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CORREGENDA.

Papua and New Guinea Agricultural Journal, Vol. 17, No. 1, June, 1964.

On Page 10, first line of last paragraph in Column 2, the word Absorbent should read : Adsorbent.

In line 7 of the same paragraph the word Chloroforms should read : Chloroform.

On page 35, part of the second line of the heading to Table 2, (100 per cent. shade) should read : (100 minus per cent. shade).

On Page 39, the second line of the heading of the article (Coffee Arabica in the Highlands of New Guinea) should read : (Coffea Arabica in the Highlands of New Guinea).

Notes to Contributors

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References to articles and books should be carefully checked. In a reference the following information should be given : initials of author, surname of author, full title of article, name of journal, volume, full date, number of first and last pages of the article. If a reference is made to an abstract of a paper the name of the original journal, together with that of the journal in which the abstract has appeared should be given with full date in each instance.

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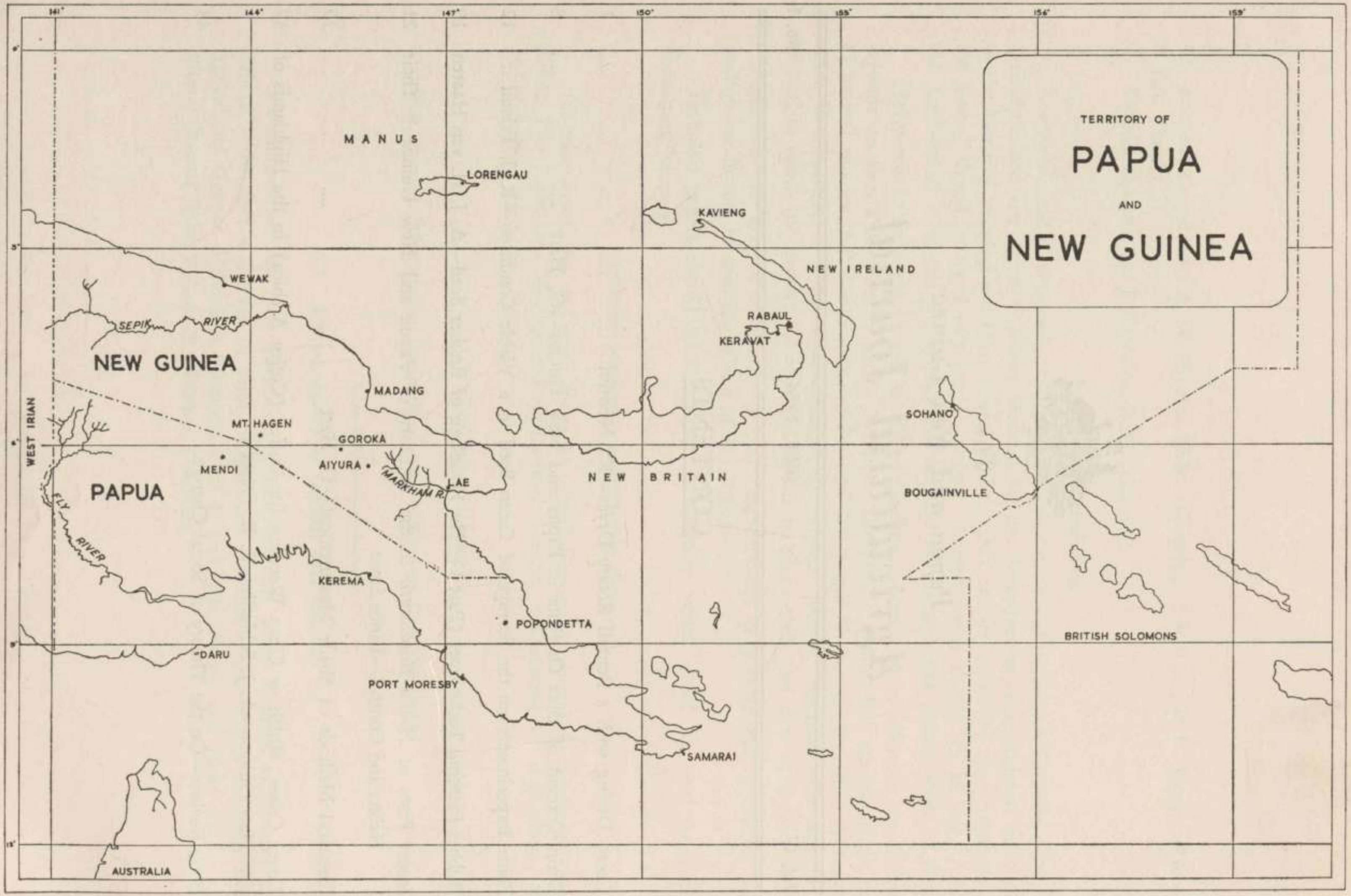

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Cacao Drying with a Bentall Rotary Dryer.

K. NEWTON.*

A SUMMARY of the results from a series of eighteen trials conducted at the Lowlands Agricultural Experiment Station, Keravat, between September, 1961, and November, 1962.

Description of the Dryer.

Trials were carried out with an 8 ft. x 6 ft. rotary drum dryer having a final gear drive fitted to a central shaft and mounted on large bearings supported by heavy concrete piers as shown in Plates I and II. Hot air is supplied through ducts leading from the heat exchanger into both ends of a central core running through the drum. Electric power was used for the drum drive (3 h.p.) the blower fan for the oil burner (1 h.p.) and the main fan connected to the heat exchange unit (10 h.p.).

Obviously the generating plant requirement to supply power for these three motors is considerable and diesel power would in most cases be preferable.

A cast iron and steel boiler type heat exchange unit mounted over a firebrick lined square combustion chamber is used for indirectly heating the air forced through it by the main fan. This fan has a rated capacity of 3,500 cubic feet per minute but no figure is available for the static water gauge pressure against which this volume is delivered.

A simple burner fitted into one side of the combustion chamber is rated as being able to create a maximum temperature rise above ambient of 110 degrees F. in the air passing through the heat exchanger. This heated air passes initially into a single duct and then through two ducts leading off to each end of the drum from a T joint with the initial outlet. Thus, air is fed from each end into the hollow central core of the drum and thence out through a series of perforated tubes projecting into each compartment as shown in Plate I. Introduction of hot air into both ends of the drum in this way allows for more even distribution of this air through the bean mass in each compartment and hence more even drying. Normally, heat distribution in rotary dryers which have an inlet duct at one end only, is poor. This assumes, of course, a uniform distribution of outlet holes along the entire length of the central duct or core. Under these circumstances the tendency is for hot air to be blown to the far end of the central core and out into the drum. Consequently, drying is faster at one end of the drum than the other. This weakness can be corrected either by suitable arrangement of hole distribution, variation in hole size along the core or by blanking off holes in progressively greater numbers from one end of the core to the other.

The drying drum itself is divided into four compartments and is constructed so that all surfaces in contact with cacao beans are aluminium alloy. Each compartment is fitted with wooden baffles and the outer shell of the drum perforated with 3/16-inch holes. A final gear drive leading from a chain drive off the three h.p. electric motor gave a drum rotation speed of two r.p.m.

Installation of the Dryer.

During installation of the dryer several difficulties were encountered which could have been avoided by better planning. The major problem in putting the unit together was the heat exchange unit. This proved to be a relatively heavy piece of equipment, awkward to handle and unsatisfactory from a grower's viewpoint. Preferably the unit should be shipped in sections which can be easily handled and bolted together at installation.

Plans supplied with the dryer were inaccurate to the extent that no measurement was given for the thickness of the back concrete

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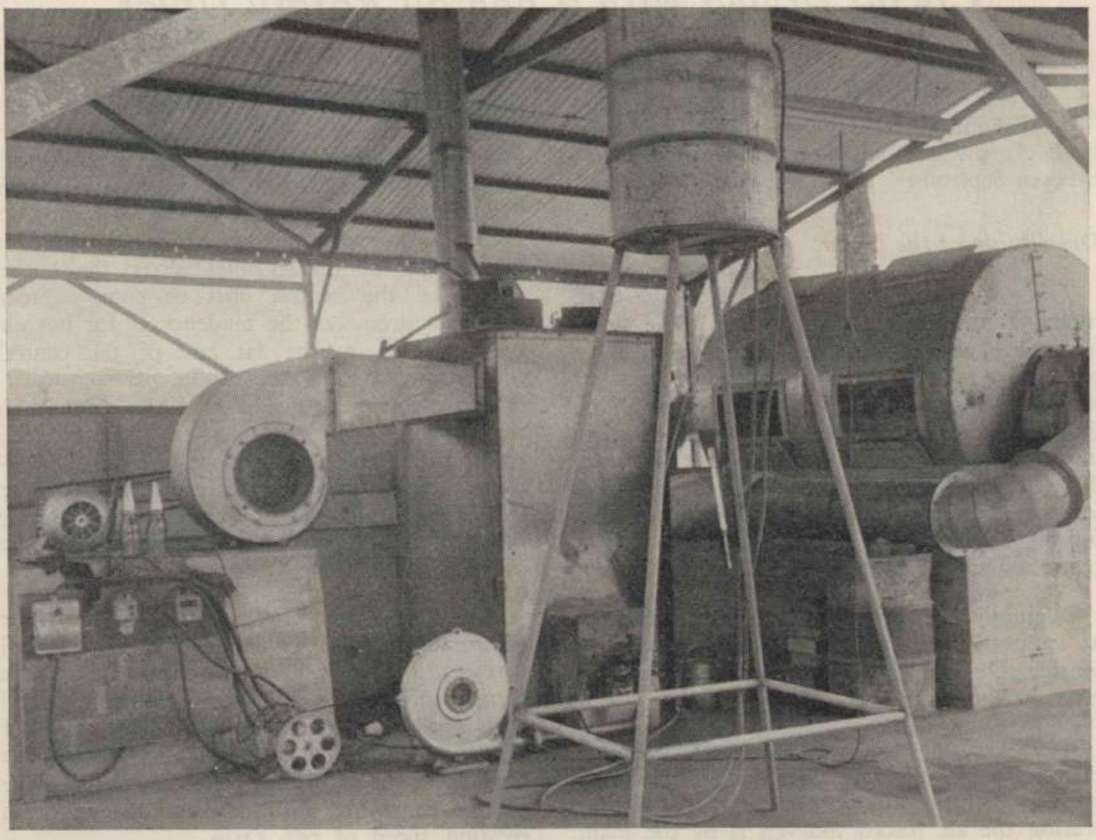

Plate I.—A general view of the dryer with fan and heat exchange unit.

wall running between the two main supporting pillars. Also, the clearance between this wall and the drum was insufficient and the distance between the two main concrete pillars incorrect. These foundations were in fact far too elaborate and heavy for an 8 ft. x 6 ft. dryer and it is very doubtful whether many growers would be interested in equipment requiring such extensive concrete work for supports. The requirement here is for sturdy, easily assembled, steel frames. Siting of the main blower fan on its concrete pillar was extremely poor, the whole unit being mounted over to one corner of the block. This resulted in one of the bolts, which had been set in the concrete to hold the base of the fan, breaking away because of its proximity to the edge. Again, the foundation was unnecessarily heavy and could have been easily replaced by a steel frame.

Drum components, particularly the outer shell, fitted together badly and the two elbow sections of the hot air ducting which fitted on to the central core of the drum had to be heated and hammered before fitting could be effected.

Finally, the unit lacks any braking mechanism to hold the drum in a given position during loading. A brake is essential to prevent the drum from moving out of position during loading operations.

Rotary Drying With Baffles Fitted.

As mentioned above, each of the four drum compartments was fitted with wooden baffles which, in effect, are long shelves running the full width of the drum and bolted to the dividing walls within it. Although the disadvantages of these baffles was anticipated, the first two trials (Trial 1 and Trial 2) were carried out with baffles left in the drum. For Trial 1, beans were first sun dried for two days before loading into the rotary dryer where drying was completed over a 48 hour period during which the burner operated for 16 hours only. Several interruptions to drying were made to allow migration of moisture from the centre of the beans to the shell without the continuation of drum rotation. However, at completion of drying approximately 50 per cent. of the beans were either shattered or else had worn or broken shells. The result of drying with baffles in the drum was much the same again in Trial 2. In this case beans had one day of sun-drying prior to loading into the dryer where drying was continued for a further 48 hours with burner operating for $12\frac{1}{2}$ hours. Drying was not carried to completion because of the high percentage of shattered beans and broken shells which had developed on the second day.

Results from the two trials illustrate again this weakness of rotary dryers which has been noted in previous work at Keravat. The stage at which the shell can be damaged occurs towards the end of drying when moisture content has been reduced down to about 10 per cent. and the shell has became fairly brittle. Two types of damage can occur. Firstly, the shell can be worn through by constant rubbing against other beans in the dryer drum. Secondly, the shell can be split or shattered as a result of beans being held by the baffle plates in such a way that as the drum rotates they crash against the sides of the drum each time they fall, instead of sliding gently around in the compartment.

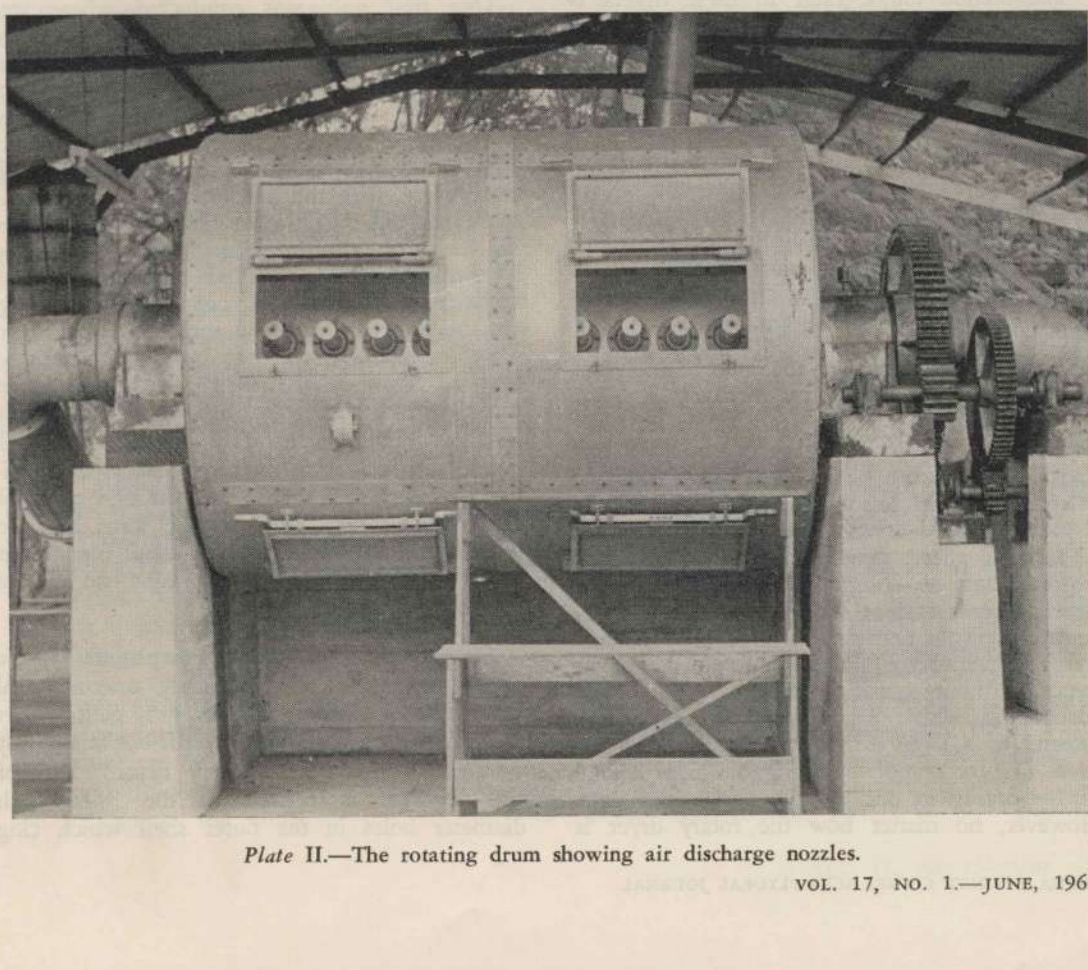

Plate II.—The rotating drum showing air discharge nozzles.

Both problems can be overcome and both are due to a combination of excessive drum speed and the presence of baffle plates in the drum compartments. Baffles are intended to break up the bean mass and prevent it rolling around and "balling". Their effect is, however, practically the opposite, particularly when beans are loaded direct from fermenting boxes. Under these conditions they tend to be held in one clogged mass between the baffles. Towards the end of drying, when the volume of the bean mass has been reduced by about 50 per cent. and each compartment is, therefore, only half full, the effect the baffles have is to hold back some of the beans as each compartment passes through the highest point of rotation until the angle is reached at which beans slide from the baffles and fall. This angle is such that beans falling from the baffle hit the outer shell of the drum and shatter or split.

The second major fault in these dryers is is the drum speed of two r.p.m. which is far too high to allow final drying of cacao beans without abrasion of the shell. The effect of a drum speed of two r.p.m. in combination with baffles, is devastating and causes a tremendous amount of damage—so much so that beans cannot be dried right out to six per cent. moisture and still command the ruling market price. A drum speed of two r.p.m. without baffles is also unacceptable as this, too, results in too much damage to the beans.

It is obvious, therefore, that two basic design requirements for rotary cacao dryers are the exclusion of baffles and a drum speed less than two r.p.m. The first requirement is easily met and the second can be realized by the addition of two or three sets of driving gears or else a variable speed drive. The reason for having a variable speed drive, or, alternatively, two or three sets of driving gears rather than one slower speed, is that variation in drum speed during drying is necessary to achieve a reduction in shell percentage and a good polish on the beans without causing damage. The exact manner in which drum speed is varied will depend to a large extent on how the dryer is used, i.e., for complete drying, for final drying or for drying in one, two, three or four days. However, no matter how the rotary dryer is used a drum speed of two r.p.m. is advantageous for the first five or six hours of drying and will do no harm. After this, drum speed will depend on method and time of drying and whether the compartment is fully loaded or part loaded (greater wear on the beans). Apart from these considerations a final drum speed of ¼ r.p.m. is advantageous as, at this speed, rotation can continue for as long as four days without causing damage to the beans. Obviously a variable speed drive covering the range of ¼ r.p.m. to two r.p.m. is the ideal. Alternatively, gearing the dryer to give speeds of 2, 1, ½ and ¼ r.p.m. or 2, 1 and ¼ r.p.m. will suffice, using 2 r.p.m. initially, 1 or ½ r.p.m. when beans become surface dry, and ¼ r.p.m. for final drying when the shell is brittle.

Complete Rotary Drying.

One trial only was conducted where wet fermented beans were loaded into the dryer direct from fermenting boxes. Clogging of the machine was anticipated and was in fact severe. The drum was loaded to full capacity with 130 cubic feet of fermented beans at 54.3 per cent. moisture content and drying commenced with the burner operating at maximum output. Within an hour or so all holes in the shell of the drum were completely blocked with mucilage and remained blocked throughout the first and second day of drying. On the third day, internal surfaces of the drum were scraped and cleaned. Inspection showed that all holes in the shell and hot air inlet tubes within the drum had been completely blocked. Inlet ducts were barely functional, being covered with a thick layer of semi-dry mucilage and beans. At the end walls of each compartment, and, at the joins between these walls and the outer shell and inner core, large masses of mucilage and beans had formed together and stuck.

Drying was eventually completed in the rotary dryer but at the highly uneconomical fuel consumption figure of 115 gallons per ton. Obviously then, this dryer is not in any way suitable as a complete rotary dryer. Part of the problem is related to the 3/16 inch diameter holes in the outer shell which clog so readily and rapidly. To some extent this can be avoided by the use of larger (5/16 or 3/8 inch) holes but even with these there is a tendency for clogging to occur. Also, with larger holes in the outer shell there is much less resistance in the system as a whole to the loss of hot air entering the drum under pressure through the central core and inlet ducts. This situation applies particularly towards the end of drying when perforations in the shell of the drum are free and the volume of beans within the drum has been reduced by about 50 per cent. Consequently air can escape rapidly through the outer shell without necessarily removing a great deal of moisture from the beans, and hence drying efficiency is reduced. One answer to this problem has been the utilization of "drawn" holes, 5/16 inch in diameter, in the drum shell. With this type of hole beans are held away from, and thus prevented from sliding over, the outer edge of the hole. Clogging is reduced to a level where it is no longer a major problem and wet fermented beans can be loaded direct from fermenting boxes and dried.

With One Day's Sun Drying.

Two trials were carried out in which fermented beans were dried initially for one day on a platform sun dryer and finished in the Bentall rotary dryer. These were Trial 3 and Trial 7, the results of which are summarized in Table 1. In both trials partial clogging occurred in the holes in the drum shell and also the inlet tubes although these tended to clear as drying continued. In Trial 3, after drying beans down to 6.4 per cent. moisture content it was found that approximately 20 per cent. of the beans were broken or worn as a result of excessive drum speed (two r.p.m.) with a fairly small load, despite the fact that drying was interrupted to avoid this damage.

Therefore the performance of the unit as a final dryer following one day's sun drying was not fully satisfactory although it would be improved by reduction of drum speed and by full loading of the drum.

With Two Day's Sun Drying.

Trials 5, 6, 9, 10 and 13-18 inclusive were all conducted with beans which had been dried for two days in the sun on a platform dryer and then loaded into the rotary dryer for completion of drying. Rotary drying was interrupted in all trials to avoid the excessive damage to the beans associated with high drum speed. As a consequence, fuel consumption figures for all trials are better than those which would have resulted from continuous rotary drying. Interruption to drying, whether with a rotary dryer or a platform dryer, allows migration of moisture from the centre of the bean to the outside during the period of interruption and, as this increases the availability of moisture at the start of the next drying phase drying is therefore more efficient. In addition, interruption to drying during the overnight period means that air at high relative humidity is not used for drying. The twelve hour period of greatest relative humidity at Keravat falls between 8.0 p.m. and 8.0 a.m. Therefore the air used for drying during the day has greater capacity to dry and drying is more efficient during this period.

Unfortunately the figures for fuel consumption against load for this series of trials are extremely variable, the variation being due to variation in fuel consumption per hour by the burner, variation in moisture content at the start of drying, and variation in load. Results are tabulated in Table 1 and graphically represented in Figure 1. For all trials up to Trial 12, fuel was supplied to the burner through a half-inch rubber hose leading from a 1,000-gallon overhead tank. Table 1 shows that when the burner was operating at maximum capacity (i.e., no smoke from the stack), fuel consumption per hour varied from 3.35 to 3.6 gallons per hour. In Trials 13-18 fuel was supplied to the burner from a 44-gallon drum fitted with a float valve to maintain a constant head of fuel. This was inserted into the pipeline system leading from the 1,000 gallon tank to the burner. The net result was a general increase in fuel consumption per hour with wide variation still evident. In Trials 17 and 18 for example, the burner was operated at full capacity throughout and gave hourly consumption figures of 3.59 and 3.94

Table 1.

Summary of Trials.

Trial Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Vol. wet beans (cu. ft.)	98	120	132	130	....	150	210	....	180	80	110	68	225	197	224	215	242	190
Per cent. moisture at end of fermentation	....	....	56.2	54.3	51.1	....	....	....	....	....	....	....	55.7	55.0	55.5	....	....	55.6
Initial sun drying (days)	2	1	1	Nil	2	2	1	....	2	2	2	2	2	2	2	2	2	2
Per cent. moisture after sun drying	....	....	41.3	54.3	36.6	44.9	41.5	....	....	....	....	....	37.1	40.0	39.3	41.0	42.0	38.6
Rotary drying system	Ib	Ib	Inb	I	I	I	I	....	I	I	C	C	I	I	I	I	I	I
Total time beans in dryer (hours)	48	48¼	48	96	50	72	72	....	48	30	24	24	48	72	48	48	48	48
Total drying time (hours)	18	14	25½	49¼	33¾	36½	39	....	17	19½	12	14	19½	22½	18¾	18¾	24¾	20
Burner operation (hours)	16¼	12½	23½	42	32¼	36½	39	....	17	19½	12	13½	15	20	17¼	17¼	21¾	16½
Burner operating conditions	....	FC	FC	FC	T	T	T	....	FC	T	T	....	T	T	T	T	FC	FC
Maximum duct temperature (degrees F.)	....	152	157	180	152	136	164	....	204	131	133	....	162	151	157	159	150	150
Burner fuel consumption (gallons per hour)	....	3.5	3.4	3.6	2.8	2.2	2.5	....	3.35	2.3	2.5	3.85	3.87	3.75	3.1	4.35	3.59	3.94
Total fuel consumption (gallons)	....	43	80	151	90	79	96	....	57	45	30	52	58	75	53	75	78	65
Per cent. moisture at end of drying	....	FS	6.4	....	5.0	....	....	....	....	....	....	....	....	....	....	8.0	9.9	13.4
Weight of dry beans (lb.)	....	2,643	2,956	2,940	4,340	3,500	4,340	....	3,920	1,900	2,300	1,680	5,090	4,511	5,075	5,016	5,700	4,659
Fuel consumption (gall. per ton)	....	36.4	60.6	115	46.4	50.5	49.5	....	32.5	53.0	29.2	69.3	25.5	37.2	23.4	33.5	30.6	31.4
Broken beans (per cent.)	50	H	20	20	17	....	....	....	....	....	....	....	....	....	....	....	....	....
Wt. (lb.) dry beans/vol. (cu. ft.) wet beans	....	22.0	22.4	22.6	....	23.3	20.7	....	21.8	23.7	20.9	24.6	22.6	22.9	22.7	23.3	23.6	24.5

Key :—Ib............Interrupted with baffles. Inb............Interrupted no baffles. I............Interrupted.
C............Continuous. FS............Finished in sun. H............High percentage broken.
FC............Full capacity. T............Turned down.

NOTE.—Owing to fuel supply difficulties, Trial No. 8 was a failure.

gallons. However in Trial 16 during which the burner was at times turned down, average fuel consumption was 4.35 gallons per hour. A satisfactory explanation for these variations could not be found.

Performance of the dryer when loaded with beans which had received prior drying for two days in the sun was best in Trial 15 in which the drying of 5,075 pounds dry bean equivalent was completed at a cost of 23.4 gallons per ton. Maximum load in all trials was 5,700 pounds dry bean equivalent and the highest fuel consumption figure was recorded in Trial 10—53 gallons per ton for a load of 1,900 pounds dry bean equivalent.

Apart from the fact that final drying in the rotary dryer had to be intermittent to avoid the deleterious effects of a high drum speed, the unit was quite satisfactory as a final dryer.

Summary.

In a series of eighteen trials, the Bentall 8 ft. x 6 ft. rotary drum dryer, fitted with baffles and supplied with hot air from an oil fired heat exchange system, was tested at the Lowlands Agricultural Experiment Station, Keravat, for its suitability as a cacao dryer.

During installation of the unit it was found that the heat exchange system was too heavy and cumbersome for easy handling on a plantation and that the foundation required to support the drum bearings was too elaborate and too extensive. It was also found that there were errors in the plans.

Initial trials were carried out with baffles fitted in each of the four drum compartments. These clearly indicated the deleterious effect which baffles have on beans towards the end

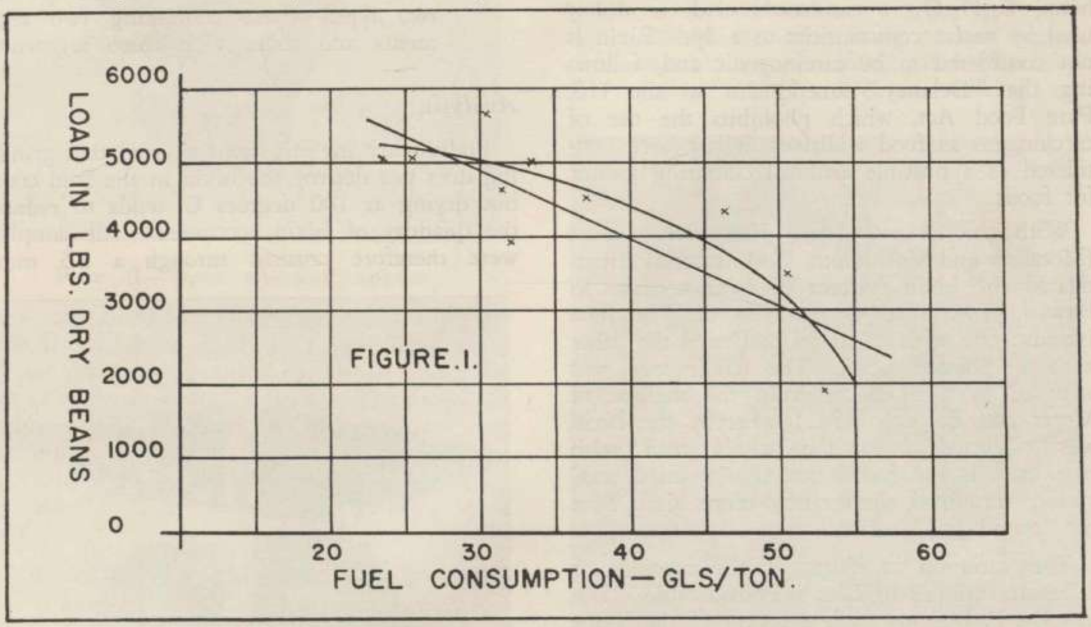

Figure I.—Graph showing relationship between load, expressed as weight in pounds of dry beans, and fuel consumption expressed in gallons per hour.

of drying and the extent to which beans can be worn or shattered. Further trials showed that although the unit was unsuitable as a complete rotary dryer, it could be used as a final dryer after one day of sun drying provided that it was fully loaded and drum speed was reduced. However, the most satisfactory performance was obtained when beans were used which had received an initial two days of sun drying on a platform dryer. Under these circumstances it proved capable of handling a load equivalent to approximately 2½ tons of dry beans and of drying this load for a cost of 25-30 gallons of fuel per ton.

Bixin Content of Bixa Orellana in Papua and New Guinea.

G. HART.

Chemist, D.A.S.F., Port Moresby.

Introduction.

Bixa orellana (Annatto or Lipstick Pod Plant) is a large quick-growing shrub, native to tropical America but now growing in many tropical countries throughout the world. It is often grown in hedges and normally reaches about twelve feet in height, although isolated bushes sometimes grow to over 30 feet. It has glabrous caudiform leaves, and bears, on the end of branches, clusters of brown capsular, ovoid or spherical fruits with fleshy spines. These contain up to 50 small seeds coated with a bright red mass which darkens when the seeds are dried. This coating, which contains bixin, $C_{25}H_{30}O_4$, a carotenoid acid, is widely used by native communities as a dye. Bixin is not considered to be carcinogenic and, following the "Delaney" amendment to the U.S. Pure Food Act, which phohibits the use of carcinogens as food additives, it has been considered as a possible artificial colouring matter for foods.

With this in view, two Hawaiian workers (Moomaw and Matsumoto, 1961) recently investigated the bixin content of *Bixa orellana* in Hawaii. Two varieties occur in the Hawaiian Islands: one with a 'round pod' and the other with a 'pointed pod'. The whole seed was analysed by a modification of the method of Meyer and de Vos (1941) whereby the bixin was extracted from the whole seed with pyridine. It was found that the 'pointed pod' variety contained significantly more bixin than the 'round pod' variety.

The variation in shape of the capsules of different varieties of *Bixa* is considerable. The late Dr. P. J. Eyma made a survey of the forms at Bogor and found that, with regard to the shape of the fruit, its colour, the colour and length of the bristles on it, and the colour of the corolla, 18 combinations were represented (Backer, 1951). In Papua and New Guinea *Bixa* thrives in many areas, both on the coast (Port Moresby, Lae, Rabaul) and in the Highlands (Wau, Garaina, Goroka). On classification by capsular shape, three varieties occur:—

1. *Broadly Ovate*—from a subtruncate base broadly ovate with a broadly rounded abruptly and shortly acuminate apex. These are probably similar to those referred to as 'round pods' by the Hawaiian workers.

2. *Elongated*—from a subtruncate base elongate-ovate with a much narrowed rather long acuminate apex. These probably correspond to the 'pointed pod' variety in Hawaii.

3. *Spherical*—spherical capsules taken from trees at Garaina. These are of two types—those containing two segments and those with three segments.

Analysis.

Preliminary investigations showed that grinding does not destroy the bixin in the seed coat, but drying at 100 degrees C. tends to reduce the quantity of bixin recovered. All samples were therefore crushed through a 2.5 mm.

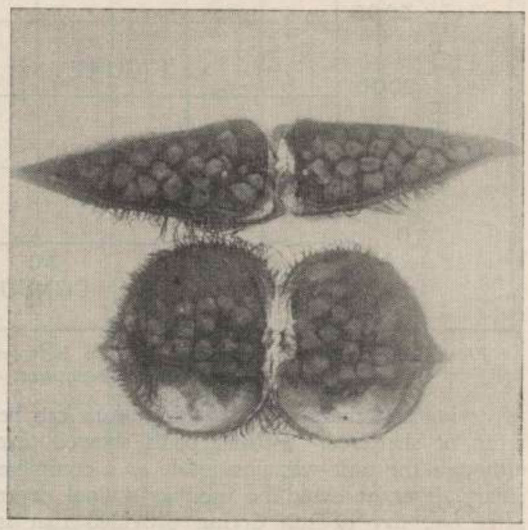

Plate I.—An open elongated capsule (top) and broadly ovate capsule (bottom).

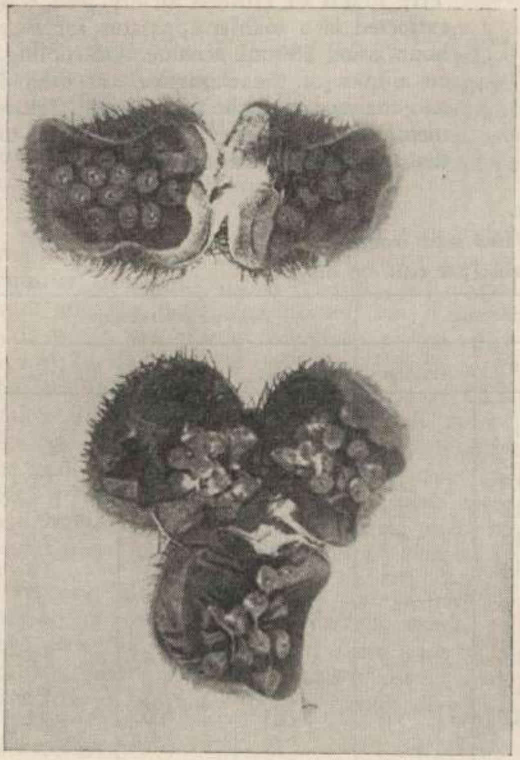

Plate II.—Open spherical capsules.

sieve and air-dried before extraction. Moisture content was determined on a separate portion of the sample so that all yields could be converted to an oven-dry basis. (The Hawaiian analyses refer to air-dry seed). Analyses were performed in duplicate and the average of the two values taken (these were always within 0.3 per cent.). Two methods of analysis were used :—

1. *Extraction with Pyridine* (Moomaw and Matsumoto). One gram of crushed air-dry seed was mechanically shaken with 30 ml. pyridine for half an hour. The dark red liquid was then poured through a glass wool plug into a 100 ml. volumetric flask, the residue thoroughly washed with pyridine and the washings added to the flask. An aliquot of the pyridine solution was dissolved in 70 per cent. ethanol and the transmittance read on a Beckman DU spectrophotometer. (In the earlier analyses an aliquot was first chromatographed on 1 : 1 sodium carbonate : filter cell, but as it was found that this purification did not appreciably influence the result, the shorter method which is described was used in later analyses. The maximum absorption of the non basic components is at 400 mu and these produce an error of less than 5 per cent. on measurements made at 455 mu. The bixin content was calculated using an

$$E^{1\ \text{per cent.}}_{1\ \text{cm.}} \text{ of } 3200 \text{ at } 455 \text{ mu}$$

(Espoy and Barnett, 1955). The residue was collected, oven-dried and weighed. Nitrogen content was determined using the Kjeldahl method.

2. *Soxhlet extraction.*
Soxhlet extraction using various organic solvents was also investigated (Karrer & Jucker, 1959). Whereas ethanol and

Plate III.—Leaves and capsules of *Bixa orellana* (with elongated capsules).

petroleum ether were not very satisfactory solvents, extraction with acetone or chloroform proved very efficient. Comparison with yields from pyridine extraction (*Table* I)) showed that these conditions of hot extraction with a low boiling solvent did not destroy the bixin.

Five grams of crushed air-dry seed was extracted in a soxhlet apparatus for four hours using 150 ml. acetone. On cooling, an aliquot of the extractive was diluted and analysed as in the first method. Treatment of the residue was also similar to that in the first method.

Table 1.

Comparative analyses of *Bixa orellana* seed from localities in Papua and New Guinea, and Hawaii. (per cent. on dry basis).

	Pyridine extraction.			Acetone extraction.		
	Soluble material	Bixin	N in residue	Soluble material	Bixin	N in residue
Garaina						
Mature elongated						
(I)	36.4	3.4	3.0	12.9	3.6	3.0
(II)	34.6	3.6	2.8	12.3	3.8	2.6
Immature elongated	32.0	4.1	3.4	9.3	4.2	2.9
Immature spherical	29.1	5.3	4.2	11.5	5.3	3.8
Wau						
Mature broadly ovate						
(I)	22.6	1.6	2.3	5.1	1.6	2.3
(II)	20.0	1.9	2.3	8.9	1.8	2.3
Mature elongated	36.1	4.6	3.0	13.3	4.0	3.1
Mageri						
Mature elongated	33.3	4.2	3.2	10.4	4.3	2.1
Goroka						
Mature elongated	27.9	4.1	2.5	19.1	4.3	2.3
Lae						
Mature elongated	38.6	4.5	2.9	19.8	4.8	3.1
Hawaii						
'Round pod'	6.7 - 8.4	2.4 - 2.9	ca.2			
'Pointed pod'	7.4 - 9.5	3.2 - 4.1	ca.2			

Chromatographic Purification.

Several chromatographic adsorbents were used for purification, and of these sodium carbonate: filter cell (1 : 1) proved by far the most successful for analytical purposes. The non-acidic fraction was eluted with petroleum ether and acetone followed by the acidic fraction with aqueous ethanol. Deactivated alumina and mixtures containing this adsorbent tended to adsorb the bixin fraction very strongly and in any case the separation was not as satisfactory.

Silica gel was a better absorbent although the separation was not as sharp as with sodium carbonate: filter cell (1 : 1). An aliquot of the *Bixa* extract absorbed on sand was placed on a silica gel column prepared in petroleum ether. The bixin was eluted with chloroform : benzene (1 : 1) and chloroform. Chloroforms : ether (1 : 1) removed a mixture of bixin and other compounds, and acetone and ethanol were used to remove the remaining compounds (not containing bixin) from the column.

Discussion.

From the results it appears that the spherical capsule variety from Garaina, and the elongated capsule variety, would be the most economical sources of dye, whereas the other variety (broadly ovate capsules) is not as satisfactory owing to its low bixin content.

Contrary to some suggestions it is doubtful whether differences due to small variations in maturity are significant. Over-ripe pods deteriorate and the bixin decomposes, but if green pods which are just opening are picked, they will ripen and give a similar seed analysis to that obtained from pods from the same bush which are allowed to ripen completely before picking. Since the pods ripen very quickly the best time for picking, on a large scale project, would probably be when the pods were beginning to open. The seed could then be kept for as long as a week before extracting.

Probably the most efficient and economical method of commercial preparation would be cold extraction of the crushed *Bixa* seeds with acetone. Extraction is rapid and relatively small quantities of solvent would be required.

Summary.

The bixin content of the seeds of three varieties of *Bixa orellana*, from various localities in the Territory, has been determined by two methods, pyridine extraction and acetone extraction. It was found that seeds taken from the spherical capsule variety had the highest bixin content (5.3 per cent. on an oven-dry basis), those from elongated capsules had 3.4—4.6 per cent. bixin and those from broadly ovate capsules ony 1.6—1.9 per cent. bixin.

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Some Experiments on the Storage of Cacao Seed in a Viable Condition.

R. J. FRIEND.*

Introduction.

CACAO is usually propagated by means of seed, and under the right conditions this is a simple procedure. It is most important that the seed selected for planting be relatively fresh for although the viability of freshly-picked seed is good, the ability to germinate begins to fall rapidly after about ten days from the time of harvesting, under normal conditions in the tropics. This short period of viability of stored cacao seed at times is a severe handicap to the industry, for it means that some places cannot receive cacao seed from the recognized sources of seed, and that distant new areas are difficult to open up to cacao.

Pyke (1) and Pyke *et al* (2) in 1934 attempted to store cacao seed in the pod by subjecting the pods to various antiseptic treatments followed by a coating of vaseline or latex. A variety of storage temperatures was tried. They found that the antiseptic treatments were of no practical value; that vaseline treatment reduced water loss but only increased storage life where there was no fungal attack; that the optimum storage temperature was about 60 degrees F. (16 degrees C.); and that the most important fungus associated with the fungal attack of stored cacao pods was *Botryodiplodia theobromae.*

Evans (3) in 1949 attempted to store cacao seed both inside and outside the pod. He found that fully ripe pods kept better than under-ripe pods though initial germination of the seed within was excellent in all cases. The coating of pods with vaseline and the injecting of the pod cavity with sterile water were both found unsatisfactory. Pods were succesfully stored for up to two months by packing them in moist charcoal. Cacao seed was layered in powdered charcoal with a moisture content of 30 per cent. and after thirteen weeks' storage, seedlings were established successfully.

Experiments on the storage of cacao seed were carried out at the Lowlands Agricultural Experiment Station, Keravat, in 1950 (unpublished). These included the layering of seeds in damp sawdust and various attempts to reduce the loss of water from the seeds. No results of importance were obtained.

STORAGE OF CACAO SEEDS OUTSIDE THE POD.

Under normal conditions, once a cacao seed is taken out of the pod it will commence to grow if conditions are suitable or it will die if conditions are not suitable. Excessive cold, heat, desiccation and fungal attack will all kill the seed. The general aim of the following experiments was to induce in the seeds by various growth inhibitors a period of dormancy that was not harmful to their later growth.

Experiment A 1 (using "Tuberite").

The seeds from twelve ripe pods were divided into five similar lots which were treated as follows:—

- Lot 1. Lightly dusted with "Tuberite" (a fine powder containing 2.4 per cent. isopropylphenylcarbamate), just sufficient to form a continuous layer on the upper surface of the seeds.
- Lot 2. Heavily dusted on the upper surface of the seeds.
- Lot 3. Completely covered on all sides by a heavy application of "Tuberite".
- Lot 4. The mucilaginous layer was removed from the seeds by washing in water and shaking with glass beads. Then the seeds were completely covered by a heavy application of "Tuberite".

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Lot 5. Untreated.

The seeds were stored in damp charcoal. At regular intervals the condition of the stored seeds, including the amount of root growth and their viability was ascertained.

This experiment gave no evidence that "Tuberite" was able to induce a period of dormancy in cacao seeds. One fact of interest was the very obvious stimulation of the seeds when the mucilage had been removed, but the "Tuberite" was not responsible for this. A similar stimulation was obtained by removing the testae of seeds or the mucilage alone with no addition of "Tuberite". The radicles of such seeds grew up to three-eights of an inch in sixteen hours in a humid atmosphere at 27 degrees C.

Experiment A 2 (using isopropylphenylcarbamate solution).

A 10 per cent. solution of isopropylphenylcarbamate in acetone was diluted with water to concentrations of 0.25 per cent. 0.10 per cent. and 0.01 per cent. Eight similar lots of cacao seeds were prepared. The tips of the cotyledons were removed from the seeds in lots 1 to 6. In lots 7 and 8 they were left entire. The lots were then soaked as follows:—

Lot 1. 0.01 per cent. solution for one hour.

Lot 2. 0.10 per cent. solution for one hour.

Lot 3. 0.01 per cent. solution for 16 hours.

Lot 4. 0.10 per cent. solution for 16 hours.

Lot 5. 0.25 per cent. solution for 16 hours.

Lot 6. unsoaked.

Lot 7. 0.25 per cent. solution for 16 hours.

Lot 8. unsoaked.

After treatment the seeds were layered in moist powdered charcoal. Samples of seeds were taken at weekly intervals from each lot and planted out to test their viability. The condition of the stored seeds and the amount that the radicle had grown were recorded. The results showed that under the conditions prevailing, isopropylphenylcarbamate was unable to induce a period of dormancy in cacao seeds. The removal of the end of the cotyledons had a small stimulating effect on the growth of the seeds. The presence of isopropylphenylcarbamate acetone also had a stimulating effect on growth.

Experiment B (using citric acid).

When citric acid was applied to cacao seeds as lemon juice it was too dilute to produce any significant effect, but when applied as pure crystals it produced a considerable effect.

Four similar lots each of 100 cacao seeds, were used in the experiment. Three lots had citric acid crystals sprinkled over the seeds in the quantities of 25, 50 and 100 grams respectively. The fourth lot of seeds was untreated. The seeds were then layered in damp powdered charcoal. At weekly intervals samples of seeds from each treatment were taken and washed to remove any citric acid, the amount of growth of the radicle was recorded, then they were planted out to test for viability.

At the two higher levels of citric acid the cacao seeds were rapidly killed. At the lowest levels however, growth of the seeds during storage was distinctly suppressed but the percentage of seedlings finally established was similar to that of the control. These results indicate that it may be worthwhile to experiment further with citric acid.

Experiment C (using coumarin).

Coumarin has been used successfully on various plants in order to induce temporary biological dormancy. Three similar lots of cacao seeds were treated as follows:—

Lot 1. A little petroleum jelly containing 1 per cent. by weight of coumarin crystals was applied to the radicle end of the seeds.

Lot 2. Coumarin crystals were sprinkled evenly over the seeds at the rate of 10 grams per 100 seeds.

Lot 3. Untreated.

The seeds were then layered in moist powdered charcoal. Samples of seeds from each treatment were taken at weekly intervals and their condition, including the amount of growth of the root, was recorded, and they were then planted out to test their viability.

Coumarin was found to be unsatisfactory. The results were similar to, though distinctly poorer, than, those obtained with citric acid.

In all the experiments described above the storage medium of damp powdered charcoal was kept in cardboard boxes. The cardboard boxes seemed to allow too much drying of the charcoal. Probably the use of perforated tins as used by Evans (3) would be more satisfactory.

Conclusions.

1. Both "Tuberite" and its active principle, isopropylphenylcarbamate, were ineffective in inducing a period of dormancy in cacao seeds.

2. Citric acid applied at the rate of 0.25 grams per seed seemed capable of retarding growth without being harmful to the seeds. Further investigation is necessary.

3. Coumarin seemed capable of retarding growth of the seeds but it appeared to be less satisfactory than citric acid.

STORAGE OF CACAO SEEDS INSIDE THE POD.

Under normal conditions in the tropics cacao pods have rather a short life, beginning to break down under the attack of fungi in from one to three weeks after harvesting. The viability of the seeds within the pod declines very rapidly soon after the breakdown of the pod commences. While the pod is in a healthy state almost all the seeds remain viable. Pyke *et al.* (2) suggested that age is an important factor in the decline in viability of stored cacao seed. However, it appears that for at least the first few months of storage, age is only of minor importance. The major factors seem to be (i) fungal attack and (ii) perhaps the presence of toxic bi-products of fungal growth. Loss of water from the pod does not seem to affect the seed directly but it is of great importance because it lowers the pods' resistance to fungal attack. The seed is killed by fungal attack before desiccation causes death.

Preliminary experiments.

Experiment D 1 (to determine the variation in viability of seeds due to time).

Nine unblemished pods were harvested from each of four trees and the seeds from one pod from each of the trees were planted out every two days. Only pods showing little or no fungal attack were used so as to minimize the effects due to the growth of fungi.

This experiment indicated that so long as the pods remained in a healthy state, the viability of the seeds within them does not change significantly. Germinations of 100 per cent. were recorded from the first to the eighteenth day after harvesting. Where there was much fungal rotting, the viability of the seeds fell rapidly. In later experiments in which pods were kept free from fungal attack for up to 96 days, germination was also 100 per cent. This showed more conclusively that age is not a primary factor in the death of cacao seeds stored in the pod.

Experiment D 2 (to compare the germination of seeds from unripe and ripe pods).

One full-sized but unripe pod, just-ripe pod and well-ripe pod were harvested from the same cacao tree and twenty seeds from each pod were planted out. The total germination of the seeds in each category was very similar. The seeds from the unripe pods showed the least uniform germination. This result is very similar to that obtained by Evans(3).

Experiment D 3 (to compare the keeping quality of unripe and ripe pods).

Three full-sized but unripe pods and three ripe pods were harvested from each of four trees. They were all stored at room temperature in the laboratory on a bench and were inspected regularly for signs of rotting.

After taking the average of the results for the pods in each category for each tree, it was found that the under-ripe pods commenced rotting and were completely rotted before the ripe pods on the same tree. There was a considerable variation in keeping quality between pods from the same tree, and a greater variation between pods from different trees but in the same category.

Experiment D 4 (to compare the keeping quality of pods from different trees).

Six pods were harvested from each of six trees and were stored on the laboratory bench. At regular intervals they were inspected for signs of rotting. The average period for which the pods remained healthy varied from 10.5 days to 17.0 days for the six trees, so there was a distinct difference between the keeping quality of pods from different trees. As in the previous experiment there was also a distinct difference between pods from the same trees. For example, the pods from one tree remained healthy for from 11 to 26 days.

EXPERIMENTS TO INCREASE THE STORAGE LIFE OF CACAO PODS.

The Use of Fumicides.

As the breakdown of pods during storage always has a fungal component, an attempt was made to inhibit the growth of such fungi by the external application of fungicides.

Experiment E 1 (using various fungicides).

Ten pods from each of three trees were harvested and treated by immersing them in a solution of the fungicide for about half a minute, except in the case of Phemox which was applied as a dust. The five treatments used, each on two pods from each tree, were 0.1 per cent. Karathene WD, 0.2 per cent. Dithan Z - 78, 0.1 per cent. Mercuric Chloride, 10 per cent. Phemox powder, and a water control. The pods were stored at room temperature in open boxes and inspected regularly for rotting.

None of the treatments increased the storage life of the pods. In all cases fungal breakdown was as rapid as with the control. Apparently the fungi are present in the healthy pod in crevices or as a latent infection in the pod tissues and so they escape contact with the fungicides.

Experiment E 2.

It was observed that with most pods rotting begins either at abrasions or at the stalk end of the pod. Special effort was made to protect these parts.

Pods were harvested from six trees and the pods from each tree were divided into three lots. In the first lot the stalk end and any abrasions were sealed with melted paraffin wax at 150 degrees C. containing 0.1 per cent. by weight of Dithane Z - 78. In the second lot the pods were surface sterilized by immersing in 95 per cent. ethyl alcohol, then the stalk end was liberally covered with 6 per cent. copper oxychloride powder. The third lot was the untreated control. The pods were stored at room temperature and were inspected regularly.

The results gave no significant difference between treatments. Alcohol burnt the skin of the pod and thereby reduced the storage life. The fungicides served no useful purpose. Those parts of pods protected by paraffin wax usually took longer to rot but as the remainder of the pod rotted as quickly as the control, there was no significant overall improvement. A number of fungi were isolated from the shells of some of these pods. The fungus which was isolated most commonly was *Botryodiplodia theobromae.*

The use of Paraffin Wax.

Loss of water from cacao pods stored under normal conditions appears to be an important factor in predisposing the pods to fungal attack. In the following experiments paraffin wax was used as a means to reduce this loss of moisture.

Experiment F 1 (immersing the pods in paraffin wax).

Some pods were harvested and the same day immersed in melted paraffin wax at a range of temperatures. The results were unsatisfactory because within three weeks all the pods had started to rot and most were severely rotted. The viability of the seeds within the pods after this period was negligible. Pods dipped in wax at 150 degrees C. had their shells browned from the heat and so should have been effectively surface sterilized. However rotting still occurred. The only fungus isolated from these pods was *Botryodiplodia theobromae* and it was isolated at every attempt. It seems that the pods must have carried a deep-seated infection of this fungus before they were waxed. Pods dipped in wax at 120 degrees C. and at 80 degrees C. had a variety of fungi in them, the fungi isolated most commonly being a few species of *Aspergillus, Colletotrichum* and an unidentified white fungus as well as *B. theobromae.*

It was obvious that upsets in respiration had been a major factor in the death of the seeds, and that sterilization of the pods was of little practical importance. Keeping the pods in a healthy condition would appear to be the best way to combat fungal breakdown during storage and thus to increase the storage life of the pods.

Experiment F 2 (delaying the wax treatment of harvested pods).

Some pods were harvested and divided into five lots then stored in open boxes in the laboratory. After storing for one day, lot 1 was treated with paraffin wax by dipping both ends of each pod in melted wax at 100 degrees C. in such a way as to leave a central unwaxed band about half an inch wide. Lot 2 was treated similarly after storing for two days, lot 3 after storing for four days, and lot 4 after storing for nine days. Lot 5 was the untreated control.

The results indicated that the keeping quality of the pods declined very rapidly if the pods were kept for any considerable length of time before treating with paraffin wax. Pods stored for one day before treatment remained without any sign of fungal rotting for up to 40 days. The other treatments declined in their effectiveness as the length of the pre-treatment period of storage was increased. The pods stored for nine days before treatment had a keeping quality no better than the control. In both these cases all the pods had commenced rotting in about two weeks after harvesting. For best results the pods must be treated with paraffin wax as soon as possible after harvesting.

Experiment F 3 (using wax at different temperatures leaving an unwaxed band).

One hundred and twenty-five pods were harvested, divided into five similar lots then treated the same day with paraffin wax. Lot 1 was immersed in melted wax at 150 degrees C. for ten seconds. Lot 2 had the ends of the pods dipped at 120 degrees C. leaving an unwaxed central strip of about three-quarters of an inch in width. Lot 3 had the ends dipped at 100 degrees C. and lot 4 at 175 degrees C. Lot 5 was the untreated control. The pods were stored at room temperature on the laboratory bench and were inspected regularly. Two pods were taken each week from each treatment and seeds chosen at random planted out to test for viability.

The results of the treatment in which the pods were immersed in wax differed very little from those of the control. With both treatments, the viability of the seeds was very poor by the eighteenth day of storage. The percentage germinations recorded were 30 per cent. and 5 per cent. respectively and no seeds germinated after the eighteenth day. The results of the three treatments in which the pods had a central unwaxed band were very similar. This showed that the temperature of the wax is not critical, at least between 75 degrees C. and 120 degrees C. The average keeping quality of the pods in these three treatments was superior to that of the control.

Some of the pods in these three treatments deteriorated as rapidly as the pods of the control, but many lasted for much longer periods; one pod gave 100 per cent. germination after 56 days of storage. It was estimated that the pods of the control and those immersed in wax kept satisfactorily for about 14 days, whereas the pods having an unwaxed band kept satisfactorily for an average of about 27 days.

The beneficial effect gained by treating pods with wax appears to result from the reduction in transpiration of the pods. Precautions need to be taken to prevent too much of the surface of the pods being covered with wax thus seriously inhibiting respiration.

The chief fungus causing pod rot was found to be *B. theobromae* in every treatment, especially during the first few weeks of storage. After the first month of storage other fungi were dominant in pod breakdown. These were weaker parasites, the most common being *Colletotrichum* sp. and *Fusarium* sp.

It was noted that about half the pods which had a central unwaxed band had commenced to rot at this unwaxed portion, whereas the pods of the control commenced rotting usually at places other than the centre, particularly at the stalk end.

Experiment F 4 (varying the size of the unwaxed portion of the pod).

Eighty-four pods were harvested, divided into three lots and treated the same day. (Immediately before treating with wax the stalk of each pod was cut off with a sterile scalpel and any abrasions were cut down to a fresh surface.) Lot 1 was dipped in melted wax at 100 degrees C. leaving an unwaxed central portion which was crescent-shaped running about half way round the pods and was from a quarter to half an inch in width at the widest part. Lot 2 was treated similarly but the wax contained 5 per cent. by weight of the fungicide "Shirlan". Lot 3 was the untreated control. The pods were stored in the laboratory at room temperature and inspected regularly.

The results showed an overall improvement in the keeping quality of pods treated with paraffin wax, though for the first few weeks of storage the control was superior. A few of the waxed pods remained healthy for quite a long period, one pod still being unblemished after 90 days of storage. It seems that the small unwaxed portion was a limiting factor with many pods. This statement is further supported by the fact that in 45 out of the 56 pods treated with wax, rotting of the pod started at the central unwaxed portion. Once again about half of the pods of the control commenced rotting at the stalk end. The pods treated with wax containing "Shirlan" seemed to have a slightly better keeping quality than the pods treated with pure wax.

Experiment F 5 (varying the size of the unwaxed portion of the pod).

Seventy-five pods were harvested, divided into five lots and treated the same day. Before treating with wax the pods were brushed free of dirt and the stalk and any abrasions were cut to a fresh surface. Lot 1 had the ends of the pods dipped in melted wax leaving a small crescent-shaped unwaxed area at the centre running half way around each pod. Lot 2 was treated similarly except that the unwaxed portion was a central band about a quarter of an inch wide and running right around the pod. Lot 3 was treated similarly but with a half-inch unwaxed band. Lot 4 was treated similarly but with an inch wide unwaxed band. Lot 5 was the untreated control. The pods were all stored in the laboratory at room temperature and inspected regularly.

The results showed that all the treatments using wax were superior to the control but there was a noticeable difference between some of them.

The pods having the one-inch unwaxed band kept best for the first three weeks but then deteriorated rapidly so that the pods having the quarter-inch and half-inch unwaxed bands kept best over the last six weeks. The pods having the small crescent-shaped unwaxed area were the least satisfactory of all the waxen pods. It appears obvious that both respiration and loss of water are important factors in the keeping quality of pods treated with paraffin wax, and that, for best results, that size of unwaxed area must be found which gives a minimum loss due to the combined effects of these factors. It would appear from this experiment that a central unwaxed band about half an inch in width gives the best results. The size of the pod, the period of storage, and the conditions of storage would all be expected to modify the optimum size of this unwaxed area.

It was noticed that as the unwaxed area was made smaller than the half-inch band, the percentage of pods in which rotting was initiated at this site became greater.

Conclusion.

1. While the cacao pods remained free from fungal attack, the viability of the seeds within them did not change with time.
2. The germination of seeds from freshly-picked pods that were full-sized but un-ripe and pods that were ripe was very similar.
3. The average keeping quality of pods harvested from any one tree could vary considerably from that of pods harvested from a different tree.
4. The keeping quality of individual pods harvested from any one tree could vary considerably.
5. The keeping quality of pods harvested when unripe was considerably poorer than that of pods harvested when ripe.
6. The external application of fungicides was ineffective in lengthening the storage-life of pods.
7. Pods immersed in melted paraffin wax were rapidly decomposed by fungi with the consequent death of the seeds within.
8. Dipping the ends of pods in melted paraffin wax so as to leave an unwaxed central band significantly increased the average storage life of the pod if it was treated within a day of harvesting. The optimum size of the unwaxed central band was about half an inch in width.
9. When the fungicide "Shirlan" was added to the paraffin wax, the results seemed to be superior to those achieved when the wax was used alone.

Summary.

The storage of cacao seed outside the pod was attempted using the growth inhibitors "Tuberite" containing isopropylphenylcarbamate, citric acid, and coumarin, in order to induce a period of dormancy in the seed. None of these substances was found to prolong the life of the seed significantly.

The storage of cacao seed inside the pod was attempted using various fungicides and various paraffin wax treatments to increase the storage-life of the pod. The methods using fungicides did not prolong the life of the seed significantly. Using paraffin wax the average period for which the seeds in a pod could be kept in a viable condition was doubled, being increased from about fourteen days to twenty-eight days, with one pod lasting for ninety days.

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Rubber Planting Techniques.—Part I.

The Handling of Rubber Seed.

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Introduction.

Increasing use is made by planters in the Territory of Papua and New Guinea of clonal rubber seed. This seed is at present mainly imported from Malaya and owing to its high cost it is essential that nursery techniques should be such as to ensure maximum germination. Complaints are received from time to time about the poor germination of rubber seed and these notes are intended to assist planters to obtain good results from their seed, whether imported or of local origin.

Treatment on Arrival.

Seeds should be planted immediately upon arrival at the plantation. Rubber seed deteriorates rapidly unless special facilities, such as refrigerated storage, are used. Normally the seed keeps its viability well for only about ten days. Loss of moisture content of the seed is probably the main cause for the loss of viability. If for any reason the seed cannot be planted immediately, it is advisable to unpack it and place it in damp charcoal or between moistened layers of hessian. It should be kept out of the direct sunlight under all circumstances.

Seeds arriving in sawdust should be washed free of all sawdust prior to planting, since ants may be attracted to the sawdust and disturb the soil around the seeds.

Germination Beds.

Pre-germination is particularly advisable prior to planting in order to reduce waste and to secure a uniform establishment in the nurseries. This is particularly important where costly imported seed is used.

Germination beds must be prepared before the arrival of the seed in order to avoid delay in planting with consequent loss of viability.

It is important to make the germination beds of loose friable material which does not compact with frequent watering. It must have plenty of air space and good water-retaining properties. Aeration is more important than nutrition since seeds depend mainly on their own food reserves at this stage. A heavy compacted soil, such as clay, will often cause water logging, which is considered to be the main cause of failure in germination.

The best germination medium is river sand with not too high a fine sand fraction. A light loamy soil is also quite suitable if well cultivated, i.e., broken down to a fine tilth to a depth of at least four inches. Heavier soils could be worked into the required structure by mixing with coarse river sand. If only a limited quantity of sand is available, it is a good practice to spread the sand on top of the soil; a depth of two inches will be sufficient. Sawdust should not be used as a germination medium as its acidity could adversely affect the seed unless the sawdust is well weathered or boiled first.

Germination beds should be raised to four inches above the general soil surface, so that excess water may drain freely. They should be situated on a level site near a reliable water supply. To guard against the washing away of the soil, the raised ground should be kept in place by flattened bamboo, planks or other suitable material. So that all parts will be accessible, beds must not be over four feet in width. The length of the beds depends on the number of seeds to be planted. On the average, one thousand seeds will cover one square yard of germination bed.

It is necessary to provide shade over the bed at a height of about five feet. Kunai grass (*Imperata cylindrica*), palm fronds or other broad leaved plants make suitable material for shading. Germination beds can also be established under rubber or other trees. Indirect sunlight should reach the beds but care must be taken to ensure that they are not exposed to strong direct sunlight for any length of time.

Planting the Seed.

Keep the seeds in a cool shady atmosphere during planting operations. Seeds are laid out on the surface of the germination bed with the grooved side downwards. They are set out very closely together and may be touching one another but not overlapping. The seeds are pressed by hand into the germination medium to a depth of about three quarters of their diameter. In a pure sand medium they may be pressed down further leaving the top just visible. At the Bisianumu Rubber Centre the seeds are not covered with sacking, as is sometimes done in Malaya, since it was found that this caused excessively damp conditions and could easily result in rotting of the seeds. But the beds are therefore lightly covered with kunai grass, leaving the seeds still more or less visible. This light covering of grass appears to ensure a more even temperature around the seeds during day and night which probably is of importance at this altitude (1,800 ft.) and seems to improve germination. The cover is taken off as soon as the seeds commence to germinate. Overhead shade remains as long as seeds are in the bed.

Watering is done several times daily and a knapsack sprayer has been found to be ideal for this purpose, since the light mist spray gives an even distribution of moisture and does not cause any disturbance or exposure of the seeds. Germination beds must be kept moist, but not wet; this is regarded as the critical requirement for successful germination. It is advisable to protect the seeds from rats, bandicoots, etc., by surrounding the beds with fine gauge chicken wire, which is dug into the ground to a depth of about one foot.

Germinated Seed.

Fresh rubber seed normally germinates within a week of sowing but germination after three weeks or more is not unusual in this Territory. On more than one occasion at Bisianumu seed has germinated four weeks after being placed in the germination beds, and most of them have grown into perfectly healthy seedlings.

On germinating, the emerging root breaks through the seed coat and appears as a white rootlet with a flattened end. This is the time for transplanting to the nursery and daily inspection and transplanting of germinated seed will ensure a uniform stand of seedlings. Seeds are carefully lifted from the bed and carried to the nursery; the delicate young seedlings must not be laid in deep layers when carried to the nursery or they may be damaged. Ungerminated seeds are reset in the bed, lightly covered, and watered. Chances of successful nursery establishment are enhanced by planting the germinated seed as early as possible, preferably before the young shoot starts to develop, although it is possible to transplant seed with a growing stem as long as it is done before the first pair of leaves unfold. Generally speaking, the earlier germinated seed is transplanted the better are the chances of success. At this early stage there are sufficient food reserves within the seed for the root to penetrate deeply and secure moisture; later these reserves are depleted and moisture is lost by transpiration through the stem. Delay in transplanting also increases the possibility of root and stem damage.

Hot and sunny days should as far as possible be avoided during transplanting operations, particularly when planting the more advanced material. It is obvious that shade over the nursery beds must be established prior to transplanting and on no account should germinated seed be exposed to direct sunlight.

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Insect Pests of Hevea Brasiliensis *In the Territory of Papua and New Guinea: Their Habits and Control.*

LANCE SMEE.

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MOST of the insects attacking rubber (*Hevea brasiliensis*) in the Territory of Papua and New Guinea are relatively unimportant. *Amblypelta lutescens papuensis* Brown (called the *Papuan* tip-wilt bug) is the most serious pest. A number of the more common insects which have been recorded on rubber are described in this article, along with the control measures recommended for use if the damage becomes serious enough to require treatment.

These insects include :—

Papuan tip-wilt bug.	*Amblypelta lutescens papuensis* Brown.
Leaf eating or 'shot-hole' weevils.	*Idiopsis caerulea* Fst. *Idiopsis grisea* Fst. and other species in the family Curculionidae.
Army worm.	*Tiracola plagiata* (Walk.).
Shot-hole borers.	various species in the families Platypodidae and Scolytidae.
Termites.	*Coptotermes elisae* (Desneux).
Brenthids.	*Miolispa* species.
Tussock moths.	*Euproctis* species.
Cockchafers.	family Melolonthidae.
Butterfly hopper.	*Colgar. tricolor* Dist.
Millipedes.	order Diploda.

Most of these insects only occur on rubber in small localized areas, but as they are mostly indigenous are generally widespread throughout the Territory ; thus they can appear at widely separated points.

THE PAPUAN TIP-WILT BUG.

Amblypelta lutescens papuensis Brown.

Amblypelta lutescens papuensis Brown has been found only in Papua, and is not recorded as occurring in New Guinea. Other species of *Amblypelta* are found on a wide variety of plants, including cacao and coconuts ; all are light brown coloured bugs about half an inch long (*Figure* 1), belonging to the family *Coreidae*.

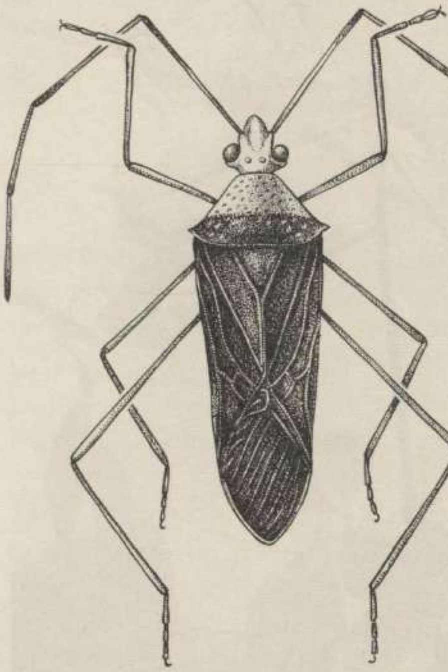

Figure 1.—Papuan tip-wilt bug, *Amblypelta lutescens papuensis* Brown.

Life History.

Very little is known about the life history of these bugs except that one generation lasts from six to seven weeks. The eggs are laid on the upper and lower surfaces of the leaves of the host plants. The nymphs which emerge are similar to the adult, except that they are wingless and their antennae are larger in relation to their size, with flattened segments. There are five nymphal stages, each being similar to the previous one except in size. The nymphs are bright orange-yellow with dark brown markings.

Damage.

The symptoms of *Amblypelta* damage on the young tips are longitudinal grooves appearing on the upper portion of the stems, followed by wilting of the tips (Plate 1). The leaves on the branches near the growing point begin to wilt and droop, eventually falling (Plate II).

Plate I.—Tip damaged by *Amblypelta.*

Often the extremities of the branches die. On older stems scars are formed which are similar in appearance to the scars on young coconuts which have fallen prematurely due to *Amblypelta* attack (Plate III). These scars are usually reddish-brown in colour, later becoming larger and turning a grey colour. If there are a large number of *Amblypelta* present, the surface of the stem becomes knotty and distorted (Plate IV).

Plate II.—Growing point dying with the leaves wilted following *Amblypelta* attack.

Observations have shown that *Amblypelta* does not occur in pockets as do the cacao capsids, but appears to be fairly evenly distributed through the plantation.

Host Plants.

While other species of *Amblypelta* are found on a very large variety of plants, *Amblypelta lutescens papuensis* is recorded only from rubber, cassava, pawpaw, *Abroma augusta* (devil's cotton), sweet potato, mango, frangipani, choko and coconuts.

On coconut palms it can cause premature nutfall similar to that caused by *Amblypelta cocophaga* in the British Solomon Islands.

Control.

Amblypelta is susceptible to the chlorinated hydro-carbon insecticides, particularly Dieldrin. The usual method of application is by hand-powered knapsack sprayers, using 0.2 per cent. to

0.3 per cent. mixture in water. The trees are usually not attacked after they reach a height of seven feet so that powerful machinery is not needed.

Plate III.—Scars formed by *Amblypelta* feeding on older tissue.

Shoulder-mounted, engine-powered misting machines can be used, with a one per cent. Dieldrin mixture.

In areas where *Amblypelta* attack is common, treatments should be carried out at regular intervals of three weeks or so.

LEAF EATING WEEVILS.

Idiopsis caerulea Fst.
Idiopsis grisea Fst. and other species of Curculionidae.

A number of species of small weevils are recorded as feeding on foliage of rubber. They are generally found on all sizes of trees, but are of importance only on small seedlings and buddings. The species involved include *Idiopsis caerulea* Fst., *Idiopsis grisea* Fst., (*Figure* 2), *Apirocalus cornutus* Pasc., *Oribus cruciatus* Fst., (*Figure* 3) and *Rhinoscapha thomsoni* Waterh. The two *Idiopsis* species are the most important.

Life History.

All these weevils belong to the same tribe, the Celeuthetini (except *Rhinoscapha*) the larvae of which feed on roots (mainly composite weeds) in the ground.

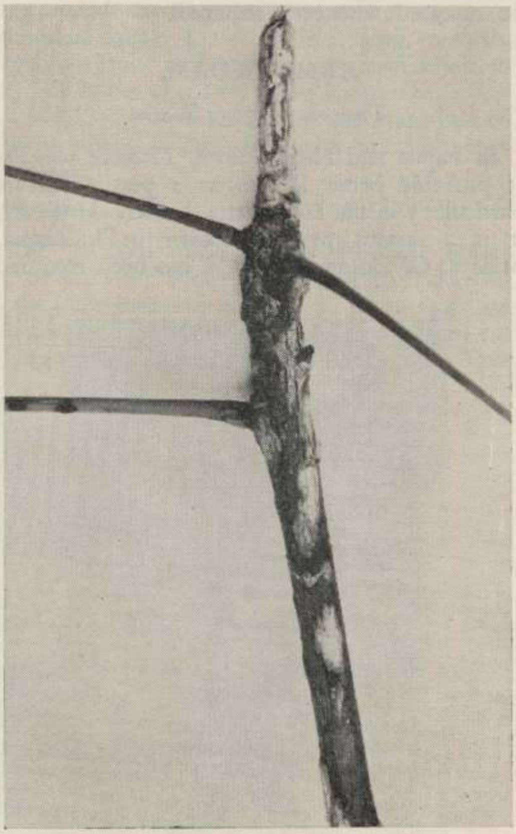

Plate IV.—Scarring and distortion caused by *Amblypelta.*

Damage.

These small weevils all cause extensive " shot-hole " damage to the foliage of rubber.

Host Plants.

Idiopsis grisea has been recorded on Hibiscus, passionfruit, citrus, sweet potato and avocado pear ; *Oribius cruciatus* has been recorded on cassia, citrus, coconuts, coffee, cassava, cacao and many other plants, while *Apirocalus cornutus* (*Figure* 4) is found on peanuts, capsicums, cassia, crotolaria, etc. In addition these insects would be found on many bush trees.

Control.

Various mixtures of DDT are recommended for weevils. A high volume spray of 0.5 per cent. DDT or a low volume mist of two per cent. DDT should give control. The treatment can be repeated whenever required.

ARMY WORM.

Tiracola plagiata Walk.

In Papua and New Guinea, *Tiracola plagiata* is probably better known as a pest of cacao, particularly in the Popondetta district. However, it is a serious pest of rubber in Indonesia, Malaya, Ceylon and Samoa, it has been recorded as attacking rubber in Papua. The first record in Papua was at a plantation in the Central District, in 1958.

Figure 2.—*Idiopsis grisea.*

The larvae of *Tiracola* in the later stages are a grey colour, with reddish-brown head and a prominent cream to yellow band along both sides of the abdomen (Plate V). The adult is a grey to pinkish-fawn moth, with a distinct dark brown to black V-shaped mark on the fore-margin of the fore-wings (Plate VI).

Life History.

The eggs are laid at night in large batches on the leaves of the host plant. The larvae hatch in 3½ to 4 days and reach full size in 15 to 17 days ; pupation then takes place in the soil, requiring another 10 to 15 days. The total life cycle, egg to egg takes 35 to 40 days under average conditions.

Damage.

At the plantation attacked in the Central District of Papua, *Tiracola* larvae moved in ' swarm lines ' from the rainforest, completely defoliating the rubber stocks and weeds. Once the foliage was eaten, the growing plants were extensively damaged and killed.

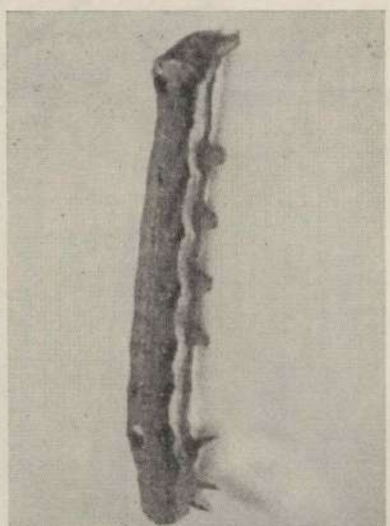

Plate V.—Sixth instar larva of *Tiracola plagiata.*

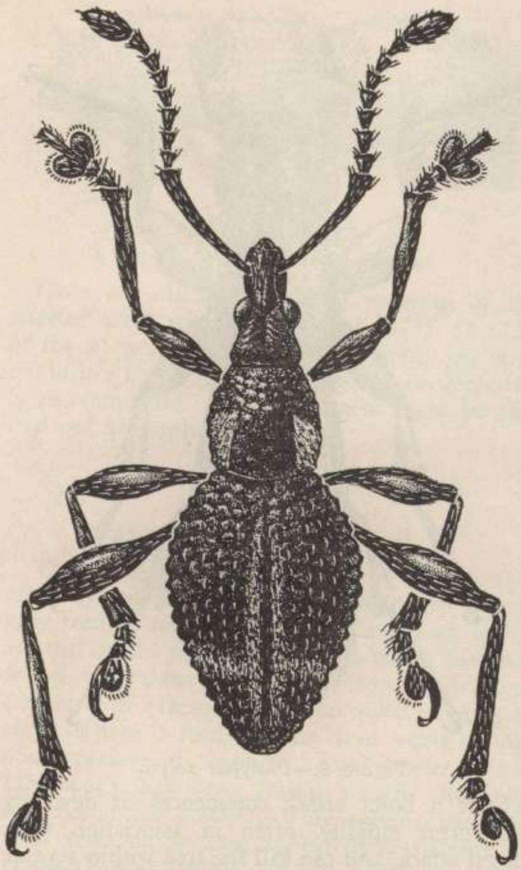

Figure 3.—*Oribius cruciatus.*

Host Plants.

Tiracola plagiata has an extremely wide host range. It includes tea, cacao, tobacco, banana, coffee, *Leucaena glauca*, sweet potato and many other plants, including many weed species.

The control measures as applied to cacao for the control of *Tiracola* are satisfactory for rubber. When using high volume equipment (knapsack sprayers) 0.25 per cent. DDT should be applied as a spray, and when using low volume equipment 2.5 per cent. DDT should be applied as a mist.

SHOT-HOLE BORERS.

The 'shot-hole' borers belong to two families of beetles, the Scolytidae and the Platipodidae. Quite a number of species of these beetles have been recorded as boring in rubber. They include a number of species of *Platypus* (a cylindrical beetle $\frac{1}{4}$ to 1/3 inch long, reddish-brown in front and a dark brown to black in the back half) (Figure 5) and *Xyleborus perforans* Woll. (Figure 6) (also an important pest of Ceylon, while *X. parvulus* Eichh. attacks rubber in Malaya).

Life History.

The galleries made by the shot-hole borers are of an even width throughout their length, as they are made by the adults. The eggs are laid inside the galleries and the larvae feed on a fungus which grows on the tunnel walls. This

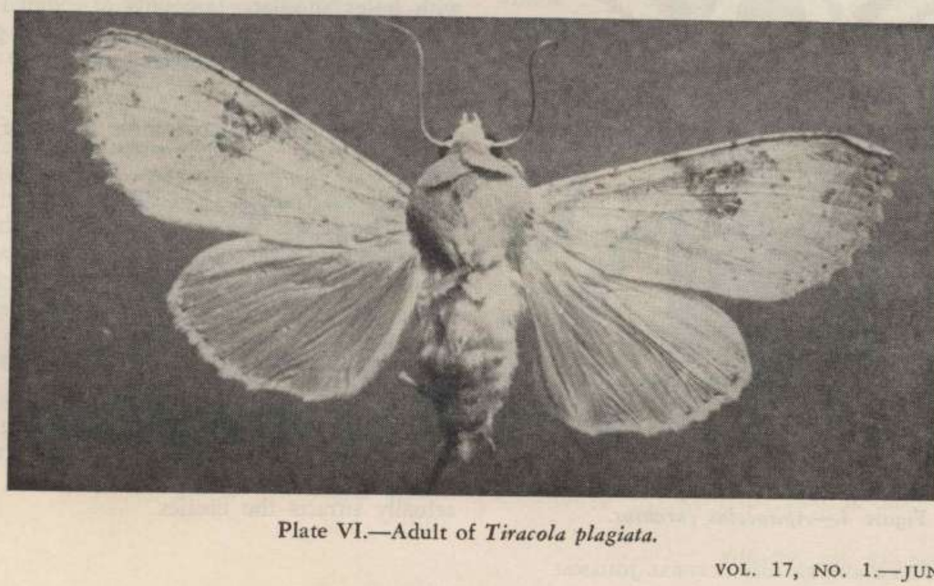

Plate VI.—Adult of *Tiracola plagiata.*

fungus is known as " Ambrosia " fungus and the beetles are sometimes known as " Ambrosia beetles ". The fungus is cultivated by the adult female, which carries the spores in its stomach. Each species of beetle has its own particular fungus, and the larvae feed on this alone. They do not eat wood.

The males of *Xyleborus* are usually much smaller than the females, are fewer in number and are incapable of flying.

Damage.

Serious borer attacks are seldom found on healthy vigorous trees, but when the outer cortical tissues are exposed by scraping or by mechanical damage, the shot-hole borers are attracted and allowed entry. When the bark of the rubber tree is scraped slightly, though not enough to cause exudation of latex, a borer can attack the exposed tissues and, although there is a copius exudation of latex which traps many of the beetles, others come along later and penetrate into the wood.

Shot-hole borers are also attracted to areas of bark which are scorched by fire, sun, fungus or even lightening.

Figure 4.—*Apirocalus cornutus.*

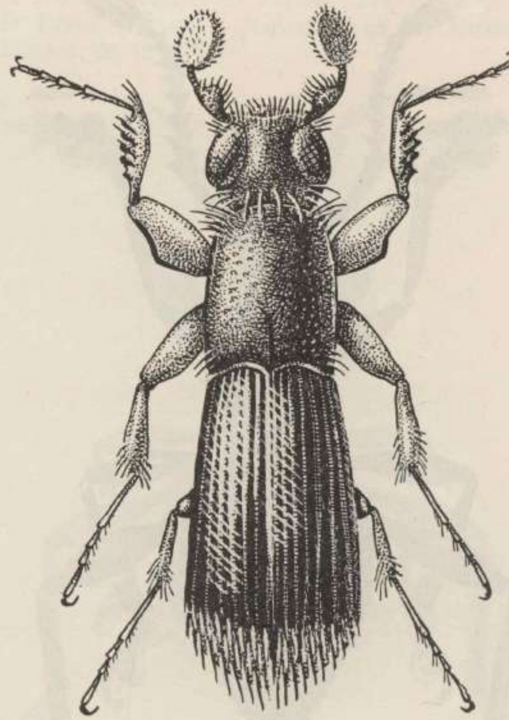

Figure 5.—*Platypus selysi.*

Once a borer attack commences, it develops with great rapidity, often in association with fungal attack, and can kill the tree within several weeks. The bark of the affected areas is riddled with holes and large amounts of exuded wood dust can be seen on the tree and the ground around the base.

Host Plants.

Shot-hole borers attack most kinds of trees.

Control.

In the years about 1914-1916 on many estates in Malaya it was the practice to scrape the bark before opening the tapping panel, as tests had shown that an increased yield of up to 14 per cent. could be expected, but this practice had to be stopped because of borer attack. Once scraping was stopped control followed without other treatment.

Thus the main means of preventing borer attack is to ensure that the bark is not damaged in any way, as it is the damaged bark which actually attracts the beetles.

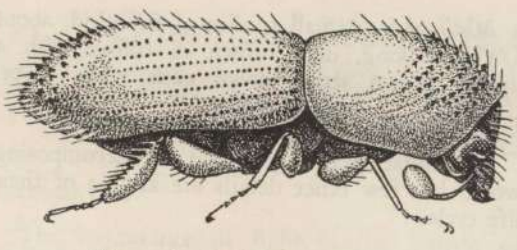

Figure 6.—*Xyleborus perforans.*

Once an attack is observed spraying of the affected areas with 0.2 per cent. DDT (1 : 125 of the 25 per cent. concentrate) or 0.1 per cent. Dieldrin (1 : 150 of the 15 per cent. concentrate) is recommended. This treatment must be carried out promptly.

TERMITES.

Coptotermes elisae (Desneux).

The nests of various species of termites are often found on rubber, but these are mostly only feeding on the dead wood and bark which are still on the tree. One species which has been found on rubber in the Territory, *Microcerotermes biroi* (Desneux) is also quite common in cacao, where it feeds on the dead wood. Only one species of termite, *Coptotermes elisae* (Desneux) has been found actually attacking live tissue on rubber. This species has also been recorded as causing extensive damage to Hoop pine at Bulolo.

In Malaya, a near related species, *Coptotermes curvignathus* Holmgr. is probably the most important pest on rubber.

Life History.

Coptotermes species are soil inhabiting termites, so that their nests are generally in a stump or tree buried underground, often with secondary nests some distance from the main nest, sometimes even on the outside of the attacked tree, above ground. Their biology is similar to that of other termites, with a male ("King") and female ("Queen") as the sexual castes, soldiers and workers.

When the eggs hatch, the young termites are cared for by the adult workers, until they are old enough to fulfil their part in the running of the colony. At intervals, waves of winged forms (normal males and females) emerge from the colony. The males pair with the females and establish new colonies.

Damage.

As *Coptotermes* are soil inhabiting, they attack from the soil, through roots or through galleries constructed on the outside of the tree. They feed inside the tree trunk and roots, weakening the system so that the tree falls when subjected to any undue strain.

Host Plants.

Coptotermes elisae will attack many different trees.

Control.

In Malaya it has been found that soil treatment using Dieldrin, Aldrin and Chlordane gives very good control of *Coptotermes curvignathus*. After the treatment has been applied, some types of soils remain toxic for as long as three years.

The recommendations are given in the following Table :—

Insecticide.	Concentration	Dilution Rates.
	per cent.	
Aldrin	0.025	1 : 800 (20 per cent. emulsifiable concentrate)
Heptachlor	0.025	1 : 800 (20 per cent emulsifiable concentrate)
Chlordane	0.04	1 : 2,000 (80 per cent. emulsifiable concentrate)
Dieldrin	0.015	1 : 1,000 (15 per cent. emulsifiable concentrate)

One of these mixtures is watered onto the ground around the base of the tree. About one or two pints are required, the actual amount depending on the size of the tree.

The above concentration should remain toxic for about two years, but in clay or peat soils the residual effect is greatly reduced. In this type of soil Aldrin, at a higher concentration (1 : 400), will give the best results.

BRENTHIDS.

Miolispa species.

Three species of the beetle family Brenthidae have been recorded as feeding on rubber. One is *Miolispa novae-guineensis* Guer. (Figure 7) and another a *Miolispa* species near *papuana* Kln. at Sogeri in the Central District of Papua.

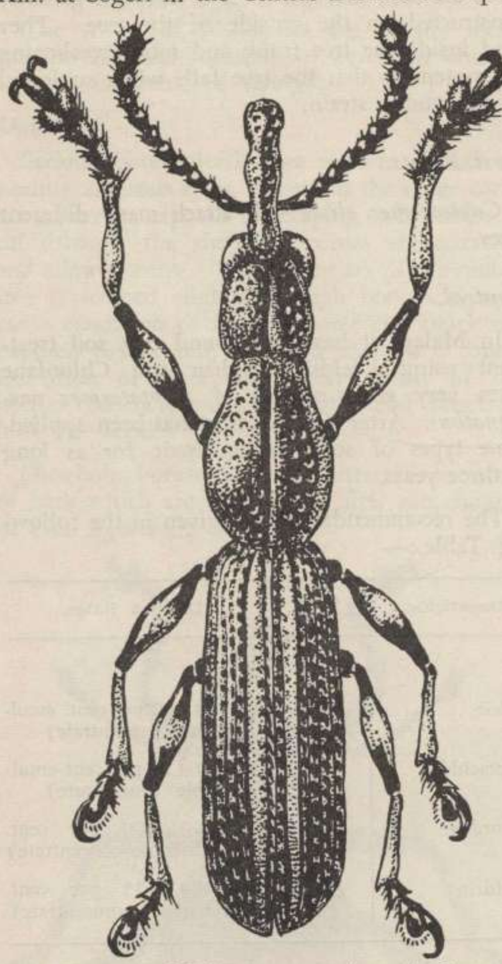

Figure 7.—*Miolispa novae-guineensis* Guer.

Miolispa is a small species of Brenthid, about 1/3 inch long, dark brown in colour with a lighter brown stripe down each wing cover.

Life History.

Brenthidae generally breed in decomposing wood, but few other details are known of their life cycle.

Damage.

In the cases mentioned above, the adults were found feeding on the petioles and growing points of young rubber seedlings, causing extensive damage and retarding growth.

Host Plants.

Miolispa is sometimes found on crolataria, but other hosts are not known.

Control.

DDT as used for weevils is recommended.

MISCELLANEOUS PESTS.

Other insects are sometimes found feeding on rubber, but are only of minor importance. These include insects such as the cupmoth *Euproctis* species (Family Limacodidae), cockchafers or grass beetles (Family Melolonthidae), and the butterfly hopper (*Colgar tricolor* Dist., Family Flatidae). Millipedes have been recorded as causing extensive damage to germinating rubber seeds in the Sepik District ; the species concerned was *Orthomorpha coarctata* (Sauss). Ants also can destroy rubber seeds after they have been planted.

For these pests a DDT spray as recommended for weevils etc. is useful, though for millipedes and ants 0.5 per cent. Dieldrin is advised.

(Received April, 1964.)

Chemical Methods of Shade Measurement.

G. HART.

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Introduction.

The importance of light in the growth of plants has prompted many investigations into its accurate measurement (Stern, 1962). In measuring the shade offered by shade trees in tropical crops such as coffee and tea, it is desirable that a large number of simultaneous light measurements be made over a large area, and hence any method must be reasonably cheap and easy to apply. As the shade at any site varies throughout the day, any measuring device must be integrating. A set of tubes containing a photosensitive chemical satisfies these requirements.

Of the many photochemical processes known (Kistiakowsky, 1928) several have been applied to light measurement. Dore (1958) and Friend (1959) used solutions of anthracene in benzene and Pearsall and Hewitt (1938) utilized acid solutions of potassium iodide. In the latter method 2 per cent. potassium iodide was mixed with 1.15 per cent. sulphuric acid and, after exposure to light, the iodine liberated was determined by titration with sodium thiosulphate. A modification of this method was investigated for possible application to the measurement of the shade given by shade trees in coffee plantations.

POTASSIUM IODIDE METHOD OF SHADE MEASUREMENT.

On exposure to sunlight, potassium iodide in aqueous solutions undergoes decomposition to iodine. This reaction has been discussed by McCrae (1923) from a chemical viewpoint, and also by Braid (1923). It is catalysed by sulphuric acid and the amount of iodine produced when this catalyst is absent is difficult to estimate quantitavely by titration with thiosulphate. However, if strong solutions are used, the yellow colouration (due to the liberated iodine) can be accurately measured colorimetrically at a suitable wavelength.

Initially 30 per cent. aqueous solutions were used, but 10 per cent. and 20 per cent. solutions were later investigated. Tubes of 20 ml. capacity and fitted with plastic screw-top lids containing plastic covered foam liners were filled with the solution, placed in shallow cardboard boxes (three per box) and covered with a series of standard 'shades' made from white cheese cloth or green savlon shade cloth. These boxes were placed in the sun and one bottle removed from each at the end of three, four and five hours. One box was left uncovered to represent 100 per cent. transmission of full sunlight and six others were covered with shades transmitting from 26 to 90 per cent. full sunlight (26, 30, 52, 66, 80 and 90 per cent.). Readings, in foot-candles, were made at 10 minute intervals with an E.E.L. lightmeter for the total period of exposure and the amount of light falling on each bottle estimated.

After exposure the tubes were allowed to cool to 25 degrees C. and the contents filtered directly into a spectrophotometer cell and the transmittance measured at 410 mu on a Beckmann DU spectrophotometer, using distilled water as a standard.

In other experiments longer exposure periods were used and the same procedure was repeated for 10 and 20 per cent. solutions. In one series of experiments sets of bottles containing 10, 20 and 30 per cent. solutions were exposed for the same period under the same set of 'shades'.

Calibration.

On five days and at one-hourly intervals from 9 a.m. to 3 p.m., the transmission of the standard 'shades' was measured with the E.E.L. lightmeter. The target was inserted in the box at the same level as the bottles and a sunlight reading made. The shade was placed in position, the reading noted, and the shade then removed and a further sunlight reading made. When the original and final sunlight readings were identical the result was recorded. For the same hour on the various days, it was found that the transmission of a particular standard was always within 1 per cent. of the mean for that standard at that hour. (For a mean of 90 per cent. the readings varied from 89 per cent. to 91 per cent.) However, the general pattern throughout each day was for the transmission of each shade to increase to a maximum at mid-day and then to decrease in the afternoon. With some shades the variation was as much as 8 per cent. (i.e., from 46 per cent. at 9 a.m. to 54 per cent. at noon). As the greatest amount of light was incident in the middle of the day the standard shade value used was the mean of values obtained from 10 a.m. to 2 p.m.

In order to determine the concentration of iodine corresponding to a particular reading on the spectrophotometer, a very dilute solution of iodine in 20 per cent. potassium iodide was prepared. 1, 2, —9, 10 ml. aliquots of this solution were made to 100 ml. with 20 per cent. potassium iodide and given the arbitrary concentration units, 1, 2, —9, 10. It was found that Beer-Lambert's Law was obeyed and standard 0 (20 per cent. solution of potassium iodide) had a transmittance of 100 per cent. and a solution of concentration 10 a transmittance of 16 per cent. at 410 mu. The sensitivity of this method is clearly shown as standards 1, 2 and 3 did not give a distinct colour with starch indicator.

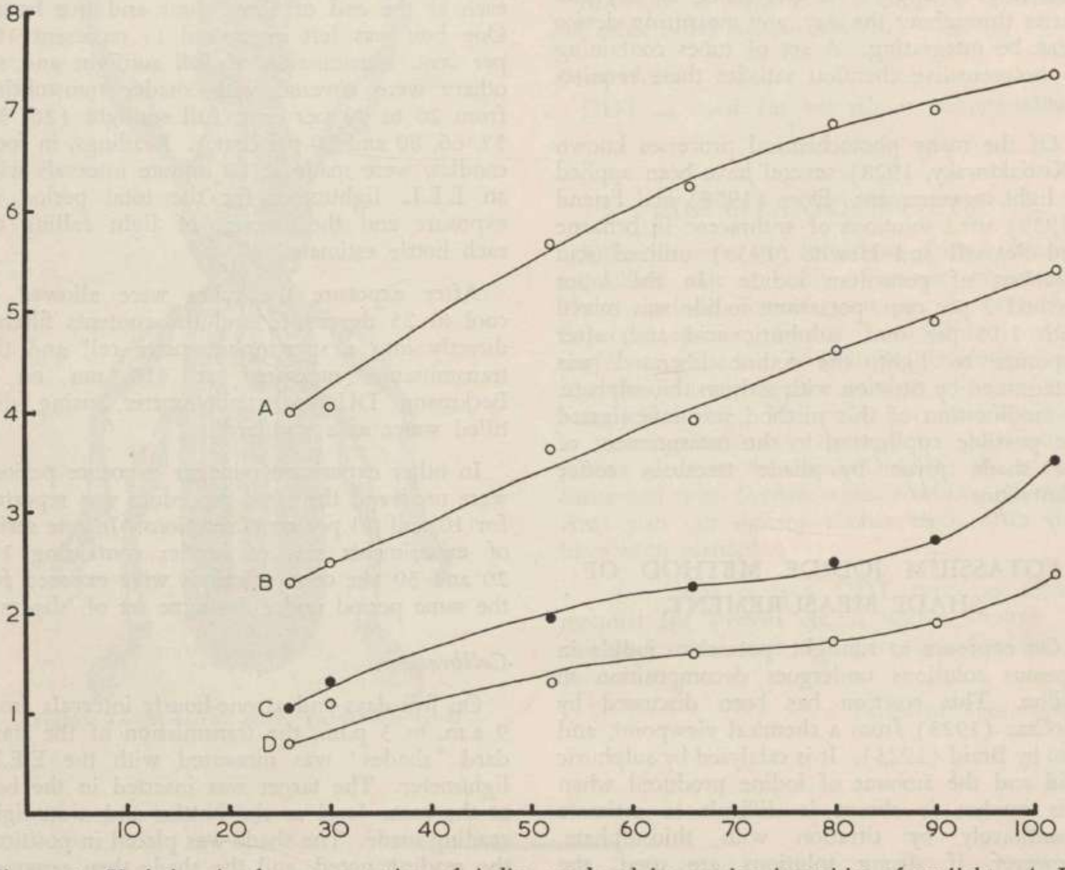

Figure 1.—Variation in the concentration of iodine produced by varying intensities of sunlight. A, B, D represent experiments with 30, 20, 10 per cent. (respectively) potassium iodide in which the full sunlight was 40,000 foot-candle-hours. C is the curve from an experiment utilising 10 per cent. potassium iodide, in which full sunlight was 48,000 foot-candle-hours.

Results.

A directly proportional relationship between the concentration of iodine produced and the amount of light initiating the reaction was not obtained. The results for several typical experiments are shown graphically (Figure 1) and it can be seen that there was a consistent relationship for solutions exposed at the same time. Graphs A, B, D show the results of an experiment in which solutions of 30, 20 and 10 per cent. potassium iodide respectivly were exposed at the same time under the same shade coverings. In this experiment 100 per cent. sunlight was 40,000 foot-candle-hours. Graph C shows the results of an experiment using 10 per cent. potassium iodide solution for which 100 per cent. sunlight was 48,000 foot-candle-hours.

For convenience of calculation when a large number of determinations is made, a calibration curve relating the transmittance of each iodine solution (as read from the spectrophotometer) with the transmission of the standard shade which covered this solution (100 per cent. shade) can be drawn. These curves are the inverse of the types shown in Figure 1.

SHADE MEASUREMENT IN COFFEE PLANTATIONS.

A field test was performed at the Highlands Experiment Station at Aiyura in the Eastern Highlands. Four experimental blocks were used :—

A6 : An entomological block with single stem coffee pruned to a height of 5 ft. 6 in. It was divided into four plots (1, 2, 3, 4) in two of which (1, 4) the *Albizia stipulata* shade had been thinned to give approximately half the shade cover of that in the other two (2, 3).

C6 (Fig. 2) : A shade, spacing, pruning trial utilizing two types of shade tree (*Albizia* and *Casuarina*), two types of pruning (single stem and multiple stem) and three triangular spacings (7 ft., 8 ft., and 9 ft.). This block was divided into 48 plots, eight of which were utilized in the light measurement determinations. The 7-foot spacing plots were omitted because of the difficulty in moving between the bushes to distribute the bottles and all multiple stem plots (where the coffee was up to 12 feet high) were also omitted because of mechanical difficulties in bottle suspension. The plots within this block are distinguished by subscripts. Thus the eight plots measured in C6 are denoted C_1 - C_8.

D6 : A duplication of C6.

A10 (Fig. 4) : A fertilizer trial with uniform *Albizia stipulata* shade over single stem coffee ranging in height from five to six feet.

Method.

Two methods were investigated : The anthracene method as used by Friend (determination of the anthracene concentration at 400 mu on a BECKMANN DU spectrophotometer) and a second method utilizing a 30 per cent. aqueous solution of potassium iodide. Bottles similar to those already described were used for all measurements.

Small wire cradles (Plate I) were suspended from the coffee bushes (in blocks A6, C6, D6) or shade trees (in block A10) with jute or

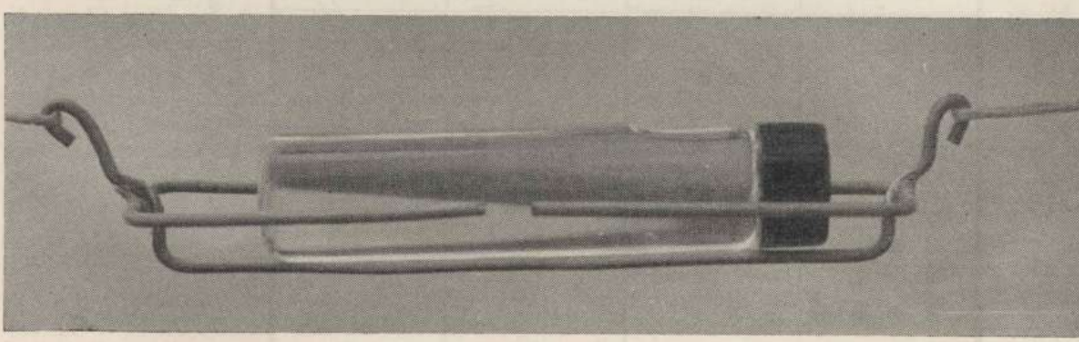

Plate I.—Bottle suspended in wire cradle.

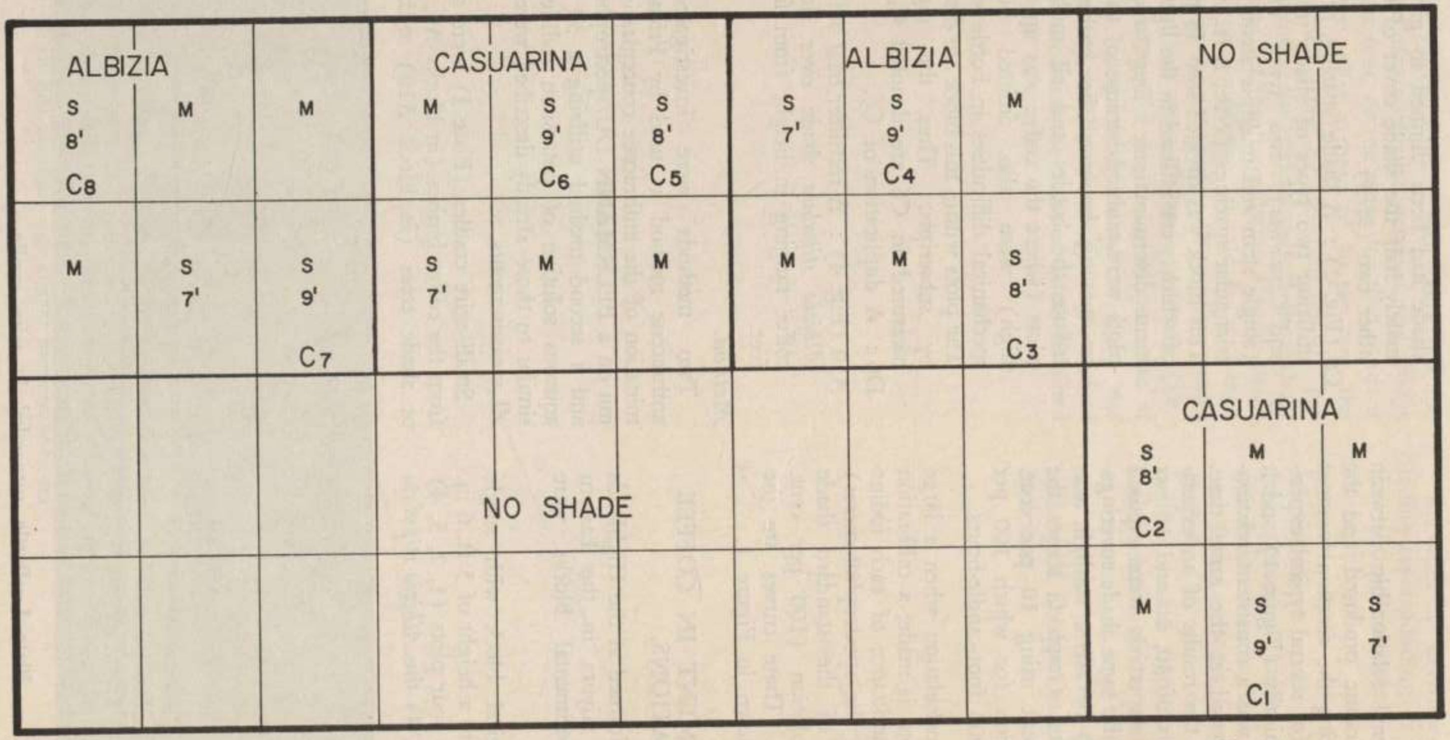

Figure 2.—Plan of Shade, Spacing, Pruning Trial C6, employing two species of shade tree : *Albizia stipulata* and *Casuarina* sp.

Three spacings : 7 ft., 8 ft. and 9 ft. triangular, and two pruning systems : Multiple Stem (M) and Single system (S). This trial is divided into 48 blocks, eight of which were used in the present work.

Plate II.—Block A10 with bottles suspended under *Albizia stipulata* shade.

binder twine (depending on the length of suspension). Where coffee bushes were utilized, approximately 6 ft. of jute twine was required to suspend the cradle in a north-south direction, equidistant from the two supporting bushes and about 5 ft. 6 in. from the ground. When shade trees were used, binder twine was used for the longer span (50 ft. between two adjacent trees) and the cradles were about 6 ft. from the ground (Plate II). The plan of cradle distribution is shown in Figs. 2, 3, 4. In each of the plots in the blocks C6 and D6 the distribution was as close as possible to that in plot C_6 (Fig. 3) (the plots were not all identical).

In the mornings the numbered bottles were placed in the cradles and in the evenings collected in the same order. The distribution of bottles occupied about 15 minutes (three persons distributed 220 bottles). Initially the exposure period was from 8 a.m. to 5 p.m. but, as morning and evening shadows fell across the whole plot, it was considered that a more accurate measure of the effect of the shade pattern would be given when the sun was more directly overhead, and so the period from 9 a.m. to 3 p.m. was used in later trials. A set of bottles under standard shades (100 to 26 per cent. transmission of full sunlight) was exposed for the same period. Table 1 shows a comparison of the two exposure periods for block A6.

The bottles were allowed to cool to room temperature and the transmittance of the solutions measured (at 400 mu for the anthracene and at 410 mu for potassium iodide). From the results of the standards, a calibration curve was drawn relating the transmittance of the solutions to the relative light intensity (per cent. sunlight transmitted) under the corresponding shade covering. The percentage sunlight falling on each site over the exposure period was read from this calibration curve.

Table 1.

Shade measurement by the potassium iodide method on trial A6 over two different time intervals.

Plot.	Relative Light Intensity (per cent. Sunlight Received)	
	8 a.m.-5 p.m.	9 a.m.-3 p.m.
1	50	64
2	49	63
3	54	57
4	64	77
Av. A6	54	65

Each value for plots 1-4 is the average of 36 sites within each block. Plots 1 and 4 were designed to have approximately half as much shade as 2 and 3.

Discussion.

The results are shown in Tables 2 (C6 and D6) and 3 (A10). The value for each plot in C6 and D6 is the mean of nine sites (see Fig. 3) and that for each row in A10, the mean of 10 sites (Fig. 4).

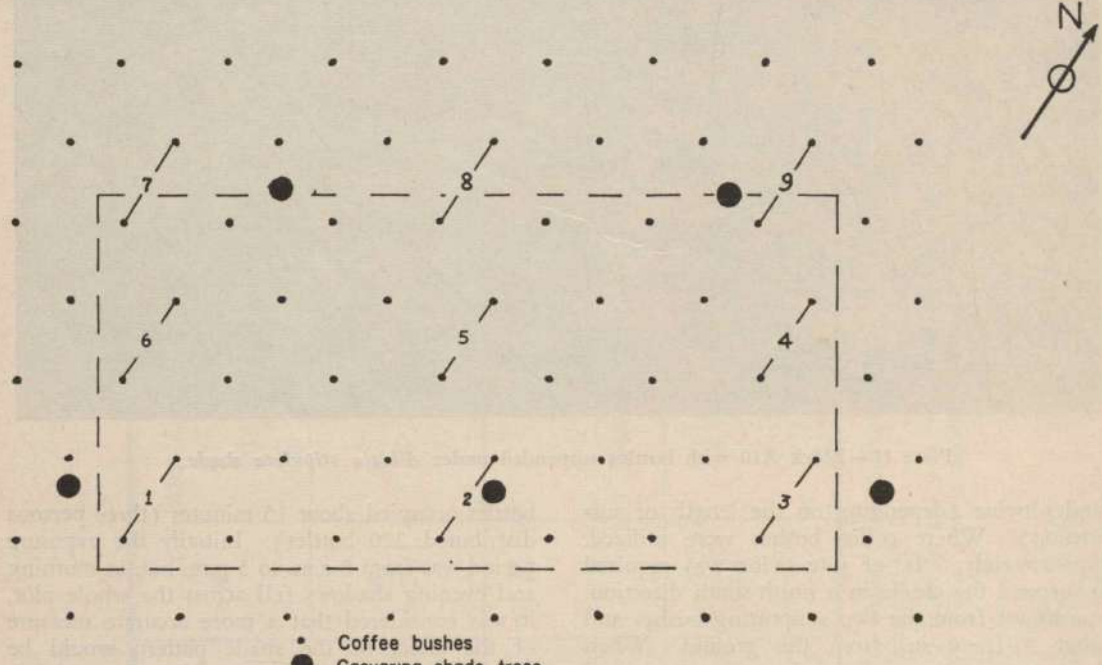

Figure 3.—Plan of C6 showing the position of measurement bottles. A similar pattern of bottle distribution and numbering was used in all blocks in C6 and D6 but the number and position of the shade trees varied from block to block.

There is good agreement between the two methods (correlation coefficient = 0.87) when whole plots are considered. There is less variability between the anthracene readings than for potassium iodide (least significant difference at 5 per cent. is 9.3 for potassium iodide and 7.1 for anthracene). There is considerable divergence between the values obtained on individual sites but this is readily explained by daily variation. The shade pattern over any site will be one of intermittent periods of full sunlight and some degree of shade. On cloudy days the times at which the clouds obscure the sun will alter the percentage light falling on any site. If clouds obscure the sun while the site is in full sunlight, the percentage sunlight received over the daily period will be less than if the times when the sun is obscured coincide with times when the site is heavily shaded. For a closer comparison of results, a number of experiments showing the daily variation for the one method is needed. This variation will be reduced when a number of sites is taken, however, and reproducible results should be obtained in experiments measuring the sunlight received over a whole block in one day.

The results show that while the *Casuarina* shade and the *Albizia* shade were fairly uniform in themselves they differed considerably from each other. This difference could be sufficient to alter the interpretation of the results which is based on the assumption that the shade is uniform throughout.

Table 3.

Results from the measurement of shade on the trial A10 (*Albizia stipulata* shade), showing the percentage of full sunlight received by each of the ten rows.

Row.	Relative Light Intensity (per cent. Sunlight Received.)	
	KI Method.	Anthracene Method.
A_1	64	68
A_2	71	67
A_3	68	66
A_4	67	69
A_5	60	69
A_6	71	69
A_7	71	64
A_8	63	64
A_9	66	66
A_{10}	75	66
Av. A10	68	67

Each value is the mean of ten sites.

Table 2.

Results from the measurement of shade on the shade, spacing, pruning trials C6 and D6 by two methods (potassium iodide and anthracene), showing percentage full sunlight (100 per cent. shade) received by the various plots.

Plot.	Block C6. Relative light intensity (per cent. Full Sunlight).		Plot.	Block D6. Relative light intensity (per cent. full sunlight).	
	KI Method.	Anthracene Method.		KI Method.	Anthracene Method.
C_1	46	46	D_1	43	44
C_2	55	55	D_2	55	52
C_3	54	54	D_3	66	59
C_4	60	56	D_4	61	55
C_5	48	48	D_5	58	50
C_6	45	48	D_6	59	56
C_7	65	64	D_7	64	63
C_8	70	69	D_8	76	69
Mean C_1, C_2, C_5, C_6 (*Casuarina* shade)	49	49	Mean D_1, D_2 D_5, D_6 (*Casuarina* shade)	54	51
Mean C_3, C_4, C_7, C_8 (*Albizia* shade)	62	61	Mean D_3, D_4 D_7, D_8 (*Albizia shade*)	67	62
Mean C6 .... (C_1 - C_8)	55	55	Mean D6 .... (D_1 - D_8)	61	57

The results from A10 were very interesting as they showed fairly uniform shade throughout the block. It was thought that there may have been a significant difference between the shade in bushes close to shade trees and those midway between shade trees. There were also some areas (see Fig. 4) where the shade directly overhead was much less than in others. In fact, over a whole day and especially when the shade trees were tall and spreading, the direct shading of any bush was given by many shade trees some of which were distant from this bush. It is probable that in many plantations where an effort has been made to plant shade trees evenly the resulting shade is reasonably uniform despite variations in growth of occasional trees.

COMPARISON OF THE TWO METHODS.

The potassium iodide method has considerable advantages, most of which are associated with the solvent used. The anthracene method requires large quantities of pure benzene. This is expensive and, in New Guinea, where transport is almost wholly by air, transportation of this solvent to and from the field is a major problem. There is considerable manipulation before each reading, and errors introduced by evaporation and during dilution can be significant. These disadvantages are avoided in methods using water as solvent. It was found that errors introduced by transferring the iodine solution directly to the spectrophotometer cell without filtration were small, and this modification enabled a large number of solutions to be measured very quickly.

The greatest advantage of the anthracene method is that it has a sounder theoretical basis for use under field conditions. The proportionality between total quantity of light, irrespective of time-intensity variations, and the logarithm of the residual anthracene concentration, means that a series of standards is not required and accurate comparisons of the total insolation in different localities can be made. The potassium iodide method is essentially an empirical one under field conditions and is limited to measuring the percentage shade given by the shade trees in any area.

Whereas the anthracene method is sensitive to light between 300 and 400 mu, McCrae (1923) has shown that radiation up to 590 mu will produce decomposition of potassium iodide although the most active region is below 500 mu. The merits of this added range are difficult to determine. In the absence of a method which is sensitive to the whole spectral range, or to the wavelengths predominantly associated with photosynthetic processes, the existing methods appear to be of equal merit from spectral range considerations, as they follow the assumption that the range measured comprises a fairly constant proportion of total sunlight.

Conclusions.

The small number of experiments performed limits definite conclusions. It appears that the potassium iodide method of measuring shade is quite valid empirically, and reliable results can be obtained. Because of the advantages already mentioned, this method would be preferable to the one using anthracene. Although the measurements for any one site are not satisfactorily consistent, comparisons between plots (by taking a mean, over say 10 sites) can be readily made. Comparisons between different localities would be unsatisfactory by the potassium iodide method.

An efficient method of bottle suspension has been demonstrated. This enables the widespread use of chemical light meters throughout a block. It is unsatisfactory for coffee more than about six feet high, and cumbersome where very close spacing of coffee bushes occurs. It is difficult to envisage any other satisfactory method under these conditions.

It is doubtful whether this type of light measurement will have general application throughout plantations. It is of little interest to a planter to know that 70 per cent. sunlight is the optimum condition for coffee on his plantation without knowing exactly how to produce this degree of shade. It could be used to test the uniformity of shade, but this could be estimated visually with sufficient accuracy for practical purposes.

This method should prove useful in experiments where accurate comparisons between blocks and assessment of the most satisfactory light conditions can be made. Present methods

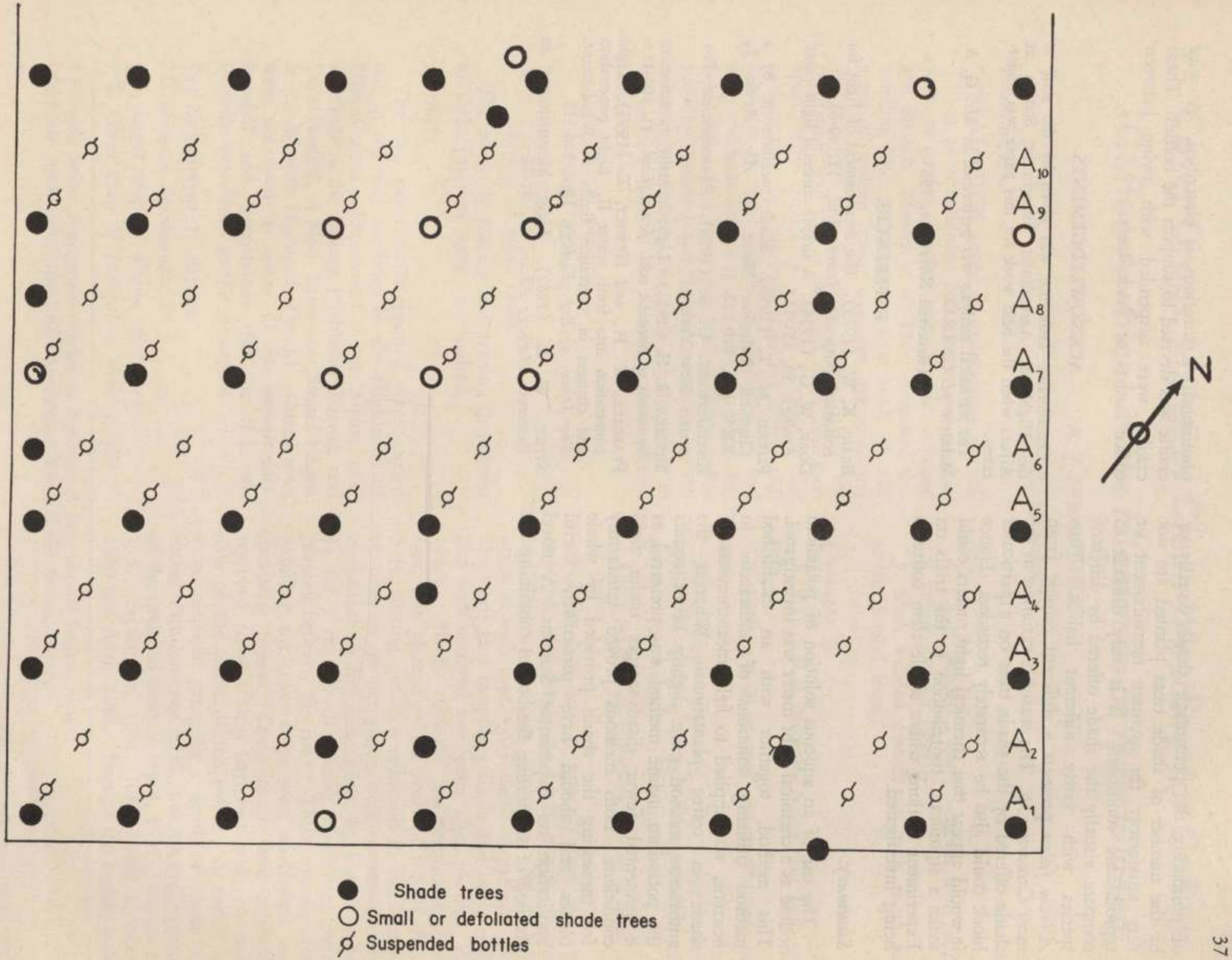

Figure 4.—Plan of the southern portion of A10, covering 900 coffee bushes.

of estimating the percentage shade visually or by the number of shade trees planted are not very satisfactory for accurate measurement or reproducible conditions. It is very difficult to compare visually the shade offered by different species with vastly different habits. Thus *Albizia fulva* presents a different canopy from most *Casuarina sp.* The seasonal variation in the shade offered by the shade trees on a particular block could also be accurately recorded. Hence it would appear that chemical light meters could make a significant contribution to the trials on Experiment Stations where single stem coffee is being investigated.

Summary.

The use of an aqueous solution of potassium iodine as a chemical light meter was investigated. This method, together with an established method utilizing solutions of anthracene in benzene, was applied to field measurements of shade in coffee plantations. Whereas the anthracene method gave slightly better results the potassium iodine method was preferred as it presented fewer disadvantages under field conditions. Both methods proved satisfactory for measuring the shade provided by whole blocks and should have particularly useful application on Experiment Stations. A novel method of supporting the bottles containing the photosensitive solutions is described. A wire cradle was devised to support the bottles. These cradles were suspended with twine between coffee bushes or shade trees.

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Cover Crops, Mulch or Clean Weeding for Coffee (Coffee Arabica) in the Highlands of New Guinea.

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Introduction.

TREATMENTS aimed at maintaining the soil in good condition for growth and production of coffee involve considerable expense. For instance, Maiden *et al*, 1961, estimated that weeding and maintenance of a block of 100 acres of mature coffee represent approximately 20 per cent. of the total expenses on the plantation, and this is the most costly operation apart from harvesting. Some system of soil management is therefore required which will ease the financial burden of maintenance, and keep yields at a high level. Much research has been devoted to these problems in other coffee growing countries and the prime purpose of the work reported here was to assess the value to the coffee grower of the following four cultural practices :—

1. Clean weeding.
2. Weed slashing.
3. Mulching.
4. Use of cover crops.

The effects of spacing and pruning in relation to these practices were also studied.

Methods.

The two experiments reported were carried out in different localities in the Highlands of New Guinea : Experiment 1, at Aiyura near Kainantu in the Eastern Highlands District, and Experiment 2, at Korn Farm near Mount Hagen in the Western Highlands District. Guard rows were not used in either of the experiments. Rainfall and temperature data of the two localities are shown in the Appendix.

(*a*) *Experiment* 1, *Aiyura.*

Management Treatments.

1. Cover crop of *Vigna oligosperma.*
2. Cover crop of *Indigofera endecaphylla.*
3. Mulch of elephant grass (*Pennisetum purpureum*).
4. Clean weeded (weeds scraped with sarifs just below ground level).
5. Slash weeded (weeds cut with sarifs just above ground level).

Spacings.

1. 9 ft. x 9 ft. triangle, giving 621 trees per acre.
2. 14 ft. x 5 ft. in rows, giving 622 trees per acre.

Management treatments 1, 2, 3 and 4 were applied to Spacing 1, and Management treatments 1, 2, 4 and 5 to Spacing 2.

There were four replicates, giving a total of 32 plots.

For the 9 ft. x 9 ft. spacing there were 56 trees per plot, while the 14 ft. x 4 ft. spacing had 48 trees per plot, giving an area of 0.09 acres in each case. *Crotalaria anagyroides* was employed as a temporary shade and nurse crop, and was removed two years after planting the coffee. *Albizia stipulata*, the permanent shade tree, was planted in the rows of the 14 ft. x 5 ft. spacing giving a reduction in the number of trees to 48 but yields were corrected to be equivalent to the same plots, having 56 trees. In the 9 ft. x 9 ft. spacing, shade trees were planted between the rows. Three months after planting, the cover crops were established and mulching began. Cover crops were regularly removed from a strip two feet wide on each side of the stems of the coffee. A mulch of dried elephant grass, to a depth of about six inches (six tons per acre), was applied to each of the mulched plots in April, 1957, November, 1957, September, 1958, July, 1959, October, 1960 and April, 1961. Because the mulch could

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not be dried completely before application it had to be turned regularly to prevent it from taking root.

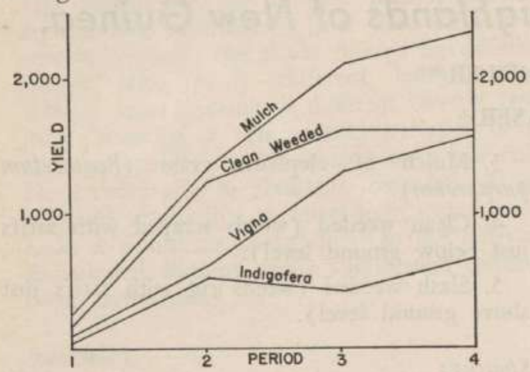

Figure 1.—Experiment 1, Aiyura. Yield in successive periods for each treatment at 9 ft. x 9 ft. spacing. (Period 1. June 1958 to March 1959; Period 2. April 1959 to March 1960; Period 3. April 1960 to March 1961; Period 4. April 1961 to September 1961.)

(*b*) *Experiment* 2, *Korn Farm*.

Management Treatments.

1. Cover crop of *Vigna oligosperma*.
2. Cover crop of *Indigofera endecaphylla*.
3. Slash weeded.

Spacings.

1. 9 ft. x 9 ft. triangle.
2. 7 ft. x 7 ft. triangle.
3. 14 ft. x 5 ft. in rows.

Pruning.

1. Multiple Stem system.
2. Single Stem system.

There were two replicates, giving a total of 36 plots. *Crotalaria anagyroides* was used in the early stages as a nurse crop and temporary shade and *Albizia stipulata* was used as a permanent shade. At all spacings the permanent shade was planted between the rows of coffee.

RESULTS.

(*a*) *Experiment* 1, *Aiyura*.

Plot yields were recorded as coffee cherry weight in pounds. The percentage recovery of raw dry coffee beans was measured on a number of occasions and although recoveries bore an inverse relationship to the yield of cherry, variation between treatments was quite small in relation to the total cherry yield, which was thus the primary factor in yield of coffee per plot. Recoveries were not measured often enough to permit accurate conversion of cherry weight to raw coffee weight. However, in order to present the results in a more meaningful form the yields have been converted to pounds per acre raw coffee by dividing cherry yields by six (which gives a good estimate of average recovery), giving the results shown in Table 1.

The sequence in order of decreasing yield—mulch, clean weeded, *Vigna oligosperma*, *Indigofera endecaphylla*—held throughout the trial at the 9 ft. x 9 ft. spacing (Fig. 1). and also at 14 ft x 5 ft. spacing for the three treatments common to both (Fig. 2). Both *Vigna oligosperma* and slash weeded crops yielded similarly during the trial and their total yields were not significantly different. Although the 14 ft. x 5 ft. spacing yielded significantly more ($P < .05$) than the 9 ft. x 9 ft. spacing, for the total of common treatments, the difference was largely due to the very low yield of the *Indigofera endecaphylla* plots at the 9 ft. x 9 ft. spacing. However, the spacing treatment interaction was not significant.

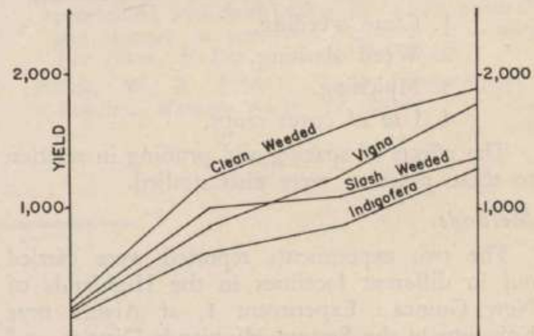

Figure 2.—Experiment 1, Aiyura. Yield in successive periods for each treatment at 14 ft. x 5 ft. spacing. (Period 1. June 1958 to March 1959; Period 2. April 1959 to March 1960; Period 3. April 1960 to March 1961; Period 4. April 1961 to September 1961.)

The trial was notable for the very large increases in yield obtained as a result of the addition of six tons of partly dried mulch per acre per year. (In Kenya 10 tons is commonly applied, see Jones *et al* 1960). The mulched plots yielded significantly more ($P < .01$) than plots of any other treatment.

Table 1.

Experiment 1, Aiyura, Yield (pounds per acre raw coffee beans).

		9 ft. x 9 ft. triangle.					14 ft. x 5 ft. in rows.					
		June, 1958 -Mar. 1959.	April, 1959 -Mar. 1960.	April, 1960 -Mar. 1961.	April, 1961 -Sept. 1961.	Total.	June, 1958 -Mar. 1959	April, 1959 -Mar. 1960.	April, 1960 -Mar. 1961.	April, 1961 -Sept. 1961.	Total.	Over-all means (3 years).
Clean weeded	....	165	1,233	1,640	1,657	4,695	201	1,183	1,587	1,879	4,850	4,778
Indigofera endecaphylla	....	52	541	487	713	1,793	147	676	875	1,263	2,961	2,377
Vigna oligosperma	....	98	615	1,344	1,634	3,691	150	831	1,214	1,770	3,965	3,828
Slash weeded	....	....	....	....	....	....	191	970	1,087	1,360	3,608	....
Mulch	....	275	1,378	2,146	2,403	6,202	....	....	....	....	....	....
Least significant	5%	86	155	296	463	862	91	244	350	408	961	597
differences	1%	124	223	426	666	1,240	130	350	503	587	1,382	819
	0.1%	182	328	626	980	1,823	192	515	739	863	2,032	1,094

Note.—

(1) The coffee began bearing in June, 1958.

(2) Most of the crop is harvested during the period April to September each year.

The amount of labour used for maintenance of the treatments was carefuly recorded from January, 1959, until the conclusion of the trial and is tabulated in Table 2.

Vigna oligosperma had to be weeded at times to ensure its survival, and because of this cannot be classed as a good cover crop. *Indigofera endecaphylla* required treatment only for the purpose of preventing it from completely smothering the coffee and, regardless of the fact that it was regularly pulled back leaving a clean weeded area two feet wide on each side of each row of coffee, root competition was such that in many plots the coffee was extremely poor (Plate I). The slash weeded plots in which all weeds except grasses were cut above the ground (the grasses were pulled up and removed from the plot), required more labour than the clean weeded plots. Slash weeding, combined with total grass removal, was tedious, and the weeds which remained were never completely killed. Slash weeding encouraged the growth of grasses rather than the soft weeds.

Table 2.

Mean number of man days required for maintenance per acre per year for the duration of the trial.

Treatment.	Man days.
Cover Crops	100
Slash Weeded	155
Clean Weeded	94
Mulch	* 228

* Includes labour for cutting, carrying and spreading the mulch.

(*b*) *Experiment* 2, *Korn Farm.*

Yields were recorded as cherry weight per plot but recovery of clean coffee was never measured. Results however, are given as pounds of raw coffee beans per acre, using a conversion factor of six, as at Aiyura.

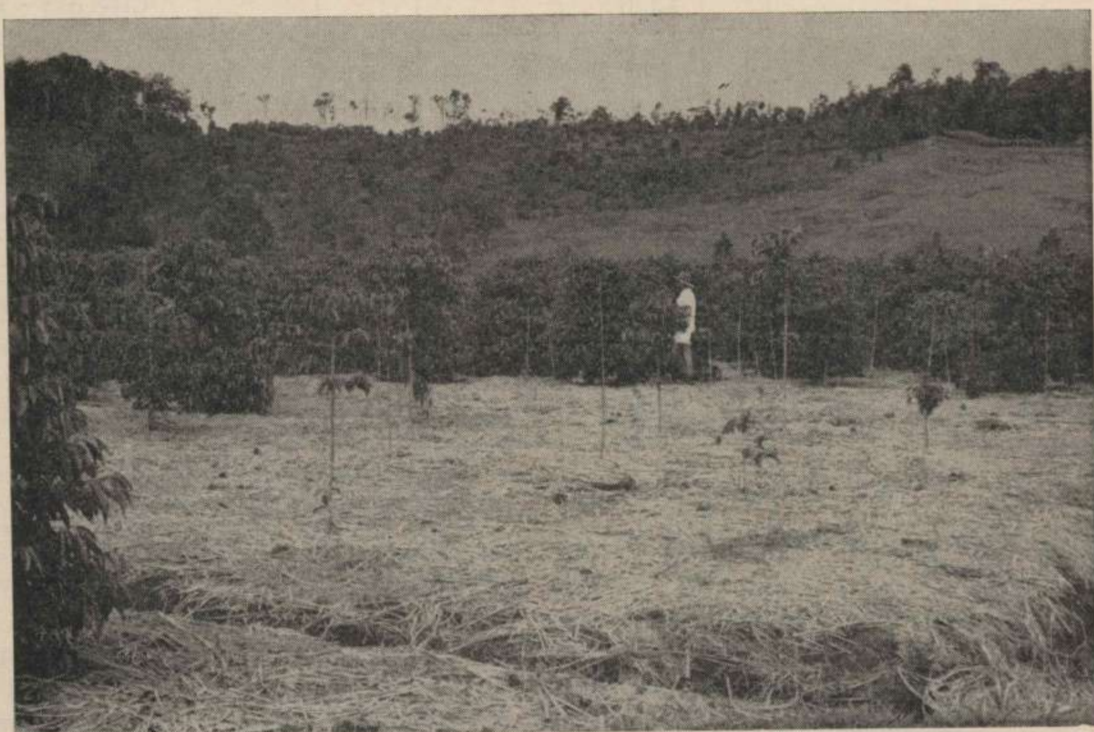

Plate I.—*Indigofera endecaphylla* plot in the foreground with coffee showing the effects of severe competition from the cover crop. The picture was taken shortly after conclusion of the trial when the cover crops had been removed and the plots mulched to help their recovery. At this stage also the *Albizia stipulata* shade had been removed to allow the implementation of a new trial without shade.

Table 3.

Experiment 2, Korn Farm, Yield (pounds per acre raw coffee beans)

	7 ft. x 7 ft. triangle				9 ft. x 9 ft. triangle				14 ft. x 5 ft. in rows.				
	July, 1959 -Mar. 1960 (1).	April, 1960 -Mar. 1961 (2).	April, 1961 -Mar. 1962 (3).	Total.	July, 1959 -Mar. 1960 (1).	April, 1960 -Mar. 1961 (2).	April, 1961 -Mar. 1962 (3).	Total.	July, 1959 -Mar. 1960 (1).	April, 1960 -Mar. 1961 (2).	April, 1961 -Mar. 1962 (3).	Total	Over-all means (3 years).
Clean weeded	310	1,274	1,321	2,905	147	915	881	1,944	148	644	905	1,698	2,182
Indigofera endecaphylla	259	713	902	1,875	163	535	297	995	101	482	651	1,366	1,412
Vigna oligosperma	438	1,367	1,135	2,940	297	1,156	932	2,385	161	1,011	953	2,124	2,483
Means	336	1,118	1,119	2,573	202	869	703	1,775	137	712	836	1,729	

Least significant differences between treatments in all spacings—

	Period 1.	Period 2.	Period 3	Total
5 per cent	133	403	220	675
1 per cent	202	610	330	1,022

The effect of pruning systems is shown inTable 4.

Table 3 shows the results of the soil management treatments and spacings. The serious decline of the *Indigofera endecaphylla* plots is again evident, and although the *Vigna oligosperma* plots often yielded more than the clean weeded plots the differences never attained significance. *Vigna oligosperma* did not achieve a good cover and weeds were always present.

Table 4.

Experiment 2, Korn Farm. Pruning and Spacing. Total Yield (pounds raw coffee beans per acre).

	7 ft. x 7 ft.	9 ft. x 9 ft.	14 ft. x 5 ft.	All spacings.
Single Stem	2,101	1,593	1.527	1,740
Multiple Stem	3,046	1,956	1,843	2,282

Multiple stem pruning gave significantly higher yields in the 33 months of trial ($P < .001$) than single stem pruning. The treatment/pruning interaction reached a level of 5 per cent. only in the period April, 1961, to March, 1962, when competition from the cover crops seemed to favour multiple stem pruning. Within the clean weeding treatment the difference between pruning treatments was small.

DISCUSSION.

(*a*) *Mulching.*

Increases in yields of coffee attributable to applications of mulch have been found to be quite substantial in other countries (Table 5).

In Kenya the increase in yield has been attributed to assistance of water penetration and control of soil and water loss by erosion (Jones *et al* 1960). It is doubtful if the effect reported here could be explained in the same way because rainfall is more uniformly distributed, total annual rainfall is generally higher and the trial was planted on flat land on which water run off was slow.

Leaf samples collected and analysed in November, 1961 after the conclusion of the trial gave the results shown in Table 6.

Table 5.

Examples of yield increases obtained using mulch in other countries.

Country.	Type of Mulch.	Percentage increased in yields.	Authority.
Tanganyika	Banana trash. (Elephant grass, Guinea grass also tried—Banana trash gave largest increase)	50	Sanders 1953.
Kenya	Elephant grass	Up to 100	Ann. Rpt. and Accounts, Coffee Board of Kenya, 1961.
Brazil	Unspecified grass	58	Medcalf J. C. *et al* 1955.
Brazil	Unspecified grass	72	Medcalf, 1956.
Venezuela	Banana stems	100	Venezuela, Ministry Agric. and An. Hus., 1959.

Table 6.

Percentage of the indicated elements on a dry weight basis in the leaves.

Treatment.	N.	P.	K.	Ca.	MG.
Clean weeded	2.34	0.107	0.57	0.85	0.50
Mulch	2.35	0.112	1.11	0.77	0.34

The notable feature of Table 6 is the higher potassium level and lower magnesium level in the mulched treatment compared with the clean weeded treatment. The response to mulch is therefore thought to be mainly due to an increase in potassium available for growth of the coffee. Warden J. C., 1961, and Robinson and Chenery, 1958, both report increased potassium uptake from mulch but the response to mulch was apparently primarily due to the favourable effect on available soil water.

Table 7 shows that returns from application of mulch exceeded costs in the third year of bearing and from the 5th year on they could be expected to show a substantial net return.

(*b*) *Cover Crops.*

Similar competitive effects to those reported here, though probably not as severe, have been described from Columbia (Rodriguez, 1958), and Venezuela (Venezuela Ministry of Agric. and Animal Hus., 1959). *Vigna oligosperma* was not vigorous enough in its growth habits to survive competition from common weeds amongst the coffee, although it exists in some places in the New Guinea Highlands mixed with low growing grasses. Thus two extremes of cover crops were tried, one competing so strongly that the coffee suffered and the other too weak to survive without removal of the competing weeds.

The cover crops were planted as a means of reducing weeding requirements and because they might have been expected to increase available soil nitrogen. They were not intended as soil erosion inhibitors although, had they been beneficial to the coffee, then this aspect of potential value would have been examined.

The yields from the *Vigna oligosperma* and weeds-slashed treatments were similar throughout, as would be expected since the poor performance of the *Vigna oligosperma* rendered the two treatments more or less equivalent. The two types of cover apparently competed with the coffee to a similar extent and the *difference in yield between the clean weeded plots* and plots under these treatments is probably a direct measure of the competition involved.

Table 7.

Balance sheet for mulching. (Experiment 1).

	January, 1958-March, 1959.	April, 1959-March, 1962.	April, 1960-March, 1961.	April, 1961-September, 1961.
Yield increase from clean weeded to mulch plots (lb./acre).	110	145	506	746
Value of increase at 2s. 0d. per lb. (a)	£11	£15	£51	£75
Increase in cost of labour from clean weeded to mulch plots (£'s/acre). (b)	£42	£42	£42	£42
Net return from mulch	Minus £31	Minus £27	Plus £9	Plus £33
Cumulative net return.	Minus £31	Minus £58	Minus £49	Minus £16

(a) From figures given by Maiden et al 1961, it can be calculated that with coffee selling at 3s. 8½d. per pound the return on operator's labour, management and capital (listed as plantation surplus) amounts to very nearly 2s. 0d. per pound of coffee produced. It must be borne in mind however, that there is an extremely wide variation in costs of production, and hence growers should not use the above table without regard to individual production and labour costs.

(b) Labour data extracted from Table 2 (cost of labour at 6s. 2d. per man day).

It had been intended that mechanical cultivation should be employed in the wide rows of the 14 ft. x 5 ft. spacing in lieu of hand weeding. This proved impracticable, however, because of the extensive system of drains which had to be dug to dispose of surface water and because the ground was impassable to a tractor for a large portion of each year.

(c) Spacings.

That the management treatments gave similar results with each spacing was the most important aspect of spacing effects in this trial. The 7 ft. x 7 ft. yielded more than other spacings in early years, as was expected, since this conforms to current trends in other trials at Aiyura. In both experiments yields were related to the density of planting rather than to the planting system. It is questionable whether this relationship would have continued to hold in later growth.

(d) Prunings.

The system of pruning also was of secondary importance in this trial. It is however, noteworthy that multiple stem pruning out-yielded the single stem system during the trial period. Multiple stem pruning is generally used in coffee plantations in the New Guinea Highlands for it is far easier to manage. At the same time, the greater advantage of multiple stem pruning when cover crops are used is of no practical importance because use of cover crops could not be recommended on present evidence.

Multiple stem gave superior results at the 7 ft. x 7 ft. spacing. This result is not supported by evidence from other coffee trials at present in progress at Aiyura and is therefore probably coincidental.

Conclusion.

Although labour requirements for mulching were fairly high, the yield increase obtained in the third and fourth years more than compensated for the extra cost involved. The advantage of mulching could be expected to increase, or at least to be maintained over the ensuing years.

Recommendations.

Although no specific recommendations can be made as a result of this trial regarding optimum quantities or time of application, it appears that a yearly application of six tons of elephant grass mulch per acre, whether in one application or two separate applications, would be sufficient to give a worthwhile return. Alternatively, any native grass or other plant material obtainable near the plantation would be useful and, if applied in large enough amounts, would give economic increases in yield. At Aiyura elephant grass has been established along creeks and in other places where it had to be cut and carried by hand. All the mulch was obtained within a radius of a mile of the coffee block to which it was applied. The cost of mulching included cutting, carting, spreading, turning, and weeding when necessary.

In weeding it is essential that the weeds be completely destroyed (clean weeded) rather than having their tops cut (slash weeded) for, in the long run as labour figures show, total weed destruction will cost less.

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APPENDIX.

Temperature and rainfall data for Aiyura and Mount Hagen (based on recordings from January, 1956, to May, 1962).

Month.	Av. Max. Temp.		Av. Min. Temp.		Average Monthly Rainfall (ins.)		Av. Daily hours of sunshine Aiyura.
	Mount Hagen.	Aiyura.	Mount Hagen.	Aiyura.	Mount Hagen.	Aiyura.	
January	77.1	75.4	55.7	56.8	9.4	7.4	4.4
February	75.5	75.1	55.8	57.7	11.9	9.9	4.2
March	75.3	75.1	55.7	56.9	11.7	10.5	4.4
April	75.5	74.6	56.5	57.2	11.4	8.9	4.6
May	76.7	74.4	55.7	56.5	7.8	4.8	6.4
June	75.3	72.5	53.6	55.9	4.4	3.3	5.1
July	73.7	71.4	54.1	55.0	6.1	4.1	5.0
August	73.5	71.5	54.1	55.8	6.9	6.3	4.9
September	74.6	72.5	53.8	54.4	7.8	4.4	5.8
October	75.4	73.9	53.3	54.6	7.9	7.4	5.8
November	76.0	75.3	54.7	55.2	7.5	7.6	6.0
December	76.3	75.3	55.7	57.5	9.3	12.3	4.5

Mount Hagen weather data by courtesy of Meteorological Office, Lae, New Guinea.)

Soil Description—

Aiyura—grey to dark grey heavy clay developed on tertiary alluvia (unpublished information from a soil survey carried out by officers of the Department of Agriculture, Stock and Fisheries).

Korn Farm—black friable loam developed on tertiary alluvia. (C.S.I.R.O., 1959, Divisional Report No. 58/1.)

Book Review.

On the Theory of Social Change.

This is a bewildering book. Its very range tends to confuse the reader as he is suddenly confronted with changes of emphasis from economics to sociology to anthropology to psychology to history. Therefore review is extremely difficult. This review is written from the viewpoint of an economist ; workers in other fields may have very different comments to make.

The author, a professor of economics, maintains in the preface that " my (the author's) formal training in economics could contribute little but a conception of the requirements for the analysis of theoretical models or systems and a sense of the inadequacy of economic theory to answer the question at hand ". The " question at hand " is an explanation of how a traditional society moves to one where economic growth is underway.

Economic theories are thus discarded and to explain the transition to economic growth it is contended that personality changes are necessary before a society can alter. This occurs because a traditional society (in equilibrium) is disrupted by forces within or outside of it. Adaptation to the new situation causes profound changes in personality development and over many generations the personality type of the society is altered, as is the society, until one emerges which is prepared to accept the social, political and economic conditions necessary for economic growth.

In order to explain the development of these personalities, psychology is used. It is maintained that " the student of society or culture who does not have thorough professional competence in the psychology of personality is obsolescent ". Within twenty lines this is followed by " it seems likely that the major flow of benefit will be from psychology to the other two disciplines " ; that is sociology and anthropology. Although there is always the danger of taking quotations out of context, these seem to be overstatements of the actual situation.

The author calls for greater integration between the sciences which normally accept social change as their field and asks for more use of the methodology of the physical sciences, for example the employment of systems analysis. He suggests that " the understanding of casual relationships among the phenoma in the social sciences has reached a point at which there is no longer any excuse for not employing the power of systems analysis ". Thus the reader is prepared to follow the construction of a dynamic model of social change. In the preface, the reader was also conditioned for a " general theory of social change ". Unfortunately these claims are not fulfilled. Furthermore, those not conversant with the multitude of theories and techniques of explaining social change are given the impression that the use of personality to understand social change is a new field. Psychoethnics is a well used tool in the study of societies.

The theory is built up in the first three parts of the book and Part IV is used to test the thesis. The transition to economic growth in England and Japan is used for verification from an historical approach while case studies of Columbia and two towns in Indonesia are used for transition stage or the present.

Part V examines the effects of colonialism on social change. It is argued that colonialism has tended to retard the transition to economic growth. Case studies of Burma and the Sioux on reservations in the U.S.A. are used to bring out the argument.

The book covers such a broad canvas that summary is extremely difficult. However, it can be recommended to those who like contentious books. The author's argument that economics has little to offer to the explanation of social change is overstated. Economists who have worked in underdeveloped countries soon realize

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EVERETT E. HAGEN.

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that the economics of the industrialized countries may not fit perfectly the situation in these countries, but the basic principle that economics is relevant where choice is concerned still remains. Choice of the type of economy to meet economic growth is an economic problem for the developing country.

The book is considerably weakened by the absence of any reference to the African countries. It can be maintained that to test his theory the author was forced to rely on countries with adequate written records but on this score the West African countries should not have been excluded. The constant reference to elites in the traditional societies does not fit in with the situations in many African countries nor many of those in the Pacific.

Despite the author's claim, a general theory of social change has not been presented. He argues that " if this analysis is correct, it suggests a minimum lag of say thirty years between the time when independence is assured and the time when economic growth becomes vigorous, and a typical lag somewhat longer ". What this means is uncertain but the thesis fails to permit such prediction.

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