CLONAL CACAO AT KERAVAT—Part II*

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As noted in Part I *the vegetative propagation of cacao trees selected for high yielding and quality attributes offers the quickest method of making improved planting material available to the planter. This paper is concerned with details of propagation experiments carried out at Keravat since* 1955 *and includes a summary of the methods in use at present.*

Introduction

If clonal cacao is to be planted on any appreciable scale in this Territory, it is apparent that apart from the initial introduction of material from Keravat, the planter will have to produce his own rooted cuttings. This is mainly necessary because of transport difficulties and expense. In the light of overseas experience there seems to be no insurmountable reasons why this could not be done eventually even though, for the present, this work will still be handled by the Department of Agriculture, Stock and Fisheries.

However, it is clear that the method at present employed is not entirely suitable for private production, although each of the factors and interactions discussed will be operative regardless of the method finally employed. Planters are urged not to rush into vegetative propagation of cacao until—

(i) they have secured from Keravat supplies of proven suitable planting material with which they have established material nurseries ; and

(ii) a more simplified technique is available.

Work on establishing a more simplified technique is continuing.

Propagating

At centres throughout the world producing rooted cacao cuttings, the number of leaves retained on each cutting may range from one to five. Otherwise most methods are similar in that the reduction of leaf size to reduce respiration is usual, as is a root-inducing hormone treatment, and placement in various types of units where high humidities, low temperatures, and low light intensities prevail. Such units include enclosed "Trinidad-type" concrete propagators, glass-covered wooden boxes as used at Keravat, open beds under continuous sprays, beds under polythene sheeting and humidified glasshouses. More recently, polythene bags each containing a single cutting have been employed and the method shows some promise. A number of media, organic and inorganic, is used. Great variation exists from method to method in the frequency and intensity of watering, and rooting periods range from 18 days to 4½ weeks. Rooting efficiency varies considerably and success claimed ranges from 40 per cent. to 90 per cent.

Early Keravat Propagation

Harris (1953) described the method used at Keravat until 1951 and it is on his work that the present methods are based. His method involved the use of wooden propagating units (30 in. x 24 in. x 12 in. inside measurements) with cloth-covered glass lids. Well leached sawdust, approximately six inches in depth was used as a medium, and a commercial preparation, "Hormone 400" (a potassium indole butyrate/potassium naphthalene acetate mixture of unknown ratio or concentration), was used at 75 per cent. to 100 per cent. concentration. Overhead shade admitted approximately 25 per cent. of incident sunlight. Rooting period was 21 to 28 days, after which cuttings were potted out in bamboo tubes using a potting mixture composed of three parts black bush soil to one part composted sawdust, fortified with fertilizer. Hardening was carried out in Trinidad-type concrete propagators over a two-week period.

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The method, after promising initial results, proved disappointing, being characterized by heavy leaf breakdown and considerable rotting of the basal end of the stem within the propagating boxes, heavy losses during and after hardening, and frequent stagnation of growth after potting.

It must be remembered that Harris worked under primitive conditions, with extremely limited resources in an area recently an active war theatre. It is not surprising, therefore, that considerable modifications to his methods were made when more satisfactory facilities became available. None the less, Harris successfully initiated this facet of cacao improvement at Keravat and provided a sound foundation for later work.

Keravat Experiment Programme

When this work was commenced, it was obvious that emphasis in the first instance should be placed on reducing the very high post-potting losses, and on eliminating stagnation of potted cuttings, if any reasonable field establishment was to be obtained. This policy was followed rather than one of attempting to increase rooting percentages, and it paid large and early dividends. However, the experimental work is reported here according to the sequence of operations involved in striking cuttings, rather than in the chronological order in which the trials were conducted.

Material Nursery Establishment and Management

A limitation on large-scale production of rooted cuttings from a single tree is the number of flushes produced by that tree. Nutrition of the leaves is also of the utmost importance and mature trees, having borne crops heavily for a number of years prior to selection, are not well placed in this regard. Hence the first cuttings from a selected tree are planted in material nurseries. This is also a sound insurance against total loss of a potentially valuable clone, due to accident or disease destroying the mother tree.

Spacings vary a great deal from country to country, being as low as 4 ft. x 4 ft. but commonly are 6 ft. x 4 ft. Initial plantings at Keravat were at 9 ft. x 4 ft., but even with heavy cutting this spacing formed an impenetrable thicket by two to two and a half years and spacings have since been gradually expanded to 12 ft. x 6 ft. Usually, first cuttings are ready to produce planting material at about 12 months of age.

Evans (1953) gave a well-balanced survey of factors within the cutting which greatly affect the success of propagation. The material nursery conditions which he investigated included soil fertility, physical conditions of the soil and light intensity. On the basis that the carbon-nitrogen ratio in the leaf was of prime importance, he recommended that in poor soils the light intensity be reduced to around 20 per cent. of natural night, increasing to a maximum of 50 per cent. with highly fertile soils.

Graham and Baseden (1956) draw attention to the inherently high nutrient level of the volcanic ash soils of the Gazelle Peninsula of New Britain. These workers emphasize, however, that maintenance of a high fertility level is entirely dependent upon maintaining a high level of organic matter in these soils. *Leucaena glauca* shade trees, together with leaf fall from cacao, provide sufficient organic matter for this purpose, and so the higher light intensities as recommended by Evans are approximated in the Keravat material nurseries.

The most important aspect of management of material nurseries is the timing of shade thinning. This is best done from the beginning to the middle of the wet season, when the weather is more overcast and duller. A good shade canopy is allowed to form in time for the onset of the dry season. Difficulties have been encountered after prolonged dry periods when rapid chlorosis of cuttings within four to six days of setting has been noticed. This is presumably due to the carbon-nitrogen ratio in the leaf being unduly high and may be corrected quickly by soil applications of urea.

Periodically it is necessary to prune the material nursery very heavily, replacing entirely the old branches with new growth. Soil dressings of nitrogen at the time of pruning are beneficial.

Collection of Cuttings

This is most convenient between 6 a.m. and 8 a.m., but several trials and long-term observations have indicated that the time of collection of cuttings has little, if any, effect on final success.

Plate I.—Leaf cuttings in propagating box at Keravat.

Cuttings are placed into sodden copra sacks immediately after removal from the tree, and are taken to the nursery where leaf area is reduced and hormone treatments are applied, prior to setting in the propagating boxes. Bags of cuttings are sometimes left until the afternoon before planting but provided that periodic applications of water are given no deleterious effects appear. Leaves must be kept moist at all times after removal from the tree.

Leaf and Stem Maturity

This is an aspect of cacao propagation which varies considerably from centre to centre, mainly because of varying conditions under which material nurseries are established, but also because of vastly differing rates of growth. The very marked effects which leaf maturity exerts on the degree of success attained has not always been appreciated.

Harris (1953) established a criterion for leaf maturity based on the texture of the laminal tissues. They were to be of the consistency of paper, sufficiently hard to rustle when crushed in the hand, but not so hard as to crack and split. Leaf colour was to be as deep a green as possible. Urquhart (1955), in reporting the work of Evans, recommended that leaves be deep green in colour and that the dorsal surface of the stem be russeted, while the ventral surface should be a light green colour.

Castro (1952) obtained best results from material in full flush, the flush being removed before planting. Superiority, however, was dependent upon the use of an optimum hormone treatment (8,000 p.p.m. indole butyric acid), as similar cuttings without hormone gave poorest results. He concluded that the limiting factor in such material was a deficiency of natural hormones.

In material nurseries at Keravat, particularly in those nurseries under 18 months old, a problem exists wherein growth is frequently so rapid that one flush has not yet "matured" to either of the first two above standards before the apical bud develops further into a new "flush". This new flush can in extreme cases be up to 8 in. to 10 in. in length before russeting of the dorsal stem surface and a deep green leaf colour develops.

An objective and simple means of assessing maturity is necessary in New Guinea and it was decided that initial trials would be based

on the degree of development of the apical bud. Results of leaf maturity trials (Appendix I) showed that the incidence and vigor of rooting increase markedly in those cuttings where the bud had either commenced development or was actively growing provided that the apical leaf (or leaves) is removed. The extent of development of the apical bud has no appreciable effect on incidence of leaf breakdown, proportion of cuttings satisfactorily struck, or extent of root development. The results strongly suggested that leaf breakdown increases with increasing age of leaf. Theoretically one would predict larger functioning leaf area to be associated with increasing rooting vigour, which is contrary to the results obtained. Stem maturity trials (Appendix II) were conducted to determine the effects of age of the tissue at the base of the cuttings. It was found that root primordia were initiated earlier in young tissues (Fig. A3). The vigour of rooting appeared to be much greater in younger tissues, but this may not have been statistically significant. Younger tissue showed greater development of basal callus in the early stages, but this did not inhibit early root development.

Apparently leaves fare better when the older stem tissue is retained (Fig. A5), but this may be due to the longer stem used, rather than its age.

Lamina Size

Establishment of a minimal size to which leaves may be reduced has some bearing on the final cost per cutting with most forms of cacao propagation. This is because it dictates the number of cuttings which may be planted in any given area of propagating space. Theoretically, the extent of leaf reduction will also affect the respiration/photosynthetic balance.

Results of an experiment to determine the effect of various leaf areas (Appendix III) showed that best results were obtained when the leaves were cut at from three to five inches along the midrib.

Planting in the Boxes

Cuttings are inserted between 2½ inches and 4½ inches into the rooting medium, the determining factor being the length of the cutting. Spacing varies from 30 to 40 cuttings per five square feet, 32 being most common. No comparative trials on spacing within the units have been carried out.

Rooting of Cuttings

A number of experiments was conducted to determine the most satisfactory means of rooting cuttings. These included a series of hormone trials to assess the relative efficiency of hormone-type rooting stimulants. Results (Appendix IV) of a trial to establish the optimum concentration of Hormone 400 (H400) using the quick-dip method showed that the number of cuttings rooted increased markedly with concentrations of hormone up to 75 per cent., but that they fell off when the hormone concentration exceeded that figure. Both leaf breakdown and basal stem rotting increased directly with the hormone concentration, whereas the formation of basal callus decreased.

Root production was most satisfactory in the 75 per cent. treatment and notwithstanding the defects of high leaf breakdown and basal rotting this was regarded as the best concentration to use.

An experiment to obtain by a "dilute method", stimulation comparable with that achieved with the 75 per cent. concentration of H400 showed that all hormone treatments—whether "concentrated" or "dilute"—increased both number of cuttings struck and the total root weights when compared with a water control. (Appendix V.) Of the treatments used, that using a 2 per cent. H400 solution and soaking for three hours gave results comparable (with regard to rooting percentage and vigour) with the 75 per cent. dip, and the level of leaf breakdown and basal rotting were appreciably lower although still at an unsatisfactory level.

Both these trials showed that the stimulative and phytotoxic ranges of H400 overlapped to an unfortunate degree.

Trials with naphthalene acetic acid (N.A.A.) showed similar trends for rotting, leaf-breakdown and callus formation as did trials with H400. However, a similar trial concerned with a 2,000 to 10,00 p.p.m. range of β indole butyric acid (I.B.A.) in 50 per cent. alcohol indicated that I.B.A. gave satisfactory results in comparison with H400. The optimum range of 6,000 to 8,000 p.p.m. gave a higher percentage strike with a strong suggestion of increased vigour of rooting, and with a markedly lower level of leaf breakdown and basal rotting than H400. A further trial to confirm these results

was also used to see if there were any significant differences in the effects of 6,000, 7,000 and 8,000 p.p.m. of I.B.A.

It was determined (Appendix VI) that a significantly greater number of cuttings struck after the 7,000 and 8,000 p.p.m. I.B.A. treatment than after the H400 treatments. Leaf breakdown and basal rotting in the I.B.A. treatments were comparable with the levels obtained when no hormone was used and were far below the levels for the H400 treatment.

Evans (1953) had found a mixture of I.B.A. and N.A.A. to be superior to I.B.A. alone; and trials with different mixtures of I.B.A. and N.A.A. were conducted at Keravat. However, the use of N.A.A. and I.B.A. to give a total hormone concentration of 8,000 p.p.m. significantly reduced both the incidence and vigour of rooting .(Appendix VII.) Because of these results, I.B.A. at 8,000 p.p.m. is now used exclusively at Keravat.

Leaf Breakdown, Basal Rot and Basal Callus

Evans (1953) considered the air-water relations of the medium to be the most critical of the external factors involved in the successful rooting of cacao cuttings. He demonstrated that basal rot was attributable to a high water-to-air ratio in the pore spaces of the medium, while a low water-to-air ratio resulted in the excessive development of basal callus. Where the water was slightly excessive, but not to such a degree as to cause rotting, he noted a proliferation of callus rods of undifferentiated tissue produced from the phellogen and growing through the lenticels. These were first white, then suberized and turned brown.

It is suggested that an important direct effect of any of the stimulants used is to heighten the sensitivity of the cutting to excessive water in the medium. This could possibly be due to increased oxygen requirements at the site of root development.

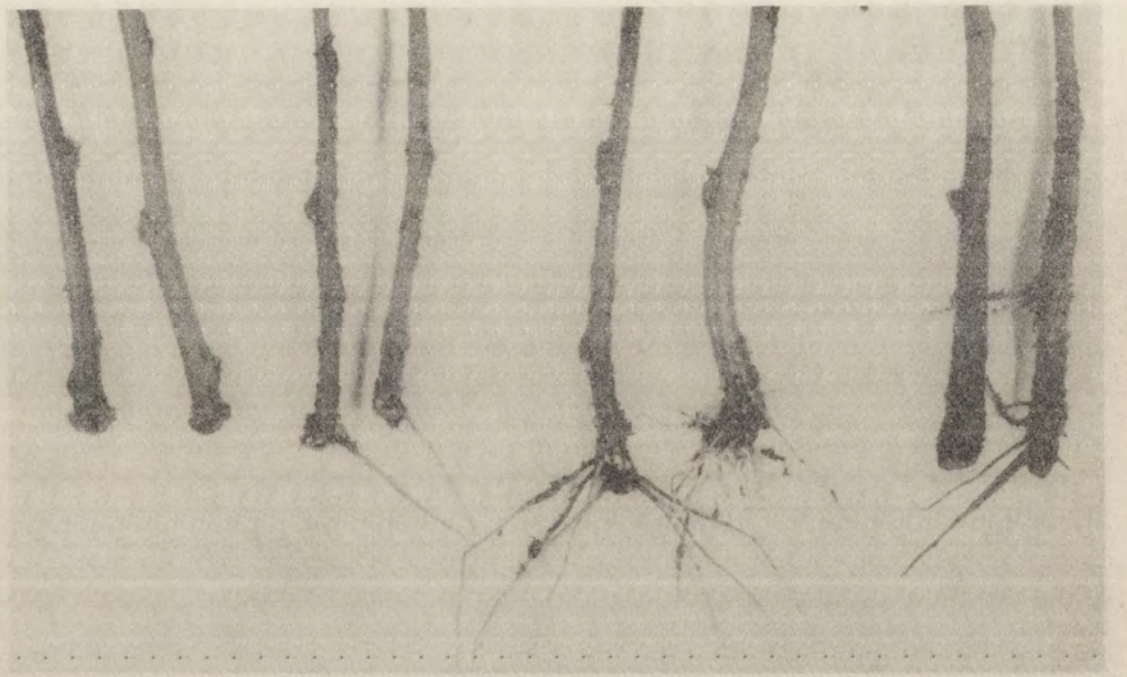

Plate II.—Bases of cuttings after 28 days in the nursery.

(The cuttings show effects of hormone concentration on root development, basal rot and basal callus. Cuttings are paired, showing dorsal side on left and ventral on right. Concentrations (left to right)—0 (water control); 4,000 ; 8,000 ; and 12 000 p.p.m. I.B.A.)

Note optimum root development at 8,000 p.p.m.; decrease of basal callus and increase of cullus rods on stem as hormone concentration increases ; and basal rot at 12,000 p.p.m. which has killed any roots developed.

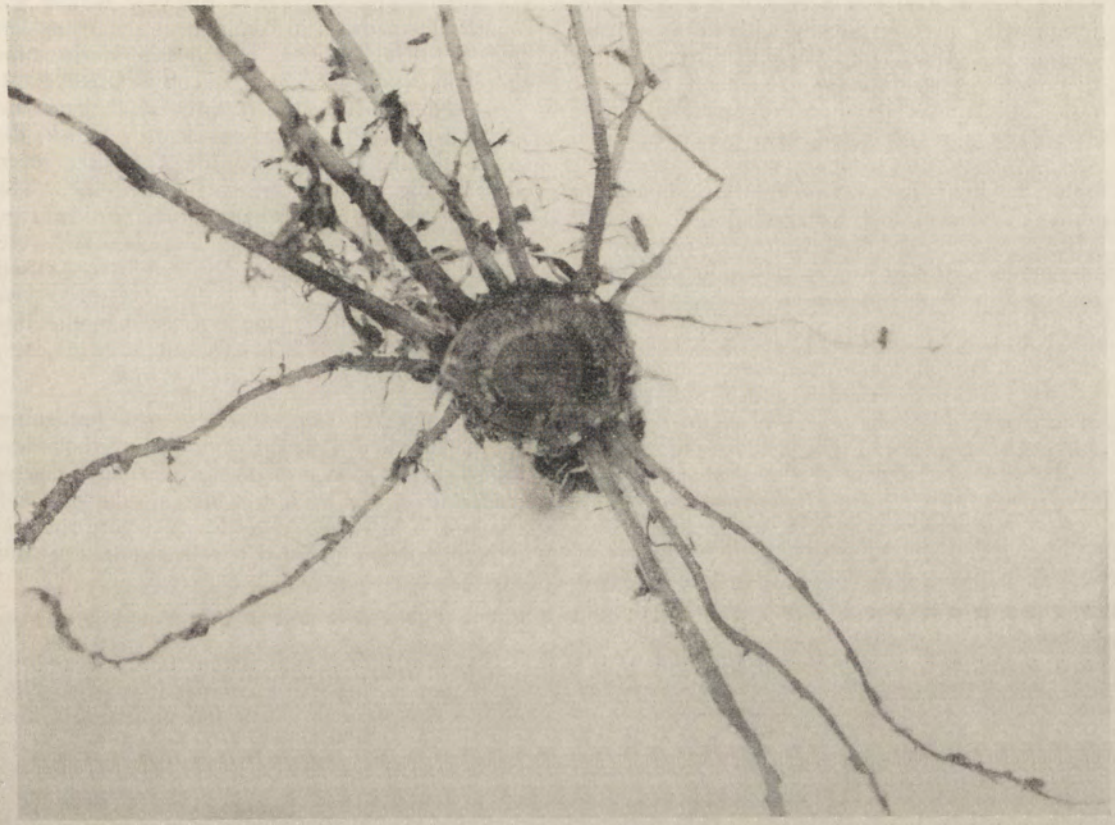

Plate III.—**Enlarged view of base of rooted cutting, treated with 8,000 p.p.m. I.B.A.**
(Whitish basal callus may be seen between the wood and the bark.)

The negative correlations noted in the dilute method hormone trial (Appendix V) between basal rotting and basal callus, together with the decreasing callus production with increasing hormone concentration, supports this hypothesis. There is also the observation that in every case where a "no hormone" control has been used, the cuttings have developed very few callus rods; the incidence of these rods appears to increase directly with hormone concentration. This occurs under air-water relationship conditions which are quite standardized. Unfortunately, due to the difficulties of devising a suitable objective measurement for this feature, no numerical data have been collected, but the photographic evidence in Plate II aptly demonstrates the point.

Basal callus pads produced on the control cuttings are typically large and hard. The incidence and total quantity of callus produced appears to lessen as hormone concentration increases, so that with I.B.A. at 8,000 p.p.m. the average cutting appears, as in Plate III to have a ring of callus tissue formed between the bark and wood of the stem. Callus tissue may or may not be present over the cut end of the stem at this concentration.

Extreme basal callus formation has frequently been regarded with disfavour, on the ground that it retards root initiation and development. This view is probably correct. However, due to the negative correlation between the incidence of rotting and callus, it is considered that, provided callus development is not excessive, it may be regarded as a sound insurance against rotting. A considerable degree of tolerance by the cutting to fairly heavy callus production has been noted. Callus and rot on a single cutting has been rarely noted.

Leaf breakdown has been observed in many instances to increase directly with hormone concentration. Apart from possible direct toxicity, this indicates an increase in general metabolic rates and stresses the need for material to be in an optimum condition when removed from material nurseries, together with the need for optimum light intensity over the propagating units. Under normal Keravat conditions using I.B.A., leaf breakdown, which is not always present, is restricted to a faint background mottling and presents no serious problems.

Alvim and Duarte (1954) incorporated fungicides with the hormone treatment with success, as did Desrosiers and von Buchwald (1955) in combating *Diplodia theobromae* and *Fusarium* spp. which caused excessive leaf breakdown and moist basal stem rotting. Pathologists at Keravat have never found causal organisms for basal rotting but even so a trial was conducted to examine whether " Cuprox ", a commercial preparation with copper oxy-chloride as the active constituent, had any effect on rooting. Results (Appendix VIII) showed that Cuprox had no ameliorating effects on either leaf breakdown or basal stem rotting but strongly suggested that they increased with increasing hormone concentration. Thus, it appears that rotting at Keravat has been physiological. There have been, however, two outbreaks of leaf breakdown caused by fungi. One very small outbreak of leaf breakdown in 1955, due to a tentatively identified *Septocylindrium* sp., was controlled by stringent nursery hygiene methods. A more serious outbreak in July, 1959, was controlled by spraying a very strong solution of Cuprox on all units and into the rooting medium. The source of these two infections is still unknown.

Hardening of Rooted Cuttings

Evans (1953) emphasized that successful hardening depends upon a realization by the nurseryman that two phases are involved in the process. They are :—

(i) A development period where root growth is encouraged so that the root system is capable of supplying the water requirements of the plant ; and

(ii) A period wherein the plant is acclimatized to lower humidities and higher temperatures than those prevailing in the propagating units.

The method of Harris (1953), which was similar to methods in common use overseas, left much to be desired, and losses during the hardening period were frequently excessive. It consisted of lifting the cuttings at 21 days and potting those that were satisfactorily struck, the remainder being returned for a further seven days before final potting was carried out. The potted cuttings were placed in Trinidad-type propagators with glass lids. The glass lids were closed for the first two days, and then raised to an inch and a half for the next three days with one watering a day. After this, the lids were raised to three inches for another nine days, with only one watering in this time.

An early introduction of *in situ* hardening (since superseded by an improved method described below) was made without any experimental evidence to justify its introduction and resulted in markedly lower losses during hardening than those normal to hardening in the I.C.T.A.-type bins.

In situ *hardening*

This usually commenced on the 23rd to 24th day after setting, and consisted of gradually raising the glass covers of the propagating box for seven to nine days, after which the glass was removed for one to three days before potting. Later, it was deemed necessary to inquire further into the optimum commencement date for *in situ* hardening, and a comparison with hardening in I.C.T.A. bins was included in the trial. (Appendix IX.)

In situ hardening proved to be a highly significant improvement over hardening in I.C.T.A. bins. Differences between dates of commencement of *in situ* hardening failed to attain significance, but this was ascribed to the cool, rainy weather which prevailed at the time the trial was run.

Although *in situ* hardening gave satisfactory results, the great amount of supervision necessary, and the unduly large amount of labour involved, render this method unsuitable when large numbers of propagating boxes are in use.

Present " hardening " method

For the method now successfully in use at Keravat, " hardening " is scarcely an appropriate term. Cuttings are lifted after 27 to 30 days and are then potted and placed on a concrete floor under a lath house admitting 50 per cent.

of incident sunlight when the sun is overhead. Above the floor is a spray installation. The spray system is powered by a 7.5 h.p. electric motor with a centrifugal pump capable of working 100 spray nozzles at a pressure of 60 lb./square inch. The spray nozzles are Rega No. 1 model with an 0.031-inch orifice and at the above pressure deliver approximately 7½ gallons per hour per jet ; the spacing of six feet by seven feet allows a fall of about 0.3 in. per hour of equivalent rainfall. Bore water of excellent quality, free from injurious salts, is available in a reasonable supply

Spray irrigation is applied fairly constantly from 8 a.m. to 3.30 p.m. for the first four to six days, after which it is cut abruptly to one to three applications a day of about 10 to 20 minutes' duration for a further two and a half to three weeks.

Extremely rapid bud development is made under these conditions. Experiments involving a range of light intensities over newly-basketed cuttings, though not conclusive, indicated that higher light intensities initiate earlier bud burst than do lower intensities, but result in slightly chlorotic and slightly dwarfed leaves if maintained for sustained periods. However, for the short period required of three to three and a half weeks, these leaf symptoms are not unduly marked, while the effect of early bud development is noticeable. It is highly probable that there is also a quicker build-up of carbohydrates under these high light conditions. This would be beneficial in cuttings which have, of necessity, been for a fairly long period under extremely low light intensities (approximately 12 per cent. inside the propagating boxes).

After removal from the spray floor, cuttings are placed under *L. glauca* shade, admitting an evenly-diffused 25 to 35 per cent. of incident sunlight. They remain there for periods ranging from six to eight weeks prior to planting in the field, although some slower clones require a longer period. The only attention given is occasional watering in dry weather, weeding and snail baiting.

Plate IV.—Potted cuttings hardening under *Leucaena* shade after removal from nursery.

Thus, generally speaking, the cuttings are retained in the nursery lath house for about seven weeks, and then go under natural shade for another seven weeks or so before field establishment. The economy of retaining the cuttings under an expensive spray system for a period of three to three and a half weeks may be queried, but it must be remembered that a rooted and potted cutting is quite expensive to produce, and once cuttings reach this stage any losses sustained are of far greater importance than losses in propagating units. The use of natural shade after this period, in place of artificial shade houses as used overseas, more than favourably counterbalances this expense.

Losses in potted cuttings being held under natural shade are rare, and due to physical damage or occasional fungal attack. The *L. glauca* evidently breaks up direct raindrop action, as damage to developing leaves is of no consequence.

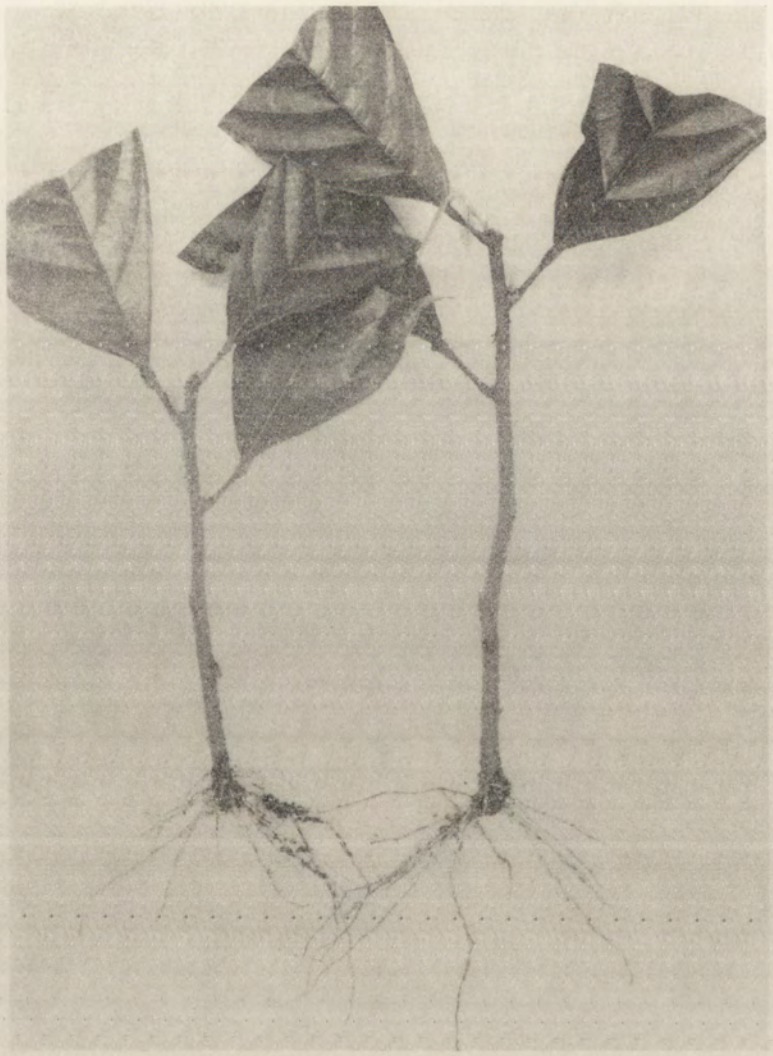

Plate V.—Well-rooted cuttings at the correct stage for potting.

Plate VI.—Potting the rooted cutting.

Potting

This is quite simply carried out, and providing a little care is exercised, presents no problems. Cuttings are lifted from the rooting boxes and shaken, or preferably tapped with the finger, in order to remove excess sawdust, though some is left adhering (Plate V). They are then carried to the potting area, where supplies of potting soil and baskets are ready. It must be borne in mind, when handling cuttings at this stage, that their roots are very brittle and will not take rough handling.

An inch or so only of potting soil is placed in the bottom of the basket, and the cutting held suspended with roots hanging while soil is dribbled into the baskets with the free hand. Plate VI). Care is taken to see that roots are not distorted and that they are evenly distributed in the soil. Only very gentle firming of the soil is carried out by hand, the main firming of the soil around the roots resulting from the action of water under the continuous spray system where the cuttings are next placed. (Plate VII).

The potting is carried out in the nursery shade house and direct sunlight falling on bare roots is avoided.

A trial was laid down to test an alternative potting soil to that employed by Harris and to determine whether fertilizer applications in the potting soil were effective (see Appendix X).

Soils used included a black bush soil consisting of volcanic sand from which a great deal of the finer particles have been removed by water and a " mimosa mulch ". This " mulch " is collected by slashing and rolling back masses of *Mimosa invisa* and raking up accumulated mulch (two inches to four inches in depth) plus

Plate VII.—Potted cuttings hardening on the nursery spray floor.
(In the background is a trolley used for moving the potted cuttings.)

approximately half an inch of topsoil. It is then sieved through a half-inch wire mesh before use. The pH is approximately 5.6.

It was evident from the results obtained that the mimosa mulch resulted in markedly improved growth rates, and caused the earlier commencement of growth. At five weeks after potting, the superiority of mimosa mulch was due entirely to an earlier growth initiation and a breaking of the stagnation common to the black soil treatments. The numbers of new leaves per flushing cutting varied to no significant degree between any two treatments, differences being confined to the proportion of cuttings flushing. Nine

weeks after potting, however, it was clear that the treatment differences were mainly attributable to different actual rates of growth, the black soil treatments producing approximately three leaves per flushing cutting and the mimosa mulch more than five leaves per flushing cutting. Such differences between soil types became further accentuated with time (see Figure 1). A

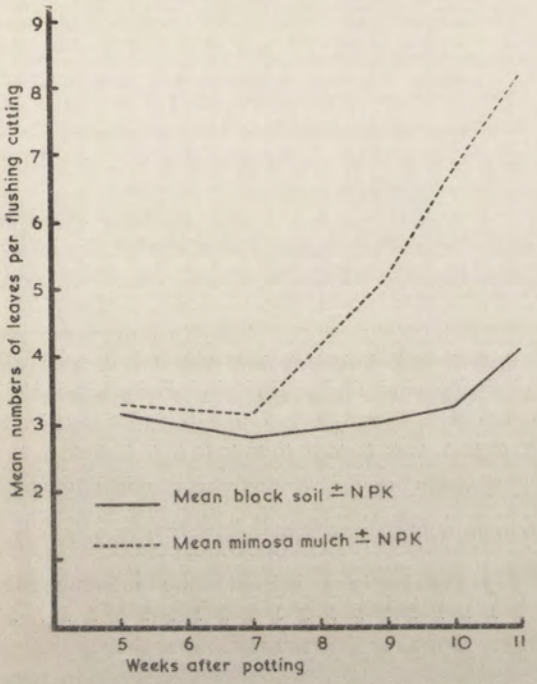

Fig. 1.—Potting soil trial—effects of different types of potting soil on rate of cutting growth.

significant response to the fertilizer treatment used was obtained only with the volcanic sand and the effects of this disappeared between seven and nine weeks after potting. The unfertilized black soil produced a significantly higher death rate at 14 weeks after potting.

The type of measurements taken, however, although satisfactorily demonstrating that significant differences existed, did not reflect the differences of greatest practical value : i.e., differences in apparent health and size of new foliage produced, in which the mimosa mulch treatments were far ahead of the black soil treatments. At the time of completion of this experiment, 14 weeks after potting, the cuttings growing in mimosa mulch were ready for field planting, whereas those in the black soil were stunted and deaths were occurring with increased frequency. Since this experiment, mimosa mulch has been adopted as the standard potting medium and calculations over large numbers of cuttings have shown that the post-potting losses up to the time of field establishment have been lowered from something in excess of 50 per cent. to between one and a half and two per cent.

Later, a similar mulch collected from under established *Pueraria phaseoloides* proved as satisfactory as the Mimosa mulch, although rather more difficult to sieve. It is also evident that mimosa needs to be established for at least 18 months before providing a really first-class mulch in suitable quantities. Accurate assessments of the amount of mulch collected per acre have never been made, but the yield is very substantial.

Pot types

A further trial was set up to determine the suitability of bamboo tubes as pots for cacao cuttings and to compare them with the type of basket used overseas. This trial was also to check the results of the "potting soil" trial and to determine any interactions between pot types and potting-soil types.

Results (Appendix XI) showed that, regardless of pot type, the black soil was inferior to the mimosa mulch (thus confirming the results of the previous trial). Considering pot type alone, there is no appreciable difference. However, there is a very marked interaction between pot type and soil type. Baskets with mimosa mulch were superior to all other treatments, and baskets with black soil were inferior to all other treatments. The discrepancy between soil types was clearly lessened when bamboo pots, rather than baskets, were used.

It is clear, therefore, that a consideration of pot type alone is insufficient when more than one potting medium is under test. It is possible that water relations may be responsible, at least in part, for this interaction.

The use of baskets as a pot type with mimosa mulch as a potting medium was adopted for all clonal cacao at Keravat after the completion of this trial, and has given highly-satisfactory results.

Other Potting Trials

A fertilizer trial was conducted involving NPK separately and in all combinations over a range equivalent to two hundredweight to 12

tons/acre added to mimosa mulch further to enhance post-potting growth. Completely negative results were obtained indicating that a highly satisfactory nutrient level was already present.

Additional trials carried out from time to time using Urea sprays, commercially prepared "complete" foliar nutrient sprays and several post-potting hormone treatments all yielded negative results, and it is evident that little scope exists for further growth improvements in the post-potting period.

Transport of Rooted Cuttings Outside the Gazelle Peninsula

Because of the Giant Snail (*Achatina fulica*) infestation in the Gazelle Peninsula, and also because of the high cost of shipping bulky material, where possible bare-root transport of cuttings by air to centres outside of snail areas has been conducted.

Cuttings are carefully removed from the potting soil and examined for snail eggs or young. They are then placed with the roots in well-leached sawdust identical to the striking medium, wrapped in brown packing paper, placed in polythene bags .002 in. in thickness, with about one-third of a pint of water and tightly sealed. Packing usually takes place during the night preceding the aircraft's departure.

In an initial consignment to the Lae area, almost 100 per cent. mortality was encountered. Cuttings were quite satisfactory for three days after transplanting, but after this an extremely rapid chlorosis without loss of turgor was evident. This was followed by loss of turgor after 18 to 30 hours with subsequent necrosis and death of the cuttings.

Investigations carried out at Keravat revealed :—

1. Washing of the roots to remove soil was not injurious.
2. No benefits were obtained by spraying with foliar nutrients either before or after transport was effected.
3. Cuttings with soft developing flushes were more susceptible to damage than completely hardened cuttings.
4. Percentage successful establishment diminished as the size of the cuttings increased.
5. There was a possibility of overcrowding in the bags, causing a build-up of CO_2. Six cuttings (remaining in the baskets) each with only hardened leaves were individually enclosed in polythene bags. Six similar cuttings were enclosed in polythene bags containing a CO_2 saturated atmosphere. A similar series of treatments was applied to cuttings each carrying a soft young flush. Treatment duration was 24 hours. Chlorosis symptoms appeared within 24 hours on five out of six cuttings in the young flush x CO_2 treatment. This was accompanied by some shrivelling of the young flushes. Systemic symptoms identical to those encountered at Lae occurred on two of these cuttings after 48 hours. These two cuttings died after six days. No symptoms appeared on other treatments.
6. It was concluded that the basic cause of the failure in this Lae shipment lay in the highly alkaline nature of the potting soil supplied (pH 8.46).

In the light of the above investigations, the following precautions are now taken with all consignments forwarded from Keravat :—

1. Proposed potting media are tested at Keravat before shipment.
2. Number of cuttings per bag is limited.
3. Only small cuttings with one or sometimes two hardened flushes are used.
4. Packing is carried out in humid conditions.
5. A minimum of delay between packing and repotting is arranged.

Attention to these details has given in most instances 100 per cent. successful establishment, heaviest losses to date for centres other than the Lae consignment being 10 per cent. in one small batch. Eighteen hours has been the maximum time interval between commencement of packing and completion or repotting with all except one consignment of 300 cuttings which was made by ship. The delay here was 38 hours and 97 per cent. were successfully established. Maximum permissible delay has not yet been assessed.

Polythene Bag Technique of Striking Cutting

Nichols (1958) devised a method of rooting cuttings individually in plastic bags, at approximately one-quarter the cost of normal methods and in such a way that the rooted cuttings were planted directly into the field at three and a half weeks after setting. The cuttings are pre-

pared in the usual manner, and the basal ends placed in a handful of moist, well-leached sawdust, which is then wrapped in coconut fibre and fastened with a rubber band. This is next placed in a plastic bag with 150 ml. of water, sealed and suspended under about 7 to 12 per cent. of natural light. The possibilities of such a method in this Territory are almost unlimited, where the costs of transport over long distances are high, where bare root transport is necessary when introducing cacao from the Gazelle Peninsula to snail-free areas and where it is obvious that we are seeking a method sufficiently simple for the use of private growers.

Preliminary experiments have been most encouraging with this method, but final assessment of the method will take at least 12 months more, as it remains to be seen whether the coconut fibre unduly restricts root development after planting in the field, and if this does happen, whether it is only a temporary setback. One drawback to the method exists in the greater amount of time needed in preparation of the cuttings, but this is compensated for by having no periodical waterings, by making greater use of available shade house space, and by not having to maintain the cuttings in the nursery until field establishment.

Future Work on Cacao Propagation

Results on a reasonably large scale of clones tentatively approved for release have, over the past few months, averaged a little more than 80 per cent. successfully struck, potted and hardened. It is considered, therefore, that little scope remains for further improvements in treatments applied to the cutting itself, such as further hormone stimulation, better leaf maturity standards, etc.

Future work will be concentrated on the economic rather than technical side of propagation : The non-durable nature of the wooden boxes and breakages of glass covers make the type of unit used to date rather expensive, and future work is to be concentrated on new types of structures, built from more-permanent materials, with wider use of polythene-type plastics in place of glass. Open spray methods of propagation are to be attempted.

Present costs of production are around 23 to 24 pence per cutting (to field establishment) and it is hoped to be able to reduce this by a very appreciable percentage.

Summary of Present Methods

In order to draw together the results of the experimental work described, the methods currently used to establish cacao cuttings will be briefly outlined.

Cutting material is preferably obtained from material nurseries, where clones are grown under *Leucaena glauca* shade, admitting approximately 50 per cent. of normal light. The nurseries are pruned periodically and fertilized with nitrogen.

Cuttings are taken from the youngest mature flush, at a stage when leaves are dark green and the dorsal surface of the stem is russeted. The apical bud will have swollen and may have grown to as much as eight inches in length. This cutting material is carried to the nursery in wet copra sacks. There, according to the degree of development of the bud, either the bud alone or the bud plus one or two apical leaves are removed and three mature leaves retained, the stem being cut three to four inches below the lowest leaf. The leaves remaining are reduced by cutting the lamina back to three and a half inches to four and a half inches in length.

The base of the cutting is dipped quickly into a solution of 8,000 p.p.m. β indole butyric acid in 50 per cent. alcohol, and inserted in the propagating medium to about the base of the oldest leaf retained. The rooting medium consists of about six inches depth of well-leached sawdust. The propagating box used is wooden, 30 inches by 24 inches by 12 inches inside measurements, with cloth-covered glass lid. Cuttings remain in the box about 28 days, during which time they are watered about three times daily with a knapsack spray.

They are then taken out, tapped lightly to remove excess sawdust, and carefully potted in baskets with mimosa mulch. The baskets are placed under 50 per cent. light with fairly constant mist spray for four to six days, thereafter occasional spraying for two and a half to three weeks. They are then transferred to *Leucaena* shade (25 per cent. to 35 per cent. light) until ready of planting usually in six to eight weeks.

ACKNOWLEDGEMENTS

The author particularly wishes to thank Mr. A. E. Charles for his care and time spent in criticizing this paper and his help in its completion.

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APPENDICES

Note to Appendices

EXPERIMENTAL METHODS.—

Unless otherwise stated, all experiments described were of randomized-block designs. Some limited use of "pilot" trials was made, and several large-scale, split plot designs were used. In the randomized block designs individual boxes represented a plot, with contiguous boxes grouped into blocks. "Difficult" clones were used wherever possible in rooting trials, the aim being to establish trends over a wide range of treatment levels. Such trends may be masked by the clonal effect should really vigorous rooting clones be used, since such clones often root well regardless of the treatment applied. A subsidiary, though important, reason for the use of "difficult" clones in rooting trials is that in the breeding programme at Keravat (Bridgland, 1959) numbers of cuttings are required from many inbred and weak trees for planting in the production of "hybrid" seed. Some of these clones make extremely poor growth and are very difficult to establish successfully.

All cuttings used were three-leaved and unless otherwise stated had the leaves reduced to three and one-half inches to four inches in length.

Appendix I.

Leaf Maturity Trial.

—	Functioning Leaves.	Cuttings Struck.	Cuttings Satisfactorily Struck.	Root Weight per plot (mgm).
Treatment A	45.4	14.1	8.3	419
B	38.4	10.6	4.6	170
C	33.5	11.8	6.9	324
D	31.8	14.9	12.4	975
E	28.6	15.3	12.6	1,059
Standard Error	± 6.46	± 2.19	± 2.00	± 195.7

Notes.—

1. Eight replicates of 18 cuttings per plot. Measurements were made 27 days after setting.

2. A "functioning leaf" is defined as one which may reasonably be expected not to absciss before a flush has developed and matured on the basketed cutting (i.e., leaf does not break down).

3. Three classes of cuttings were collected—

Class I.—The apical bud still dormant, the leaves were medium green, and in most the dorsal surface of the stem remained green, although first signs of russeting were present.

Class II.—The apical bud was between bud swell and an inch and a half growth of new flush. Leaves were deeper green than Class I, and russeting was general. Ventral surface of the stem remained green.

Class III.—The apical bud was between four inches and eight inches long. Leaves were deep green as was the ventral surface of the stem.

Treatments were.—

A—Class I cuttino—apical, second and third leaves retained.

B—Class II cutting—apical, second and third mature leaves retained, the developing flush nipped off with fingers.

C—Class III cutting—apical, second and third mature leaves retained, the developing flush nipped off with fingers.

D—Class II cutting—apical leaf removed—second, third and fourth mature leaves retained.

E—Class III cutting—apical and second leaves removed, third, fourth and fifth mature leaves retained.

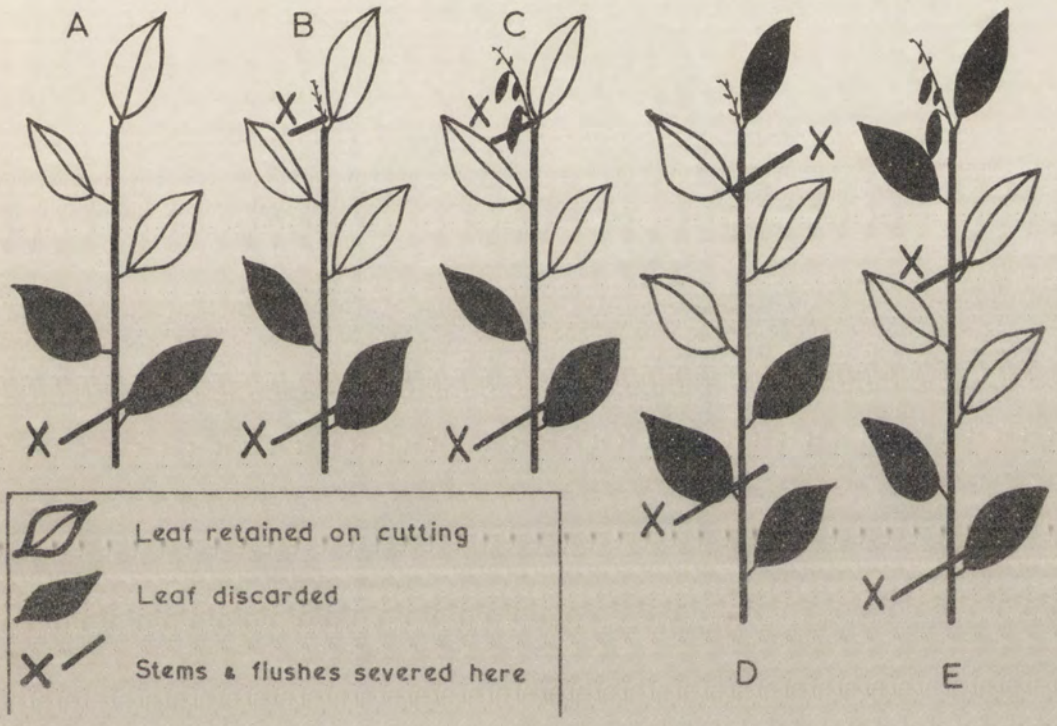

Fig. A1.—Diagram showing treatments used in leaf maturity trial.

DISCUSSION.—

The differences between treatments B and D, and between C and E are probably due to an increase in an inhibiting substance which is produced either in the apical leaves or at the base of the apical bud at the time of bud swell and subsequently while the developing flush is rapidly growing.

Since the differences in treatment between B and C, and D and E involve the removal of tissues, it is much more likely that the superiority of the latter treatments is due to the removal of an inhibitor rather than to any function of natural stimulants. An additional support for this theory lies in the strong inference of depressed rooting after discernable bud development has commenced—viz., difference A—B, A—C. Subsequent observations have indicated a probable clonal response to these types of treatment which can be very strong. An alternative explanation could be one of differing physiological age of the stem tissues at the site of the basal cut, whereby the older tissues may be able to differentiate primordial roots more rapidly than younger tissues.

Appendix II

Stem Maturity Trial

The aim of this trial was to inquire into the effects exerted by the age of the tissues at the base of the cutting.

Two treatments were used, all material conforming to the standards of either Classes II and III as described in the previous trial, which were found to be not significantly different.

Treatment A—Apical, second and third leaves retained; fourth leaf removed and basal cut made above the fifth node. This corresponded to treatments B and C in the previous trial.

Treatment B—Apical, second and third leaves retained; fourth, fifth and sixth leaves discarded with the basal cut made above the seventh node. This combined the leaves of treatments B and C with the basal cut of treatment E in the previous trial (Figure A2).

Two clones were involved and results represent the yield figures for the combined clones as no differences in trends between clones were noted. Four samples of four cuttings and eight samples of three cuttings (total of 40 cuttings) were taken on each sampling day, the days being the 16th, 20th and 22nd days after setting in the propagating boxes. No statistical analyses were made on the data collected, but results can clearly be seen from Figures A3, A4, A5 and A6.

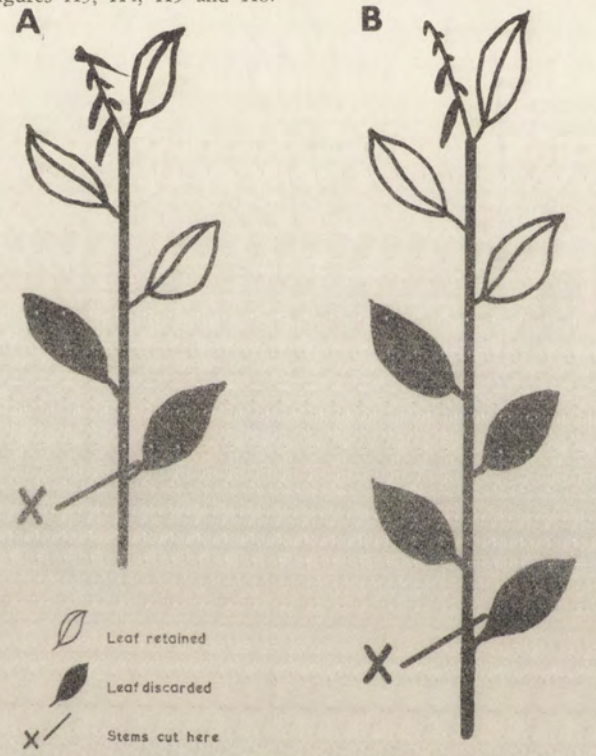

Fig. A2.—Diagram showing treatments in stem maturity trial.

The total number rooted did not vary greatly at the time of the final sampling, but earlier initiation of root primordia in young tissues is evident (Figure A3). The vigor of rooting appears to be much greater in younger tissues, but this difference is only really pronounced after 20 days from setting, and may have been due to sampling errors (Figure A4). From a comparison of Figures A4 and A5, it is fairly clear that early callus formation does not inhibit early root development. Leaves appear to fare better when the older stem tissue is retained (Figure A6) although this could easily be due to the greater length of stem used, rather than to its age. It is evident that under the conditions of this trial the optimum rooting period is longer than 22 days as, up to the 20th day, roots were still just appearing through the cortical tissues of many cuttings and the rate of increase in vigour (Figure A4) was increasing markedly.

It is apparent that the second hypothesis mentioned in the previous trial, namely, that older stem tissues may be able to differentiate primordial roots more readily than younger tissues, is not tenable. In fact, the reverse is the case when comparable leaves are retained on the cutting.

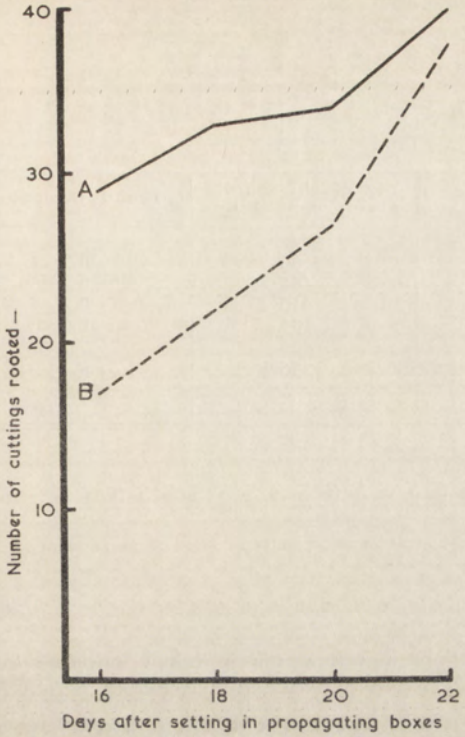

Fig. A3.—Stem maturity trial—effect of stem maturity on time taken for root development.*

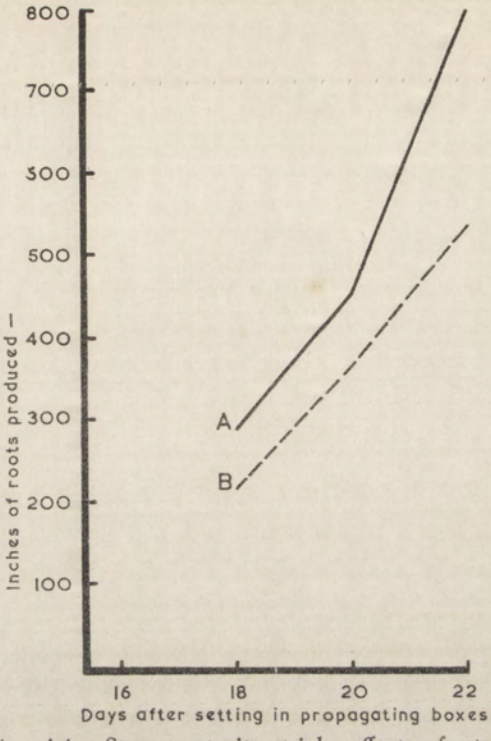

Fig. A4.—Stem maturity trial—effect of stem maturity on vigour or rooting.*

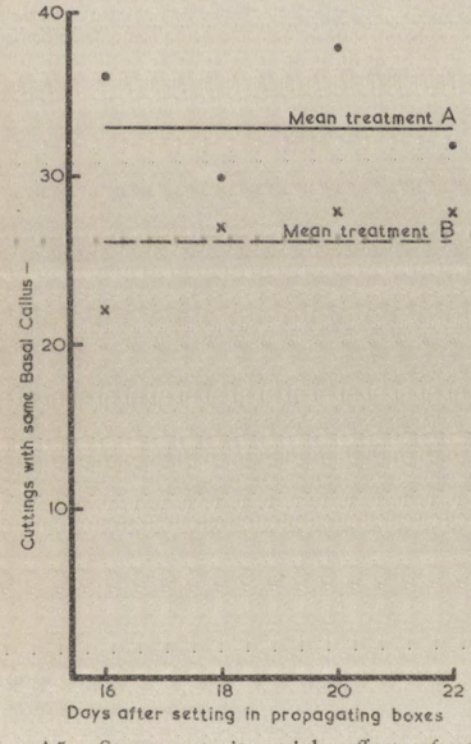

Fig. A5.—Stem maturity trial—effect of stem maturity on development of basal callus.*

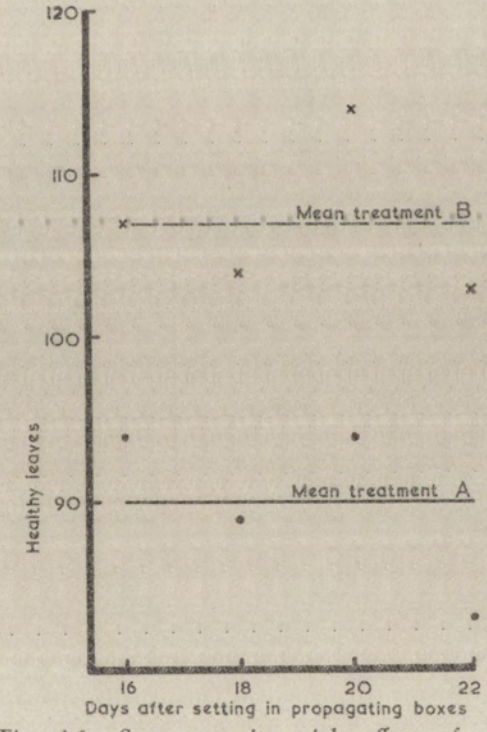

Fig. A6.—Stem maturity trial—effect of stem maturity on leaf breakdown.*

* Forty cuttings sampled on each date.

Appendix III.

Optimum Leaf Size Trial

—	Cuttings rooted.	Dry Weight of roots per plot (mgm).	Leaf Breakdown.
Lamina cut 1 in. along midrib	7.7	66	20.5
Lamina cut 2 in. along midrib	17.5	485	16.6
Lamina cut 3 in. along midrib	15.0	410	9.2
Lamina cut 4 in. along midrib	16.0	593	8.6
Lamina cut 5 in. along midrib	17.2	492	7.7
Lamina cut 6 in. along midrib	14.0	256	8.4
Standard Error	± 1.87	± 112.31	± 1.84

Notes.—

1. Eight replicates with 21 cuttings per plot. Measurements were taken 21 days after setting.
2. All treatments received 8,000 p.p.m. I.B.A. hormone treatment.

DISCUSSION.—

A correlation coefficient $r = 0.996$, $P < .01$ for laminal length and area was calculated showing length to be a satisfactory index of area.

The one-inch treatment, with low percentage strike and root weights, together with high leaf breakdown was obviously below the minimum satisfactory leaf size. At the other end of the scale the six-inch leaves appeared to have a markedly depressed root weight with a strong suggestion of reduced rooting percentage, although the difference is not significant. The two-inch treatment was unsatisfactory in regard to leaf breakdown and it would appear that the optimum length lies between three inches and five inches.

One striking feature of the trial not apparent from the data, was the similarity observed between the six-inch treatment, and to a lesser extent the five-inch treatment, and "control" cuttings in hormone trials. Leaves in these treatments remained a very deep green colour, basal rotting was entirely absent, basal callus was quite heavy and callus rod production negligible. The reverse situation was evident in the one-inch and two-inch treatments.

Appendix IV.

Trial to determine optimum concentration of Hormone 400.

—	CONCENTRATION OF H400						STANDARD ERROR
	100%	75%	50%	25%	5%	0%	
Total Struck	15.0	20.6	18.9	20.6	18.6	13.1	± 1.66
Dry Weight Roots/plot mgs.	500	1016	554	641	252	100	± 108.82
Leaf Breakdown	32.6	26.5	18.9	12.1	15.3	7.8	± 3.92
Basal Stem Rot	21.9	16.2	9.6	7.3	4.1	1.0	± 1.48
Basal Callus	0.0	0.6	1.1	3.4	3.8	11.6	± 1.18

Note.—

Eight replicates of 24 cuttings per plot. Recordings were made 21 days after setting.

DISCUSSION.—

Both leaf breakdown and basal stem rotting increased directly with hormone concentation, whereas the formation of basal callus increased inversely with hormone concentation. A positive correlation $r = 0.974, P = < .001$ was noted between leaf breakdown and basal stem rotting; a negative correlation coefficient $r = -0.796$ for stem rotting and basal callus just failed to attain statistical significance at the 5 per cent. level. Root production was most satisfactory in the 75 per cent. treatment.

Appendix V.

"Dilute method" trial using Hormone 400.

—	Number Struck.	Dry Wt. Roots/plot (mgm).	Leaf Breakdown.	Basal Rot.	Basal Callus.
75 per cent. H400 concentrated dip	9.9	285	18.9	10.4	0.9
5 per cent. H400 with 2-hour soaking	10.4	250	16.3	11.9	0.6
5 per cent. H400 with 1-hour soaking	11.8	510	16.8	9.1	2.1
0.5 per cent H400 with 6-hour soaking	11.0	194	8.9	1.3	10.1
2 per cent H400 with 1-hour soaking	11.6	241	9.8	4.5	6.8
2 per cent. H400 with 3-hour soaking	11.5	355	11.6	5.9	4.8
Water control	6.9	56	3.4	1.3	12.6
Standard Error	± 1.10	± 68.70	± 2.31	± 1.12	± 0.83

Note.—

Eight replicates of 14 cuttings per plot. Measurements were made 21 days after setting.

DISCUSSION.—

Correlation coefficients $r = 0.922$, $P < .01$ between leaf breakdown and basal rotting, and $r = -0.973$, $P < .001$ between basal rotting and basal callus were calculated.

Appendix VI.

I.B.A. Concentration Trial.

—	Cuttings Struck.	Root Wt. per plot (mgm).	Leaf Breakdown.	Basal Rot.	Basal Callus.
Water control	3.8	19	8.3	0.8	15.3
75 per cent. H400	11.1	397	30.9	17.5	0.2
6,000 p.p.m. I.B.A.	13.0	386	7.8	0.4	12.4
7,000 p.p.m. I.B.A.	14.3	429	9.2	1.2	11.8
8,000 p.p.m. I.B.A.	14.1	533	8.8	0.0	10.9
Standard Error	± 1.14	± 81.58	± 2.04	± 0.45	± 1.39

Notes.—

1. Twelve replicates of 18 cuttings per plot. Measurements were made 21 days after setting.

2. The differences in root weights between hormone treatments were mainly attributable to the differences in the number of cuttings struck, rather than to differences in vigour of rooting

Appendix VII.

I.B.A.—N.A.A. Mixture Trial.

—	Cuttings Satisfactorily Struck.	Root Weight per plot (mgm).
8,000 p.p.m. total hormone comprised of—		
I.B.A. alone	5.7	590
2 parts I.B.A. : 1 part N.A.A.	4.2	271
1 part I.B.A. : 1 part N.A.A.	2.2	108
Standard Error	± 0.55	± 75.5

Notes.—

1. Twelve replicates of eight cuttings per plot. Measurements were made 28 days after setting.

2. No attempt was made to measure the activity of the N.A.A. which may have been low thus causing the divergence from the results of Evans (1953).

Appendix VIII.

Cuprox Trial.

—	NO CUPROX				1 OZ. CUPROX/C. FT. MEDIUM				2 OZ. CUPROX/C. FT. MEDIUM				—
	Water Control	25% H400	75% H400	Total	Water Control	25% H400	75% H400	Total	Water Control	25% H400	75% H400	Total	Standard. Error
Leaf breakdown	3.4	14.0	22.7	40.1	5.4	14.4	22.0	41.8	5.5	12.5	25.4	43.4	± 2.69
Basal Rot Incidence	0.9	5.9	11.0	16.8	0.6	6.6	11.4	18.6	1.1	5.6	11.7	18.4	± 0.92
Basal Callus	9.5	4.4	0.2	14.1	9.5	3.1	0.5	13.1	7.5	2.7	0.0	12.2	± 1.11

Note.—
Eight replicates of 12 cuttings per plot. Measurements were made 21 days after setting.

Appendix IX.

Hardening Trial.

—	Cuttings Satisfactorily struck and potted.
In situ hardening :—	
commenced 21 days after setting	22.1
commenced 25 days after setting	21.5
commenced 29 days after setting	21.8
Hardening in I.C.T.A. type bins	17.7 (5.9)
Standard Error	± 1.36

Notes.—

1. Ten replicates of 25 cuttings per plot.
2. The method of hardening in the I.C.T.A bins was similar to Harris's, except that bins were closed for the first five days with four applications of water per day. Lids were then gradually raised over a further five days and watering frequencies diminished to nil over this period. Basketed cuttings were removed from the hardening bins after another four days.
3. The figure in parenthesis represents the number satisfactorily struck and potted at the 21-day period.
4. Post potting losses were not significantly different between treatments and approximated 1 per cent.

Appendix X.

Potting Soil Trial.

—	5 weeks after potting		9 weeks after potting		14 weeks after potting
	New leaves per plot	Non flushing cuttings per plot	New leaves per plot	Non flushing cuttings/plot	Dead cuttings per plot
3 parts black bush soil to 1 part composted sawdust mixture	6.2	7.8	16.5	4.7	1.5
As above plus fertilizer	15.8	5.3	20.8	3.0	0.7
Mimosa mulch	23.8	2.5	55.0	0.2	0.0
Mimosa mulch plus fertilizer	27.7	2.0	54.3	0.3	0.3
Standard Error	± 3.25	± 0.79	± 3.45	± 0.67	± 0.36

Notes.—

1. Six replicates of 10 cuttings per plot.
2. The fertilizer was a 6 : 1 : 2 N.P.K. applied at 2 oz. per cubic foot of the medium.
3. Cuttings were potted in baskets approximately 10 inches in height and 8 inches in diameter.
4. For a description of the black bush soil and mimosa mulch see the section "Potting".

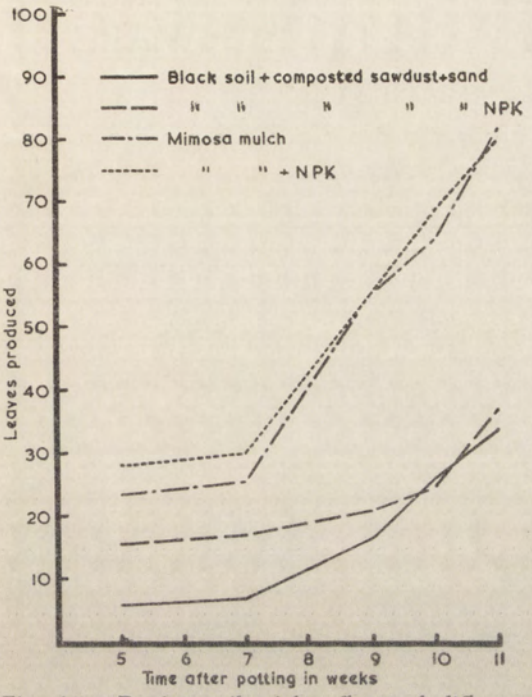

Fig. A7.—Potting soil trial—effects of different types of potting soil, with and without NPK fertilizer, on numbers of leaves produced by the cuttings.

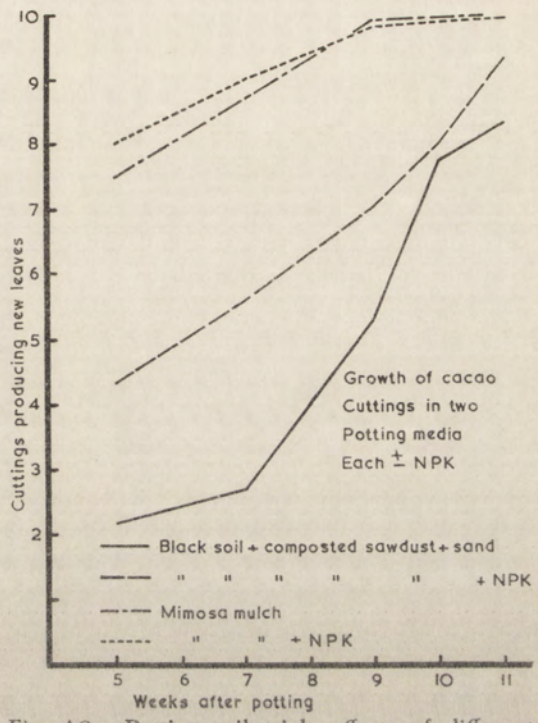

Fig. A8.—Potting soil trial—effects of different types of potting soil on time of initiation of new growth.

Appendix XI.

Comparison of Bamboo Tubes and Baskets as Pots for Cuttings.

—	New leaves per plot
Bamboo pots—	
With a black soil/composted sawdust mixture	41.3
Baskets—	
With mimosa mulch	49.3
With a black soil/composted sawdust mixture	25.0
With mimosa mulch	59.2
Standard Error	± 2.63

Note.—

Six replicates of nine cuttings per plot. Measurements were made 13 weeks after potting.