seasonal cycle.

A further group of trees which remains ill-defined, are those which, while setting readily from crossing, set only occasionally from selfing. It would seem, therefore, that the method of identification of compatibility developed by Cope (1939) based on cytological studies would give much quicker and surer results.

The most significant incidental finding arising from compatibility determinations on some 200 S_1 trees is that in no case has it been possible to demonstrate self-incompatibility. In all cases, S_1 trees which could not be selfed also could not be crossed with a self-compatible. Compatibility determinations on the progeny of self-compatible x self-incompatible crosses, identified both self-compatibles and self-incompatibles. Insufficient trees were tested to determine segregation. From this it can be concluded that, for compatibility to occur in our cacao population, the factor must be present as a homozygote and it is recessive. This is in accordance with Cope's (1957) finding, but insufficient evidence is available to confirm or discount the three loci postulated by him.

Importance of Compatibility to the Hybrid Programme

The inheritance of compatibility is a matter of signal importance in our hybrid programme, because of the usefulness of self-incompatibility in the production of hybrid seed in commercial quantities. Future steps in the programme, therefore, depend largely on this question.

In producing hybrid seed in commercial quantities, the simplest method will be to pair a self-compatible parent with a self-incompatible parent in a large, isolated seed garden where pods harvested from the self-incompatible will yield the cross. This factor has been a major determinant in the crossing programme described above. Owing to the absence of incompatibility among the inbreds, it has been possible to draw only male parents from this population and female parents (self-incompatibles) have been largely drawn from the S_0 generation.

This limitation could be removed if a method could be found for distinguishing the pods resulting from selfing and from those resulting from the crossing of two self-compatible parents. Similarly, the problem would be solved if a method could be devised enabling us successfully to self-fertilize self-incompatible trees.

However, in the event of neither of these alternatives being possible, it would seem that our only other alternative will be to cross the inbreds in Group A with a Criollo-type self-incompatible from the S_0's and cross the inbreds from Group B with a Forastero-type self-incompatible from the S_0's to reintroduce self-incompatibility to the inbreds. The choice of parent trees in the S_0's for these crosses will be a critical matter and full attention will have to be paid to their general combining ability. The results of Henderson's open-pollinated progeny trials give a rough indication of the general combining ability of a wide group of S_0 parents.

Subsequently, divergent crosses between Group A and Group B can be made, again choosing self-compatibles and self-incompatibles from each group. Such crossing would resemble the double cross method. In the programme of crossing described above, such crosses are included and we may well have to use the progeny of such crosses to carry on the programme.

SUMMARY

The origin of cacao in Papua and New Guinea is described. This cacao population falls within the "Trinitario" complex. The scope for possible improvement as indicated by the range of variation within the cacao population is discussed. The objects, problems and methods of cacao improvement as used at Keravat are described. The bases for selection in a variable cacao population and the actual selection programme at Keravat are briefly reviewed. Particular attention is drawn to the potential importance of competition effects when selecting for yielding ability. The necessity for satisfying the requirements of both growers and manufacturers is emphasized.

A programme for the production of clonal seed is summarized. The use of the term "clonal seed" in this paper means seed derived from the crossing of two clones. Trials designed to throw light on normal pollen movement within a block of cacao are described.

The development of clones for commercial use and the method of testing at Keravat are given. The possible direct effects of male parentage on bean quality and the difficulties introduced by self-incompatibility in designing clone-testing trials are discussed.

A programme for the development of uniform hybrids through seed is described. This involves the inbreeding of divergent lines followed by selection, out-crossing and progeny testing. The problem of producing hybrid seed in commercial quantities is discussed. Problems introduced by the inheritance of factors for self-compatibility are described. Field trials associated with this programme are designed to test 48 specific crosses and to test the generalization that divergent crosses are likely to give superior results to close crosses. The effects of inbreeding to mature S_1's and to S_2 seedlings are recorded. These effects consist largely of loss of vigour and the appearance of various defects. Mention is made of possible future trends in this programme.

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