AN INVESTIGATION OF SOME OF THE FACTORS AFFECTING THE ROOTING OF CACAO CUTTINGS.

by

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Erratum: For Hortamone read Hortomone throughout.
I. **INTRODUCTION.**

While at the present time it is not claimed that cuttings of cacao necessarily give better trees than seedlings or budded material, it is quite evident that cuttings will play an increasingly larger part in the improvement of cacao. For any precise scientific work uniformity of material is essential, such uniformity not being found in seedlings owing to the heterozygous nature of their parents, nor in buddings on seedling stocks owing to the physiological effects of the different rootstocks. When the cacao research scheme was started therefore at the Imperial College of Tropical Agriculture the first problem was to establish cacao on its own roots by vegetative propagation, and thus to build up a stock of clonal material on which future experiments could be based. Side by side with this went the selection in the field of exceptionally good trees for the foundation of clones, and in the first instance one hundred of these were chosen and are briefly described in the annual report of the scheme. (9 - 11) In the propagation work cuttings stools and layers were first tried, and softwood cuttings being found the most successful, the technique in dealing with these was gradually improved and the root and branching systems investigated. (3, 4, 12 - 14) Thus a technique in propagation was evolved, and with a few minor modifications the same technique is used today.
II. AM OF WORK.

The cost of producing cacao plants from cuttings is fully dealt with elsewhere (5) and is considerable compared with the cost of producing seedlings. Even so the greatly superior results that would undoubtedly be obtained from selected clonal material would justify some extra cost. By increasing the speed of rooting of the cuttings it would be possible to pass more cuttings through the process per year, and thus the cost per cutting would be reduced. It was to this end that these experiments were made, and the effect of three different factors on the rooting process was studied; namely, the effect of different concentrations of root forming substances, the effect of different light intensities and the effect of water content. Although speed of rooting was the primary consideration this was not actually measured, the cuttings being left in the rooting medium for a standard time - four weeks. At the end of this time they were removed and the number of roots counted and their length measured; these would be in a direct ratio to the speed of rooting. The averages taken were based on the number of cuttings set. This assumes all non-rooting to be due to the factor being investigated; it is likely however that it may give an unfair result - the non-rooting being due to other factors.
III. Method.

The technique used was the standard technique used at the Imperial College in the routine propagation work (3), with minor modifications. It will be as well therefore to give a complete account of this standard technique and deal with the modifications later under their relevant headings.

Cuttings, both fan and chupon, are taken from nurseries of the I.C.S. selections. The purpose of these nurseries is to enable the propagator conveniently to obtain cutting material in a suitable condition. They were originally set up with budwood from the selected trees but this has since been replaced by fan and chupon cuttings. G/ricidia and banana shade is used. Semi-hardwood cuttings are taken—that is, cuttings bearing the leaves of the last flush fully hardened and that have not yet commenced on a new flush. These leaves are of a certain hardness that is easily determined by practice, and little difficulty is found in selecting suitable material.

The cuttings are removed from the plant with a pair of secateurs—cutting them as long as is possible—and immediately placed with the cut end under water in a bucket; this is to prevent air from being drawn up into the vessels. In this manner they are brought back to the propagating shed.

Here a sharp knife is used to remove, under water, a quarter to half an inch from the base of the cutting. This gets rid of any air that may have become entrapped in the vessels. The lower leaves are pulled off for four or five inches from the base, and the remainder of the leaves have their tips cut off—reducing their length by about one third. Originally done to reduce transpiration, this is continued with on account of the saving of space in the propagating bins—even though its use
in reducing transpiration is doubtful. The cuttings are then tied into bundles according to the number to be planted in each bin, and these bundles are stood in glass jars containing Hortamone A solution at a strength of half a fluid ounce per gallon, about one and a half to two inches of the stems being immersed in the solution. These jars are then stood in the bins in which the cuttings will be planted out; since the atmosphere in these bins approaches saturation, transpiration is reduced and the amount of hormone taken up is more or less constant.

In theory a high carbohydrate content of cuttings is important for rooting, and so in the wet season cuttings are probably best taken in the afternoon. In the dry season however cuttings taken in the afternoon are liable to poor rooting and shedding of leaves, so it would appear that the water content of the cutting is more important and that cuttings should thus be taken in the early morning. For practical purposes the afternoon is the more convenient time as the cuttings can be left in the Hortamone solution overnight - a period of 14 to 17 hours - this being the recommended time of application of the solution. At the end of this period the bundles are removed from the solution, their bases washed under the tap to terminate uptake of Hortamone and the binding strings cut. The cuttings are then planted in the bins, three to four inches of the stem being in the rooting medium; they are well watered with a fine spray immediately after planting, and from then on three times a day.

The propagating bin as used at the Imperial College is a concrete bin three feet long and two feet six inches wide with a sloping lid. The height is not a matter of importance,
though for convenience it is made three feet at the back and two feet ten inches at the front. Drainage holes are provided at the bottom of the bin and large stones are put in, then gravel, and then the sand in which the cuttings are rooted; this is a coarse calcareous sand and keeps exceedingly free from algae and mosses, not having had to be replaced once. The surface of this sand comes to about a foot from the lid. The lids are glazed, and the glass is covered with a double layer of cheesecloth (Appendix A) which assists in controlling the light intensity, and is kept wet, thus controlling the temperature to a certain extent. The lids have handles at the front and on top so that they can be completely removed from the bins, or lifted from the front. These bins are arranged in banks of twelve, being two rows of six each built as one unit back to back. Over the bins is a canopy of domestic (Appendix A) supported on a metal framework; this is seven or eight feet from the ground and extends beyond the bins at the ends and sides so as to give an adequate shade.

After three weeks the cuttings are lifted, and those that have sufficient root development are potted up while those whose roots are not yet strongly developed are replaced in the sand for a further week. This refers to fan cuttings; chupon cuttings take a considerably longer time to root.

Only fan cuttings of clone I.C.S.1. were used for the experiments. I.C.S.1. is an easily rooting clone and stocks of it in the nursery are abundant. It was intended to use cuttings both from the Glicericidia shaded nursery and the banana shaded nursery and compare their behavior, but the material in the former was never in a suitable condition at the right time so only
material from the latter was used. Eight bins were used in the experiments - being the eight inside bins of one of the blocks of twelve. And for subsidiary experiments two other bins were used - of a slightly different pattern - having been converted from a solar propagator.

The diversity of results obtained with different species would seem to indicate however that there can be little generalization and that results with one plant cannot necessarily be applied to another; thus the worker with a previously uninvestigated species must find out the best substance to use on that plant by the method of trial. Here no one should a certain amount of help from earlier work however is in the matter of method of application and in obtaining a list of substances to try. Payne (8) has published a summary of practical work up to 1939 which is useful in directing the attention to relevant papers.

Three methods of application of the post-stimulating hormones to cuttings have received attention: a local application is inoculated uptake by the cutting from a solution and application in solid form in a dust carrier. The first method was largely used in the older experiments but today has generally given way to the latter two, about whose respective merits there is some controversy. Stutzeneyer (12) has found dust to be very good, while Miller and Dowd (17) state that they have found dust being taken up as a carrier - to be inferior to solutions, and give the following reasons. It is very difficult to determine the amount of dust adhering to the base of the cutting and this is very likely to get rubbed off on planting the cutting in the rooting medium and for our experimental work the fact that there is no termination of the time of application of the hormones is
IV. HORMONES.

(i) Introduction.

Ever since the discovery of substances which influence root formation much work has been done with many plants and numerous papers published on the effect of these substances on the rooting of cuttings. The diversity of results obtained with different species would seem to indicate however that there can be little generalization and that results with one plant cannot necessarily be applied to another; thus the worker with a previously uninvestigated species must find out the best substances to use on that plant by the method of trial. Where he can obtain a certain amount of help from earlier work however is in the matter of method of application and in obtaining a list of substances to try. Pearse (8) has published a summary of practical work up to 1939 which is useful in directing the attention to relevant papers.

Three methods of application of the root stimulating hormones to cuttings have received attention; a local application in lanolin, uptake by the cutting from a solution and application in solid form in a dust carrier. The first method was largely used in the older experiments but today has generally given place to the latter two, about whose respective merits there is some controversy. Stoutemeyer (16) has found dusts to be very good, while Tincker and Unwin (17) state that they have found dusts - using talc as a carrier - to be inferior to solutions, and give the following reasons. It is very difficult to determine the amount of dust adhering to the base of the cutting, and this is very likely to get rubbed off on planting the cutting in the rooting medium; and for any experimental work the fact that there is no termination of the time of application of the hormone is a
disadvantage. They also found that roots arise from a much smaller portion of the stem than if solutions are used. On the other hand for the practical man the ease and rapidity of the use of dusts is an important point. Kirkpatrick (6) working with evergreens found both solutions and dusts equally efficacious. It is interesting that Roelofsen (15) found with coffee that hormones inhibited rooting - especially when applied in solution. On the whole it seems as if the solution method gives as good results as any, though maybe in the future the ease of the dust method will lead to its more widespread use.

Zimmerman and Wilcox (19) working with a lanolin paste on tomatoes put the six most effective hormones in the following order: It is meant that only a few could be done in the time available. 

- napthyl acetic acid
- Indolyl butyric acid
- Indolyl acetic acid
- Indolyl propionic acid
- Phenyl acetic acid
- Fluorene acetic acid.

Tincker and Unwin (17) arrange the most effective hormones in three groups as follows: we have an appreciable effect on rooting.

Group 1: (i) Indolyl butyric acid (v) Dihydro-1-napthylacetic acid
(ii) Tetrahydronapthylidene-1-acetic acid "A" (vi) Tetrahydronapthylacetic acid
(iii) Powder containing 70% (v), 20% (ii) and 10% (vii) Group 2: (iv) napthyl acetic acid Group 3: (vii) Tetrahydronapthylidene-1-acetic acid "B" (viii) Indolyl acetic acid.
While for different species the order within the group may change, they believe that the composition of each group will be constant for all plants.

It was found that substances immediately available included α-napthyl acetic acid, β-indolyl acetic acid, β-indolyl butyric acid and β-napthyl acetic acid - the first three being given prominent places in the above groups and being favoured by the majority of workers: the last one is also mentioned as a root inducing substance. It was therefore decided to limit the hormone work to work with these readily available substances and to apply them by means of solutions. It was realized that this would necessarily leave the work very incomplete, but the nature of the experiments meant that only a few could be done in the time available and it was thought best to leave further work to future investigators.

Accessory substances have been found to be of use in root formation. These are applied either with the hormone or at a later stage, sugar, Vitamin B1 (aneurin) and biotin being the three most widely experimented with. Conflicting results have again been obtained and it is to the future to show whether these accessory substances have an appreciable effect on rooting. It would probably be of interest however to try some of them on the rooting of cacao. Blackman's principle of limiting factors (see Appendix B) shows sugar as the primary factor; this would not be so in a leafy cutting such as is used, where the sugar content would be reasonably high.

Spencer did experiments with Hortamone A and β-indolyl acetic acid on the rooting of cacao cuttings, and an unpublished note he wrote upon them is given in Appendix D. It will be seen
that the data he based his results upon were - the average number of roots per cutting and the average length of roots. In the present work more importance is attached to the average of the total length of root per cutting, this figure being more directly related to the time a cutting must be in the rooting medium before it is adequately rooted for its own support. Spencer's success with Hortamone gave rise to the present technique.
(ii) Methods and Results.

For all these experiments the working solutions were made up as follows. Hortamone A - by simple dilution. The other substances were weighed out and dissolved in 95% alcohol - using 5 cc's of alcohol to dissolve every 0.1 gram of substance. This was then made up to one litre with tap water. The alcohol is necessary because of the low water solubility of some of the substances; it has no effect on the cuttings in such a dilute solution.

A preliminary experiment was first carried out to obtain familiarity with the technique. This was a repetition of Spencer’s work with Hortamone A in its essentials. Only four bins were used and the time of application and concentration of Hortamone A solution were varied. No control with tap water was used - the standard treatment of ¼ fluid ounce per gallon Hortamone A for 14 to 17 hours being taken as the control throughout the experiments.

All results given below are actual results. Results expressed as a percentage of the control and represented graphically will be found in Appendix D.

Preliminary experiment. Nov. 6th - Dec. 6th 1940.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Ctgs. set</th>
<th>Ctgs. rtd.</th>
<th>Av. no. r./ctg.</th>
<th>Av. 1. r./ctg.</th>
<th>Av. 1. r.</th>
</tr>
</thead>
<tbody>
<tr>
<td>½ oz. 7 hrs.</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>36 cms.</td>
<td>3.1 cms.</td>
</tr>
<tr>
<td>½ oz. 14 hrs.</td>
<td>10</td>
<td>9</td>
<td>20</td>
<td>68 -</td>
<td>3.2 -</td>
</tr>
<tr>
<td>½ oz. 14 hrs.</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>20 -</td>
<td>1.7 -</td>
</tr>
<tr>
<td>¼ oz. 28 hrs.</td>
<td>10</td>
<td>9</td>
<td>15</td>
<td>45 -</td>
<td>2.3 -</td>
</tr>
</tbody>
</table>

From these results it is seen that Hortamone A at a strength of ¼ fluid ounce per gallon for 14 hours gives the best
rooting. This is the concentration and duration of treatment recommended by the makers. It is also seen that doubling the strength and doubling the time of application do not have equal effects. This is presumably due to a differential rate of uptake.

This preliminary experiment was followed by Experiment I. In this, varying concentrations of the chosen substances were used, these concentrations being arbitrary ones, selected as being of about the right order after examination of results with other plants given by Pearse (8). \( \frac{1}{2} \) oz./gall. Hortamone A was included as control. Results are as follows:

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Ctgs. set</th>
<th>Ctgs. rtd.</th>
<th>Av. no. r./ctg.</th>
<th>Av. l. r./ctg.</th>
<th>Av. l. r.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{1}{2} ) oz./gall Hortamone</td>
<td>10</td>
<td>10</td>
<td>13</td>
<td>35cms.</td>
<td>2.4cms.</td>
</tr>
<tr>
<td>100mg./litre ( \alpha ) nap. acet.</td>
<td>10</td>
<td>10</td>
<td>17</td>
<td>31</td>
<td>1.4</td>
</tr>
<tr>
<td>50mg./litre ( \alpha ) nap. acet.</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>13</td>
<td>0.9</td>
</tr>
<tr>
<td>100mg./litre ( \beta ) nap. acet.</td>
<td>10</td>
<td>10</td>
<td>15</td>
<td>35</td>
<td>2.2</td>
</tr>
<tr>
<td>100mg./litre ( \beta ) ind. acet.</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>10</td>
<td>1.2</td>
</tr>
<tr>
<td>50mg./litre ( \beta ) ind. acet.</td>
<td>10</td>
<td>10</td>
<td>7</td>
<td>17</td>
<td>2.1</td>
</tr>
<tr>
<td>100mg./litre ( \beta ) ind. but.</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>0.7</td>
</tr>
<tr>
<td>50mg./litre ( \beta ) ind. but.</td>
<td>10</td>
<td>10</td>
<td>13</td>
<td>23</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Application of hormone for 17 hours.

These results show that none of the treatments gave better results than Hortamone A, though a concentration of 100 mg milligrams per litre of \( \beta \) naphthyl acetic acid gave equally good results. Concentrations on each side of this were therefore chosen
for the next experiment, as well as concentrations which seemed likely to give better results with the other substances. Hortamone A was again included as a control and it was hoped by expressing the results as a percentage of the control to obtain a direct comparison between the results in this and the previous experiment. Tap water was included for the sake of completeness.

Experiment II.  

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ctgs. set</th>
<th>Ctgs. rtd.</th>
<th>Av. no. r./ctg.</th>
<th>Av. 1. r./ctg.</th>
<th>Av. 1. r.</th>
</tr>
</thead>
<tbody>
<tr>
<td>½ oz. /gall Hortamone</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>29cms.</td>
<td>2.0cms.</td>
</tr>
<tr>
<td>Tap water</td>
<td>10</td>
<td>9</td>
<td>7</td>
<td>17</td>
<td>2.1</td>
</tr>
<tr>
<td>150mg./litre α nap. acet.</td>
<td>10</td>
<td>6</td>
<td>6</td>
<td>13</td>
<td>0.9</td>
</tr>
<tr>
<td>150mg./litre α nap. acet.</td>
<td>10</td>
<td>9</td>
<td>10</td>
<td>31</td>
<td>2.2</td>
</tr>
<tr>
<td>50mg./litre α nap. acet.</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>40</td>
<td>3.3</td>
</tr>
<tr>
<td>30mg./litre β ind. acet.</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>34</td>
<td>3.1</td>
</tr>
<tr>
<td>70mg./litre β ind. but.</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>39</td>
<td>2.1</td>
</tr>
<tr>
<td>30mg./litre β ind. but.</td>
<td>10</td>
<td>8</td>
<td>14</td>
<td>48</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Application of hormone for 17 hours.

When these are expressed as a percentage of the control (Appendix E) it is seen that there can be no comparison between this and the last experiment - the results in this being uniformly better than the results in the last except for α naphthyl acetic acid. A possible suggestion is that some internal factor in the cuttings which varied between the experiments causes different degrees of rooting in conjunction with the different hormones.

From these experiments however it is seen that β indolyl butyric acid at a concentration of 30 milligrams per
litre gives greatly superior rooting to Hortamone A, and it was decided to continue the experiments no further. Subsidiary experiments were carried out later for confirmation of this superior rooting. These in the main consisted of two bins side by side - the cuttings in one treated with oz./gall. Hortamone A, and those in the other with 30 mg./litre indolyl butyric acid. The results were:

Experiment III.  Feb. 21st - Mar. 21st 1941.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Ctg. set</th>
<th>Ctg. rtd.</th>
<th>Av. no. r/ctg.</th>
<th>Av. 1. r./ctg.</th>
<th>Av. 1. r.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hortamone A</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>9cms.</td>
<td>0.9cms.</td>
</tr>
<tr>
<td>β ind. but.</td>
<td>7</td>
<td>7</td>
<td>15</td>
<td>46</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Experiment IV.  Mar. 26th - Apr. 25th 1941.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Ctg. set</th>
<th>Ctg. rtd.</th>
<th>Av. no. r/ctg.</th>
<th>Av. 1. r./ctg.</th>
<th>Av. 1. r.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hortamone A</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>22cms.</td>
<td>2.2cms.</td>
</tr>
<tr>
<td>β ind. but.</td>
<td>8</td>
<td>8</td>
<td>24</td>
<td>93</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Experiment V.  May 14th - June 11th 1941.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Ctg. set</th>
<th>Ctg. rtd.</th>
<th>Av. no. r/ctg.</th>
<th>Av. 1. r./ctg.</th>
<th>Av. 1. r.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hortamone A</td>
<td>6</td>
<td>5</td>
<td>11</td>
<td>31cms.</td>
<td>2.2cms.</td>
</tr>
<tr>
<td>β ind. but.</td>
<td>6</td>
<td>6</td>
<td>19</td>
<td>64</td>
<td>3.0</td>
</tr>
<tr>
<td>Hortamone A</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>18</td>
<td>2.2</td>
</tr>
<tr>
<td>β ind. but.</td>
<td>6</td>
<td>4</td>
<td>7</td>
<td>24</td>
<td>1.9</td>
</tr>
<tr>
<td>Hortamone A</td>
<td>12</td>
<td>11</td>
<td>9</td>
<td>25</td>
<td>2.2</td>
</tr>
<tr>
<td>β ind. but.</td>
<td>12</td>
<td>10</td>
<td>13</td>
<td>44</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Application of hormone in each case for 14 - 17 hours.

The last of these experiments was arranged in a different manner from the others. Half the cuttings were taken at 7.0 a.m. and the other half at 3.30 p.m. In all, 24 cuttings were taken from six plants - four from each - one for each bin - thus ensuring the greatest uniformity possible between the bins.
There was a difference in water content of approximately 6\% dry weight in the leaves between the morning and afternoon material. In both morning and afternoon cuttings, indolyl butyric acid gave a better result. It would be unwise to pay too much attention to the variation in rooting increase between the morning and afternoon cuttings as the fewness of the cuttings and the practical difficulties of this type of experiment might easily make this non-significant. The figures for both are therefore combined at the bottom of the table.
(iii) Conclusions and Recommendations.

In all experiments carried out using $\beta$ indolyl butyric acid at a strength of 30 mg./litre in comparison with Hortamone A solution $\frac{1}{2}$ fl. oz./gallon the former gave superior rooting. It seems likely that the extent of this increase in rooting varies with outside conditions, and from the results it would appear possible that it is especially marked in the dry season.

Experiments should be carried out with other clones, and if this result applies to them also, $\beta$ indolyl butyric acid will replace Hortamone A in the routine propagation with advantage. Appendix C gives directions for making up a stock solution of this substance. It is highly probable that still better rooting can be obtained by the use of accessory substances with a hormone, and further experiments with these and with other hormones would undoubtedly repay the time and trouble spent.
V. LIGHT.

(i) Introduction.

For the rooting of cuttings there is an optimum light intensity. This is correlated with the type of cutting to a large extent, and is closely bound up with the question of carbohydrate and hormone storage. In leafless cuttings taken from resting temperate plants the carbohydrate reserves are high, and a low light intensity gives better rooting. With cacao however, as with all other plants in an active state, reserves are low and light is essential so that a carbohydrate and hormone supply can be kept up. On the other hand too bright light is liable to stop photosynthesis. Thus in the standard routine propagation there is a certain amount of shade over the bins - a domestic canopy 7 to 8 feet above them - and double cheesecloth on the bins themselves. In the course of several months fungi grow, both on the cheesecloth and on the canopy, and the light passing through to the cuttings is thus cut down. These experiments were done therefore to determine the rooting response to differing light intensities, and thus obtain a curve with an optimum; to compare this with the shade in use; and from this comparison to determine the optimum time a canopy can be left up with due regard to the cost of replacement and the rooting of the cuttings. Unfortunately the experiments had to be abandoned after a short while owing to a breakdown in the light measuring apparatus.
(ii) Method.

It was essential before any work could be started to obtain a suitable instrument for measuring the light intensity. The only light meter that could be obtained locally was of a pattern in which the photoelectric cell and the galvanometer were in one piece, and thus it was impossible to take readings inside the propagating bins. The meter was therefore dismantled, and the photoelectric cell remounted as a separate entity and connected to the galvanometer by a length of flex. As the instrument was too sensitive for the light intensities usual in the bins various methods of reduction of sensitivity were tried. Filters and diaphragms over the cell were found to give no standard reduction, and eventually the use of resistances as shunts was adopted. Two resistances were wound, one of which reduced the galvanometer reading to a tenth - the other to a hundredth. For use these were connected across the terminals of the galvanometer in parallel with the photoelectric cell. Since it was probable that the connexion of the resistance with the galvanometer might itself cause an extra resistance, the method of taking readings was as follows. The cell was partially shaded so that a reading $x$ on the galvanometer could be obtained. This was adjusted to lie between 150 and 250 on the scale. The resistance was then put in and a reading $y$ obtained. The shading was removed and a third reading $z$ was taken. The corrected reading was thus give by $x/y$ times $z$. This was repeated for every reading that was taken unless it was so low that no resistance had to be used and it could be read directly off the instrument.

At the start of the experiments the domestic canopy over the bank of bins used was renewed, and regular light measurements were taken on top of the bins to get a curve for
darkening of the canopy. Varying light intensities were obtained in the bins by different thicknesses of different materials on top. (Appendix A) The photoelectric cell was always placed in the same position when taking the readings. It was put on top of a box 10\(\frac{1}{2}\) inches high stood on the sand six inches from the front and right hand side of the bin. These distances were purely arbitrary, the 10\(\frac{1}{2}\) inches being the height of a convenient thermos box, and the six inches being the length of the lid of the tin in which the cell was kept. The lid of the bin was lowered on to the flex and the galvanometer taken to the full length to ensure that no shading effect was instituted while taking the reading. Many difficulties were met with. Although all readings were taken at the same time of the day (2 - 3 p.m.) when the sun was actually shining, great variations in light intensity existed depending on the amount of cloud in the sky. Ideally all readings should have been taken with a cloudless sky but this was not feasible. Usually there were numbers of white clouds about and this increased the intensity of light in the bins. Also when readings were being taken the light intensity would alter - due to a cloud moving towards the sun or away from it - although the sun was never actually obscured. To minimise this and the inevitable inaccuracy of the readings due to any slight error being multiplied by ten when the corrected reading is obtained, several readings were taken in each bin and averaged. It was often found that all the readings would be quite close except one which would be some way off. In averaging therefore this was ignored - and much more reasonable results ensued.

Readings were taken in the bins once each week and averaged over the month the experiment was in progress.
It was intended to standardize the instrument later and to correlate the readings taken with readings in direct sunlight - but owing to its breakdown this could not be done. Thus the readings could not be expressed as a percentage of direct sunlight but only of light on top of the bins. This was decreasing as time went on, owing to fungal growth on the canopy.

In all the bins the standard treatment of ½ oz./gallon Hortamone for 14 to 17 hours was used on the cuttings. Eight different light treatments were given, and a bin of a slightly different type with a double cheesecloth cover (as in routine propagation) was used as a standard for comparing the rooting.

Apart from the readings taken in the experimental bins, various readings were taken in other bins where the routine propagation was in progress.

|------------|-------------|--------------|--------------|--------------|------------------|--------------|-------------------------------|-------------------|----------------|-----------------------------|-----------------------------|--------------|----------------------------------|
(iii) **Results.**

<table>
<thead>
<tr>
<th>Experiment I.</th>
<th>Feb. 21st - Mar. 21st 1941</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treatments</strong></td>
<td><strong>AV. light intens.</strong></td>
</tr>
<tr>
<td>2 netting</td>
<td>609</td>
</tr>
<tr>
<td>1 netting</td>
<td>604</td>
</tr>
<tr>
<td>1 cheesecloth</td>
<td>563</td>
</tr>
<tr>
<td>1 ch. + 1 net.</td>
<td>547</td>
</tr>
<tr>
<td>2 cheesecloth</td>
<td>479</td>
</tr>
<tr>
<td>2 ch. + 1 net.</td>
<td>470</td>
</tr>
<tr>
<td>3 cheesecloth</td>
<td>412</td>
</tr>
<tr>
<td>4 cheesecloth</td>
<td>398</td>
</tr>
<tr>
<td>Standard</td>
<td></td>
</tr>
</tbody>
</table>

**Average light intensity on top of bins 1147.**

<table>
<thead>
<tr>
<th>Experiment II.</th>
<th>Mar. 23th - Apr. 25th 1941</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treatments</strong></td>
<td><strong>AV. light intens.</strong></td>
</tr>
<tr>
<td>2 chee. + 1 net.</td>
<td>215</td>
</tr>
<tr>
<td>4 cheesecloth</td>
<td>185</td>
</tr>
<tr>
<td>1 open sacking</td>
<td>159</td>
</tr>
<tr>
<td>1 close sacking</td>
<td>55</td>
</tr>
<tr>
<td>2 chee. + 2 newspaper</td>
<td>13</td>
</tr>
<tr>
<td>1 op. + 1 cl. sacking</td>
<td>7</td>
</tr>
<tr>
<td>2 chee. + 4 newspaper</td>
<td>5</td>
</tr>
<tr>
<td>2 close sacking</td>
<td>2</td>
</tr>
<tr>
<td>Standard</td>
<td></td>
</tr>
</tbody>
</table>

**Average light intensity on top of bins 605.**
Little can be seen directly from these results. The reason that the second experiment gave better rooting than the first is probably that the cuttings for the first were taken in the afternoon and those for the second in the early morning. Appendix F gives these results expressed graphically as percentages of the standard. Owing to the inexactitude and liable error in taking measurements of light the percentage light intensity has been split up into divisions of five and all results falling within each division have been averaged. For the low light intensities where the inexactitude is liable to be even greater the results have been averaged over a range of ten percent. From this it would appear that the curve of rooting with varying light intensity is a skew curve - though this effect may be due to the darkening of the canopy. For a correct curve to be obtained the light intensity should be expressed as a percentage of direct sunlight and not as a percentage of the light under the canopy.

Appendix F also contains a graph of the darkening of the canopy over a period of six weeks. It is seen that the points on the graph lie on two more or less parallel curves. The reason for this is that on the days when the readings were taken the amount of cloud in the sky varied. The readings on the lower curve were taken when the sky was cloudless, and those on the upper curve when there were white clouds about.
Conclusions and Recommendations.

Although the readings taken in the routine propagation bins varied considerably, the impression was obtained that the intensity of light there corresponds approximately with the optimum intensity as determined. Propagation at the Imperial College is thus going on under the best light intensity for the rooting of I.C.S.1. at least. It would probably be as well however to renew the canopy in the wet season, and not in the dry season when the total light is greater. Since rooting appears to fall off more slowly as the light falls below the optimum than it does as the light rises above, it will be more economical to have a clean canopy giving the optimum light intensity in the bins than a clean canopy giving above the optimum. The average rooting over the length of life of the canopy will be higher in the former than in the latter. If the canopy is partly dirty at the onset of the dry season, in the first case the higher light intensity will cause the light in the bins to move towards the optimum; in the second case the light in the bins will move above the optimum.

If in the future any similar work is done with light measuring instruments, great care must be taken to keep them dry. The humidity in and around the bins is high, and unless extra precautions are taken the galvanometer is very liable to go out of order. When not in use the instrument should always be kept in a desiccator. It would save much trouble if an airtight box with a glass lid was obtained, and the galvanometer sealed into this with a little calcium chloride or other water absorbing substance. Thus any damage due to humidity would be completely avoided.
It has been thought for some years that in the dry season cacao cuttings do not root as well if they are taken in the afternoon as if they are taken in the morning. This has been attributed to differing water contents in the plant. Briggs and Shantz (2) and Maximov (7) investigated the transpiration of various plants throughout the day and obtained similar results. At night transpiration can be looked upon as zero. As the sun rises so does transpiration, to give a maximum between midday and 2.0 p.m. after which it falls. As transpiration rises to the maximum it is ahead of absorption of water from the soil, and there is a water deficiency in the plant. This increases during the day, but as the transpiration falls off the absorption catches up, and at night the plant regains its full water content. At the period of maximum transpiration a deficiency of a quarter of the total water in the plant was found. These results were obtained on cloudless days. According to Maximov, light is an important factor in regulating transpiration, though it is difficult to dissociate it from other environmental factors. He also refers to work by Bachmann (1) in which it was found that even in plants growing under conditions with plenty of available water there was a definite lowering of water content in the middle of the day.

Thus it is quite likely that any decrease in rooting of afternoon cuttings over morning ones will be due to a lower water content, although other undetermined factors may also play a part. Therefore when it was found impossible to continue with the light experiments, an experiment was instituted to see if
there was any great difference in rooting between cuttings taken in the morning and those taken in the afternoon, and whether any difference could be correlated with change in water content.
(ii) Method.

The plants in the nursery were examined and any with two or a greater even number of potential cuttings were labelled - a label being affixed to each cutting. Half of these cuttings were taken in the early morning and the other half in the afternoon. Thus the afternoon set duplicated the morning set in having come from the same plants. The labels were left on the cuttings in order that individual ones could be compared if necessary. In some cases four cuttings were obtained from one plant and to two of these an indolyl butyric acid treatment was applied, the Hortamone treatment being applied to the others. A rough measurement of the difference in water content was made by collecting the basal leaves from the morning cuttings (removed in the normal preparation) and determining their water content, and repeating with the afternoon cuttings. Maximov (7) states that any water difference is exaggerated in the lower leaves as the more vigorous upper leaves take water from them to make up their own deficiency. With cacao cuttings however all the leaves are from the last flush, and therefore the water deficiency might be minimized - water having been drawn from older leaves on the plant.

The water content determinations were only rough and served to show that there was a difference between morning and afternoon cuttings. They were done as follows. The fresh leaves were placed in a previously weighed tin and the whole lot weighed. They were then dried in an oven until no further change in weight occurred, cooled and weighed again.
(iii) Results.

The difference in water content was found to be approximately 6% of the dry weight. This was less than expected, and was probably due to the fact that although the day when the experiment was made was fine and sunny, some previous days had had rain. The soil therefore contained more moisture than would be normal in the dry season.

The differences in rooting between corresponding individual cuttings taken in the morning and the afternoon varied considerably; the averages were therefore calculated.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>May 14th - June 11th 1941.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatments</td>
<td>Ctgs. set</td>
</tr>
<tr>
<td>Morning</td>
<td>16</td>
</tr>
<tr>
<td>Afternoon</td>
<td>16</td>
</tr>
<tr>
<td>Morning</td>
<td>9</td>
</tr>
<tr>
<td>Afternoon</td>
<td>9</td>
</tr>
<tr>
<td>Morning</td>
<td>25</td>
</tr>
<tr>
<td>Afternoon</td>
<td>25</td>
</tr>
</tbody>
</table>

Application of hormone for 16 hours.
(iv) Conclusions and Recommendations.

Few conclusions can be drawn from one experiment. It would appear however that morning cuttings root better than afternoon ones. In the case of Hortamone the difference in rooting is hardly significant, but with indolyl butyric acid it is fairly well marked. Whether this difference is due to the difference in water content or to other factors cannot be said, but for practical propagation if any difference is shown to exist the cause is unimportant. Further experiments should be done, with a greater difference in water content if that can be obtained.
VII. CORRELATIONS.

That there are correlations between factors is evident; the last experiment shows correlation between hormone and the time of day the cutting is taken, and the first experiments show a similar correlation between hormone and season. It seems likely that it is the water factor that is operating in both these cases. Since there are so many factors influencing the rooting of cuttings however, internal and external, known and unknown, it is difficult to show definite correlation between any two of them. Before this can be done more knowledge must be obtained about these other factors. Here is scope for much future work, as well as repetition and expansion of the experiments described in this paper. In conclusion it should be again stressed that these are only pointers which may serve to show the possibilities and difficulties of this sort of work to those who will continue with it in the future.

7. In the dry season cuttings taken in the morning root better than cuttings taken in the afternoon.

8. This is possibly due to a water shortage in the plants in the afternoon, and should be verified by further experiments.

9. Cuttings treated with 10% Lysol mutric acid showed this afternoon better than those treated with Hewitt's A.

IX. ACKNOWLEDGMENTS.

Acknowledgments are due to Dr. Phillips of the Empire Propagation Station for great help and suggestions in regard to quest measurements, and also to Professor Strain and Professor Bask of the Imperial College for suggestions and advice and for the loan of equipment.
VIII. **SUMMARY.**

1. All experiments were carried out with fan cuttings of Clone I.C.S.1. taken from the same nursery.

Hormones:
2. The optimum time and concentration of application of Hormamone A for rooting was checked and found to be 
   \( \frac{1}{6} \) fluid ounce per gallon for 14 to 17 hours.

3. \( \beta \) indolyl butyric acid at a concentration of 30 milligrams
   per litre was found to give greatly superior rooting to Hormamone A.

4. This increase in rooting varied, being more marked in the dry season.

Light:
5. The curve of rooting with varying light intensity is a skew curve, though this may not be so if the light is expressed as a percentage of direct sunlight.

6. The light intensity in the routine propagation bins at the Imperial College of Tropical Agriculture is approximately at the optimum.

Water:
7. In the dry season cuttings taken in the morning root better than cuttings taken in the afternoon.

8. This is possibly due to a water shortage in the plants in the afternoon, and should be verified by further experiments.

9. Cuttings treated with \( \beta \) indolyl butyric acid showed this difference better than those treated with Hormamone A.

IX. **ACKNOWLEDGEMENTS.**

Acknowledgements are due to Dr. Phillis of the Empire Cotton Growers Association for great help and suggestions in regard to light measurement, and also to Professor Cheesman and Professor Hardy of the Imperial College for suggestions and advice and for the loan of literature.
X. REFERENCES.


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   which cause initiation of roots and other
   responses in plants"
APPENDICES.

A. Samples of materials used for shading the propagating bins.
C. Directions for making up a stock solution of $\beta$ indolyl butyric acid.
D. A note by Spencer on the treatment of cacao cuttings with Hortamone A and Indole-3-acetic acid.
E. Graphs illustrating the results obtained with hormones.
F. Graphs illustrating the results obtained with light.
APPENDIX A.

Samples of materials used for shading the propagating bins.

Domestic.

Cheesecloth.

Mosquito netting.

Open sacking.

Close sacking.
APPENDIX B.

Diagram from Went and Thimann (18) illustrating Blackman's Principle of Limiting factors as operating in root formation on etiolated pea cuttings.

APPENDIX C.

Directions for making up a stock solution of \( \beta \) indolyl butyric acid.

A stock solution can be made up as follows, and this will keep for a short period if stored in a cool dry place. 1 gram of the acid is dissolved in 50 ccs. of 95\% alcohol, and this is made up to 100 ccs. with tap water. 3 ccs. of this stock solution made up to a litre with tap water will give a working concentration of 30 milligrams per litre.
APPENDIX D.

Note on the treatment of cacao cuttings with Hortamone A and Indole-3-acetic acid. by G.E.L. Spencer. (ca. 1939)

Hortamone A.

Preliminary experiments undertaken with a view to finding out whether its use in the rooting of cacao was of any value and if so what was approximately the optimum concentration, were so promising that Hortamone A treatment has been for over a year now a matter of routine. The results of these tests were as follows:

<table>
<thead>
<tr>
<th>Hortamone Conc.</th>
<th>No. ctgs. set</th>
<th>No. rtd. (1 mnth.)</th>
<th>Av. no. r. / ctg</th>
<th>Av. l. r.</th>
</tr>
</thead>
<tbody>
<tr>
<td>½ fl. oz./gall.</td>
<td>10</td>
<td>10</td>
<td>14</td>
<td>2.1 in.</td>
</tr>
<tr>
<td>¾ fl. oz./gall.</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>2.5 -</td>
</tr>
<tr>
<td>½ fl. oz./gall.</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>1.3 -</td>
</tr>
<tr>
<td>Control</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>0.3 -</td>
</tr>
</tbody>
</table>

Duration of treatment - 14 hours.

The strength of the solution now in use is that recommended by the manufacturers, viz. ½ fluid ounce per gallon of water. The ends of the cuttings are immersed 3 to 4 inches deep in the solution contained in a glass jar, which is then placed in one of the propagators which is afterwards closed, the resulting % humidity inside being somewhere between 90 and 100. This is an absolutely necessary precaution for cacao as cuttings kept under ordinary atmospheric conditions for the duration of the treatment, viz. 15 to 18 hours suffer heavy leaf shedding when subsequently set out in the bins.
Indole-3-acetic acid.

Preliminary trials carried out with this substance in concentrations reported by other workers to have given a high degree of success in the rooting of cuttings other than those of cacao were not encouraging. The strengths used were 6.5 grams and 0.25 grams per litre, the cuttings being immersed for periods varying from 2 to 10 hours. In most cases serious leaf shedding occurred with abnormal brown discolorations of the parts immersed. It is quite possible however, that with further trials a concentration more suitable to cacao may be found.
APPENDIX E.

Graphs illustrating the results obtained with hormones.

Sheet 1. Average number of roots per cutting.
Sheet 2. Average length of roots.
Sheet 3. Average length of root per cutting.

The most importance is attached to the graphs on sheet 3.

Top left are the results of the Preliminary experiment. At the bottom are the results of Experiments I and II with different concentrations of different substances compared. And at the top right are the results obtained with a concentration of 30 milligrams per litre of β indolyl butyric acid in the different experiments, compared with the Hortamone standard.
APPENDIX F.

Graphs illustrating the results obtained with light.

At the top is a figure showing the darkening of the domestic canopy with time. The three readings lying on the upper curve were taken when there were white clouds in the sky; the other three readings when the sky was completely cloudless.

The lower three figures show the rooting with differing light intensity.

Figure 1. Average number of roots per cutting.
Figure 2. Average length of roots.
Figure 3. Average length of root per cutting.

The most importance is attached to figure 3.
1. Light intensity as % of that on top of bin.

2. Light intensity as % of that on top of bin.

3. Light intensity as % of that on top of bin.