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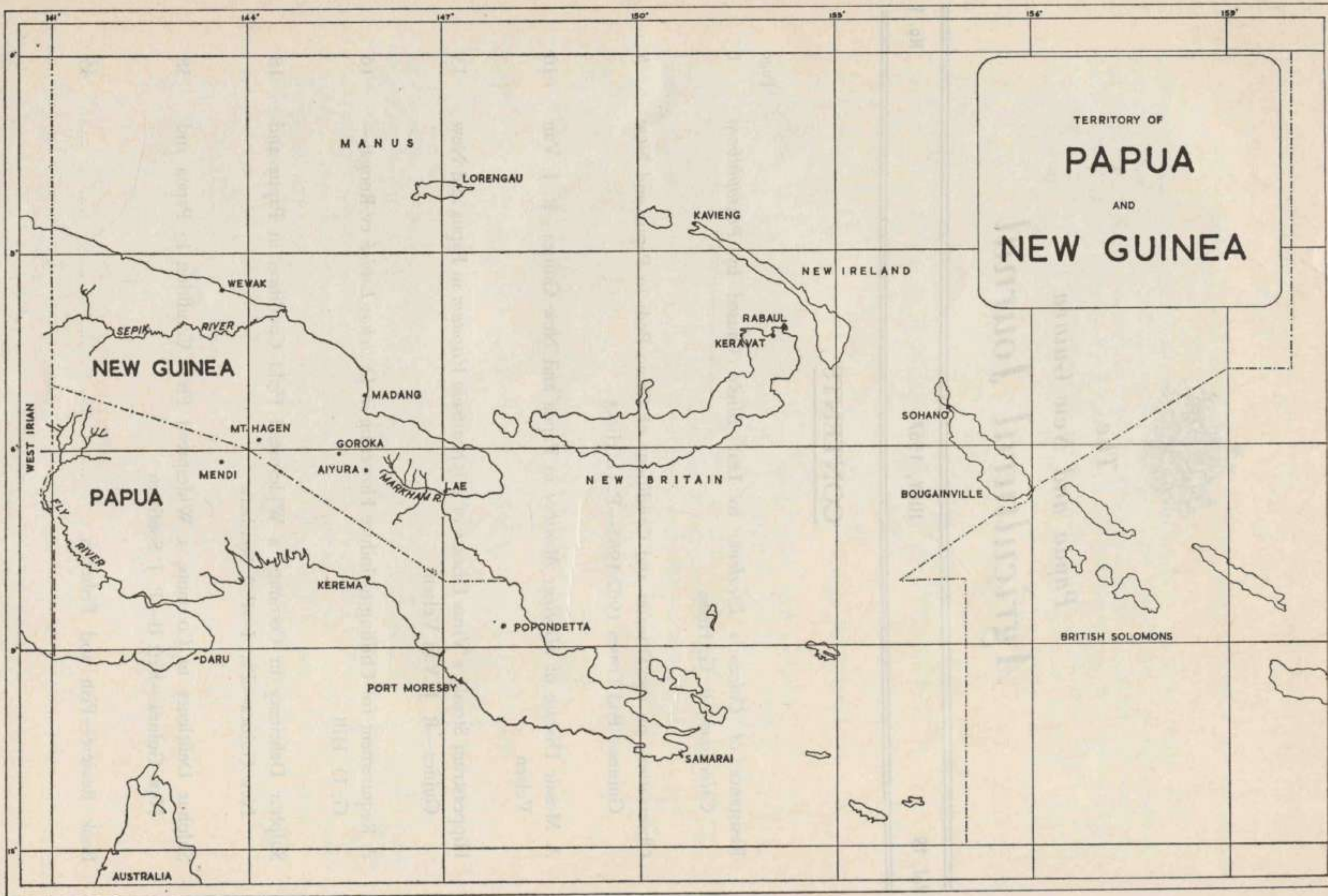
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# *RESISTANCE OF* COLOCASIA ESCULENTA *TO LEAF BLIGHT CAUSED BY* PHYTOPHTHORA COLOCASIAE.

P. G. Hicks.*

ABSTRACT.

*Trials conducted at Keravat from* 1960 *to* 1965 *showed that seven selected taro clones were weakly to moderately resistant to* Phytophthora *leaf blight. Production of suckers, normally very variable between clones, considerably affected results.*

## INTRODUCTION.

INOCULATIONS in Hawaii (Anon. 1938) showed that none of the 45 varieties of taro (*Colocasia esculenta*) tested was resistant to leaf blight (*Phytophthora colocasiae* Racib.). Parris (1941) tested 32 varieties in Hawaii and found none resistant.

Deshmukh and Chhibber (1960) found an Indian variety of *C. antiquorum* on which there was reduced sporulation on black, presumably hypersensitive, lesions caused by *P. colocasiae*. Paharia and Mathur (1964) conducted a laboratory test on leaf discs from 20 Indian selections of *C. antiquorum* and found only one immune from leaf blight. The significance of neither this immunity nor the partial resistance of several other clones (varieties) mentioned in this paper has been stated.

For some years *Phytophthora* leaf blight of taro (*C. esculenta*) has caused occasional concern in parts of the Territory of Papua and New Guinea. Seven clones comparatively free of the disease were collected from food gardens on Buka Island, Bougainville District by Mr. J. C. Lamrock. Trials were conducted to estimate the level of resistance in these selections and, if possible, make suitable varieties available for distribution.

All taro clones tested were collected from village gardens and can therefore be classed as acceptable from a culinary angle. However, taste tests were conducted to check the suitability of the selections.

* Pathologist, Lowlands Agricultural Experiment Station, Keravat.

## METHODS.

The first trial was conducted by Dr. R. J. van Velsen, at Keravat. Setts of each selection were planted in June, 1959, in single rows, alternating with rows of a clone, designated Local Taro, commonly grown near Keravat and often moderately or severely blighted. The plants were naturally infected with *P. colocasiae* and records of infection were taken in March, 1960. Counts were made on ten plants of each selection and on 20 of the Local Taro. Taste tests were conducted on tubers roasted over an open fire with Nakanai labourers doing the judging.

The second trial, conducted by the author, was planned similarly to the first, replacing the Local Taro with agronomic selections not selected for freedom from leaf blight. The area was planted in January, 1963, spray-inoculated with a suspension of sporangia in June and records taken in July, 1963. Flavour tests were made on boiled tubers in November.

The third trial was a randomized block experiment, blocks I and II of which were planted in November, 1964, and blocks III, IV, V and VI in February, 1965. Each block consisted of two sections of 100 plants each. Each section contained four plots of four plants each with double rows of Local Taro between and around each plot. The plants were unified as much as possible by periodic pruning, leaving one sett in each plant. No permanent labels were used, thereby eliminating any possible bias during recording. Blocks I and II were inoculated in January, 1965 ; the remainder were naturally infected from these. Records were taken in

May, 1965, and March, 1966, of number of lesions on each leaf. Pruning and weeding were not supervised from June, 1965, to March, 1966.

## RESULTS.

The results for all trials are shown in *Table* 1. Significance, denoted by letters a, b, etc., was calculated using a 2 x 2 contingency test, exemplified in the Appendix. Only the results of the third trial at the first reading are relatively unbiased by the growth habit of the plants; these show only one clone, Seeru-Lemankoa, with significantly more blight-free leaves than the Local Taro. Seeru-Lemankoa may be classed as moderately resistant; the remaining clones, all having less blight than unselected material in all trials, as weakly resistant.

An analysis of variance of mean numbers of uninfected leaves per plant (= sett) at the first reading in the third trial proved insignificant at the 5 per cent. level.

Tests conducted at the completion of the first trial showed favourable taste in selections Seeru-Iltopan, Hububin-Lontis and the Local Taro. Tests after the second trial showed best taste in (in decreasing order of suitability) :—

Remat A (variety not selected for blight resistance);

Seeru-Lemankoa;

Seeru-Tahai Tahai;

Seeru-Iltopan; and

Hububin-Lontis.

## DISCUSSION.

### *Assessment of disease.*

Mean numbers of lesions per leaf were difficult to analyse. Within a sett the youngest leaf usually had few or no lesions and the number of lesions was greater on successively older leaves. The oldest living leaves were often a mass of lesions (*Plate* I), impossible to count; it was difficult to judge whether some nearly moribund leaves should have been included in the assessments. For this reason, the simple record of presence or absence of lesions on a leaf was considered in the main analysis. There was no difference between any of the varieties in the colour, size and shape of lesions on which to base an assessment.

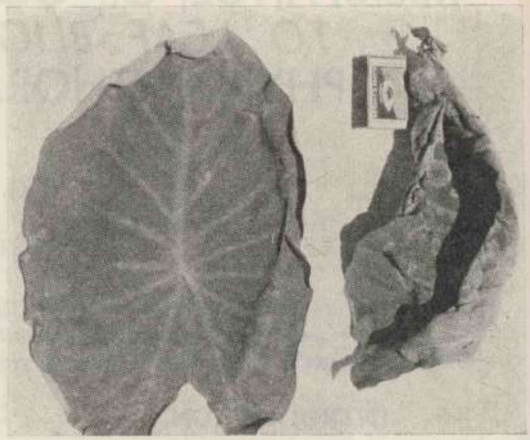

***Plate* I.—Leaves of *Colocasia esculenta* with six (left) and many (right) blight lesions respectively caused by *Phytophthora colocasiae*. The lesions are indicated in the inset by shaded areas.**

### *Suckering.*

Unpruned plants of clones selected for resistance very frequently produced more suckers than the unselected ones (unpublished results) and frequently more leaves (see *Table* 1 except for the third trial, first reading). This led to a higher turnover of leaves and consequently at any time, the plants with greater leaf numbers had relatively more young ones. For example, at the time of reading the second trial, Kaf Kaf 1, unselected, had 265 leaves on 60 setts while Seeru-Iltopan, selected, had 245 leaves on 86 setts. The mean numbers of uninfected leaves per sett were 1.30 and 1.48 respectively, much closer figures than the percentage infected of total leaves.

From one trial to the next some clones produced consistently high or low numbers of suckers but others, notably Seeru-Tandeki and Seeru-Tahai Tahai, fluctuated considerably. Pruning had little residual effect as can be seen in *Table* 1, third trial, second reading, where numbers of leaves per plant are much higher than they were nine months previously.

The results in unpruned taros were therefore biased against Seeru-Lemankoa and the unselected taros which generally produced few suckers.

*Table* 1.—Assessment of Leaf Blight of Taro at Keravat.

| CLONE (For blight-free selections the name of the village from which they were selected follows the native name for the morphological type.) | NUMBERS OF LEAVES RECORDED (WITH NUMBERS OF PLANTS IN PARENTHESIS) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1st TRIAL * | | | 2nd TRIAL | | | 3rd TRIAL FIRST READING | | | 3rd TRIAL SECOND READING | | |
| | I | U | % I / I + U | I | U | % I / I + U | I | U | % I / I + U | I | U | % I / I + U |
| Seeru-Iltopan .... .... | 78 | 399 (10) | 16.4 b † | 118 | 127 (16) | 48.2 a | 34 | 48 (24) | 41.5 ab | 18 | 124 (11) | 12.7 ab |
| Seeru-Lemankoa .... | 45 | 199 (10) | 18.4 bc | 27 | 30 (8) | 47.4 ab | 34 | 56 (24) | 37.8 a | 19 | 190 (20) | 9.1 a |
| Seeru-Tandeki .... | 74 | 420 (10) | 15.0 b | 90 | 77 (13) | 53.9 ab | 20 | 21 (12) | 48.8 ab | 1 | 42 (10) | 2.3 a |
| Pi-Tahai Tahai .... | 52 | 295 (10) | 15.0 ab | 158 | 142 (16) | 52.7 ab | 40 | 49 (24) | 44.9 ab | 27 | 232 (18) | 10.4 ab |
| Hububin-Lontis .... | 46 | 135 (10) | 25.4 c | 207 | 149 (15) | 58.1 cb | 45 | 46 (24) | 49.5 ab | 5 | 66 (8) | 7.0 a |
| Seeru-Tohatsi .... .... | 91 | 472 (10) | 16.2 b | 175 | 127 (16) | 57.9 cb | 38 | 47 (24) | 44.7 ab | 9 | 98 (12) | 8.4 a |
| Seeru-Tahai Tahai .... | 67 | 603 (10) | 10.0 a | 89 | 41 (16) | 68.5 cd | 48 | 42 (24) | 53.3 ab | 47 | 172 (17) | 21.5 cb |
| Local Taro .... .... | 112 | 150 (20) | 42.7 | | | | 42 | 32 (22) | 56.8 b | 16 | 35 (10) | 31.4 c |
| K. Taro 9 .... .... | | | | 130 | 18 (16) | 87.8 e | | | | | | |
| Kaf Kaf 10 .... .... | | | | 122 | 24 (12) | 83.6 ed | | | | | | |
| Ramat A .... .... | | | | 157 | 63 (16) | 71.4 d | | | | | | |
| Kaf Kaf 1 .... .... | | | | 187 | 78 (16) | 70.6 d | | | | | | |

* Results due to R. J. Van Velsen ; analysis by the author.

† Results associated with the same letter do not differ significantly from one another at the 1 per cent. level.

I = number of leaves infected. U = number of leaves uninfected.

*Palatability.*

Although there were differences between clones in palatability of the cooked tubers, they were originally selected from native gardens and probably have acceptable flavours.

*Yield.*

No yield records were made since tubers often failed to mature, mainly due to grub (Scarabidae) invasion.

*Identity of varieties.*

Three of the clones, Seeru-Lemankoa, Seeru-Tahai Tahai and Local Taro were identified at the Division of Botany, Department of Forests, Lae as belonging to the species *Colocasia esculenta* (L) Schott. Flowers and seeds of the remainder have not been collected but it may be assumed, meanwhile, that all of the clones are *C. esculenta.*

## CONCLUSION.

None of the taros selected for low incidence of *P. colocasiae* infection in the field proved immune when grown with susceptible taros in the field at Keravat, New Britain. One clone, Seeru-Lemankoa, may be considered moderately resistant as a result of these tests, the remainder weakly resistant. All clones may be considered to have an acceptable taste.

Growth habit had a marked effect on incidence and must be controlled for comparable results between clones.

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ACKNOWLEDGEMENTS.

Mr. Mesulam Wanariu, Field Assistant, Keravat, assisted with most of the above trials. Dr. Dorothy E. Shaw, Principal Pathologist, Konedobu, and several other officers of the Department of Agriculture, Stock and Fisheries assisted with ideas, correction, etc., in the preparation of the above paper.

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Appendix.

## CALCULATION OF SIGNIFICANCE OF RESULTS.

The results for Seeru-Tandeki and Local Taro in the first trial are used to show how the significance in the table was calculated by the 2 x 2 contingency test as follows :—

| | | Infected. | Uninfected. | Total for variety. |
|---|---|---|---|---|
| Seeru-Tandeki | .... | 74 | 420 | 494 |
| Local Taro | .... | 112 | 150 | 262 |
| Class Total | .... | 186 | 570 | 756 |

$$x^2 = \frac{((150 \times 74) - (112 \times 420))^2 \times 756}{186 \times 570 \times 494 \times 262}$$

$$= 71.2$$

A value of $x^2$ of 3.85 is significant at the 5 per cent. level,

6.64 is significant at the 1 per cent. level,

and 10.9 is significant at the 0.1 per cent. level.

Therefore, 71.2 is significant at a level less than 0.1 per cent.

# OBSERVATIONS ON THE DISEASES AND CONDITIONS OF CACAO PODS IN PAPUA AND NEW GUINEA—POD LOSSES 1962-1965.

P. G. HICKS.*


ABSTRACT.

*Birds and flying foxes destroyed* 8.7 *per cent. and rot following borer damage* 6.2 *per cent. of pods over* 12 *cm. long in a representative block of cacao at Keravat, New Britain, from* 1962 *to* 1965. *Other losses amounted to* 6.2 *per cent. including only* 1.2 *per cent. due to the fungus,* Phytophthora palmivora. *It is recommended that beans from rotten pods be kept separate from the main ferment.*


## INCIDENCE.

### *Prior to* 1962.

Three reports prior to 1962, showed *Phytophthora palmivora* as the major cause of cacao pod losses in the Territory of Papua and New Guinea.

Bryce (1924) reported *Phytophthora palmivora* pod rot and canker as important diseases of cacao at that time in New Guinea. It was not until 1956 (Thrower 1960a), that critical observations were made at Keravat on the incidence of the pod rot disease. An actual figure was not given for losses due to *P. palmivora* but losses of pods over 10 cm. long, except for parrot damaged ones, amounted to 46 per cent. The histograms show that two-thirds of the losses were caused by the fungus. A second rot described was associated with the fungi *Botryodiplodia theobromae* and *Colletotrichum* sp. Some pods wilted from physiological causes (Thrower 1960b). Dr. R. J. van Velsen (unpublished data) recorded average incidence of 7.4 per cent. *Phytophthora* pod rot from November, 1958, to October, 1959, and 23 per cent. from November, 1960, to November, 1961, in a representative block of cacao at Keravat.

* Pathologist, Lowlands Agricultural Experiment Station, Keravat.

### *Recent observations.*

Pods over 12 cm. long, lost from any cause over the period 1962 to 1965, were recorded from 312 trees (1.39 acres) in a trial at Keravat where :—

One-third of the trees were harvested at weekly intervals ;

One-third at three-weekly intervals ; and

One-third at three-weekly intervals, each harvest followed by spraying with Bordeaux mixture.

The sprayed plots had somewhat lower ($P = 0.04$) incidence of *Phytophthora* podrot than the unsprayed ones harvested at three-weekly intervals. Otherwise, the treatments had no appreciable effect on pod losses which can be considered representative of untreated areas of cacao. The results are summarized in *Table* 1.

## CAUSES.

Five main causes of losses of cacao pods were recorded at Keravat over the period 1962-1965.

Birds and flying foxes caused considerable losses. Bird damage may appear as a hole of varying size and position on the pod. In some cases (*Plate* I) the contents of the pod are con-

*Table* 1.—The main causes of losses of cacao pods over 12 cm. long at Keravat, 1962-1965 and the number of pods recorded for each cause.

| Cause. | Period.* August, 1962, to March, 1964. | Period.* April, 1964, to September, 1965. | Combined. % |
|---|---|---|---|
| *P. palmivora* † .... | 565 | 41 | 1.2 |
| Insect borers .... | 2,498 | 481 | 6.2 |
| Birds, flying foxes | 3,031 | 1,119 | 8.7 |
| Harvested green | 252 | 231 | 1.0 |
| Physiological .... (wilt) | 283 | 305 | 1.2 |
| Others .... .... | 463 | 245 | 1.5 |
| Unidentified ‡ .... | 585 | .... | 1.2 |
| Total losses .... | 7,677 | 2,422 | 21.1 |
| Total pods harvested | 32,796 | 14,994 | 100.0% |

* The area was heavily pruned about November, 1963, and incidence of respective losses may have been affected by this.

† If it were doubted whether **P. palmivora** caused the rot of a moribund pod, then the pod was included in this group.

‡ Early in the trial some reject pods not infected with **P. palmivora** were recorded only as miscellaneous pods. Most of these were lost due to flying foxes or birds.

*Plate* I.—A mature cacao pod, 15 cm. long, destroyed by a parrot.

sumed ; in other cases the husk is only punctured, allowing microbial putrefaction of the pulp. Flying fox damage is similar except that the tip of the pod is more commonly attacked (*Plate* II). In the Morobe District, on the mainland, rat damage is relatively more common than the above and is characterized by a hole approximately 2 in. x 3 in. along the middle of the pod (*Plate III*).

Pod borer also caused considerable losses. *Olethrutes* sp. and other Lepidoptera (Szent-Ivany 1961) may feed in the outer husk of the pods without penetrating the hard layer and in

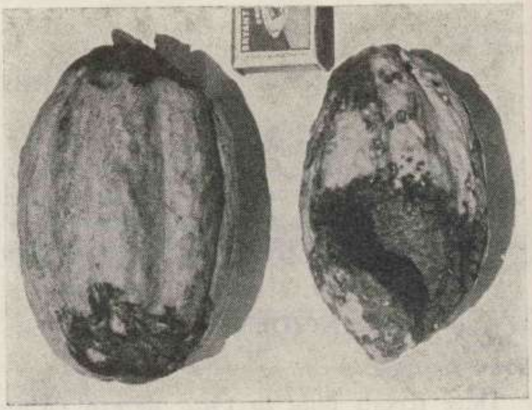

*Plate* II.—Mature cacao pods attacked by flying foxes. The one on the left has been only lightly attacked near the tip, the shallow rot at the base being unrelated. The one on the right was initially attacked by capsids but this did not affect the destruction of the pod by the flying fox.

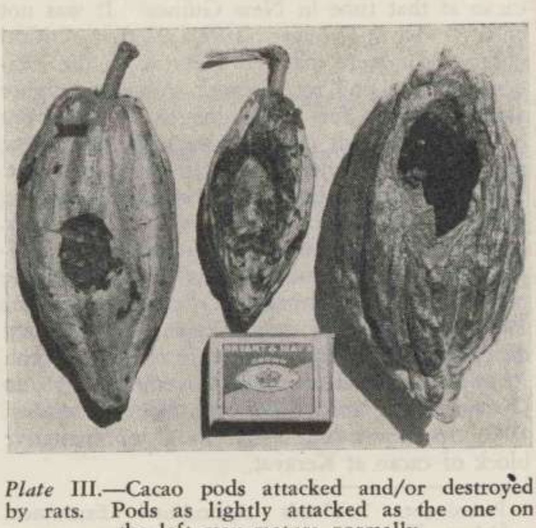

*Plate* III.—Cacao pods attacked and/or destroyed by rats. Pods as lightly attacked as the one on the left may mature normally.

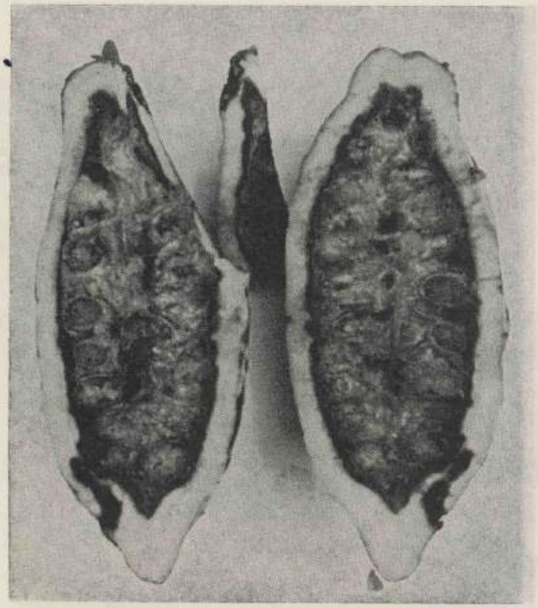

*Plate* IV.—Dissection of a mature cacao pod, 15 cm. long, showing internal rot following entry of borers. The husk is apparently healthy except for the small dark regions near the base and tip where the borers entered the pod.

these cases the pulp rarely rots. They may, however, puncture the hard layer allowing other organisms into the pulp which rapidly putrefies (*Plate* IV). In a plantation infested with pod borer, 50 to 80 per cent. of the pods in which pulp has putrefied may show no external signs except for a small borer hole or puncture from a bird or flying fox.

The fungus *P. palmivora* causes a rot first appearing as one or more distinct brown spots on the pod. The lesion then progresses at the same rate through pulp and husk (*Plate* V), except in ripe pods where the pulp may rot later. *P. palmivora* is rarely associated with rot following bird, flying fox or borer damage.

Physiological disturbances in the tree or pod may result in wilt. The pod becomes yellow before normal ripening time. Often, the whole surface of the pod to a depth of ⅛ in. becomes brown in the subsequent day or so, before any internal browning sets in (*Plate* VI).

Conditions of lesser note in cacao pods include 'dry pulp' (where mature beans fail to form the mucilage so important in fermentation), premature harvesting, and rot following knife damage, failure to harvest when ripe or damage by sucking insects (Miridae).

Important pod diseases in other countries not yet recorded on cacao in Papua and New Guinea are witches' broom and Monilia pod rot. The only comprehensive list of pod losses in any overseas country is reported by Owen (1951) for an area at Tafo, Ghana in 1949-1950 where *P. palmivora* and squirrels were the main causes.

## FACTORS AFFECTING INCIDENCE AND CONTROL METHODS.

The level of *Phytophthora* pod rot reported in this study is much lower than that previously recorded at Keravat or usually recorded in other cacao areas of the world (Tollenaar 1958). Although rainfall at Keravat is higher, minimum daily temperatures and sunshine duration are

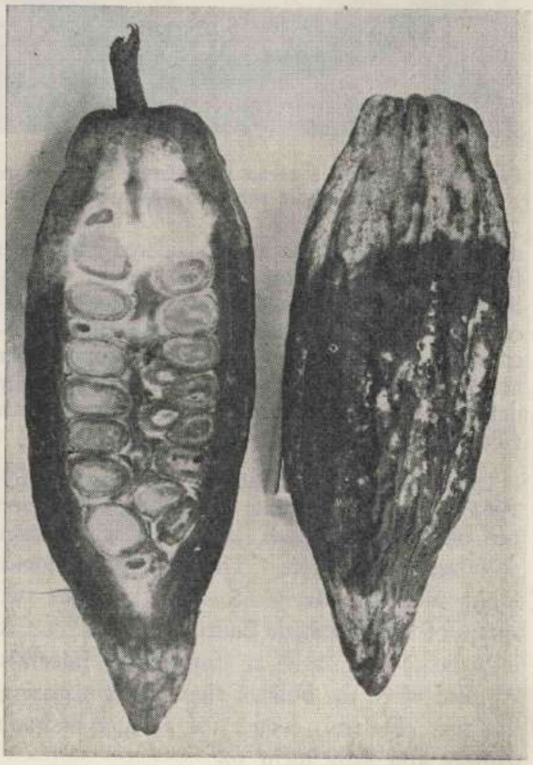

*Plate* V.—A large (13 cm. long) immature cacao pod partly rotted by *P. palmivora.* The rot has progressed equally in the husk and pulp.

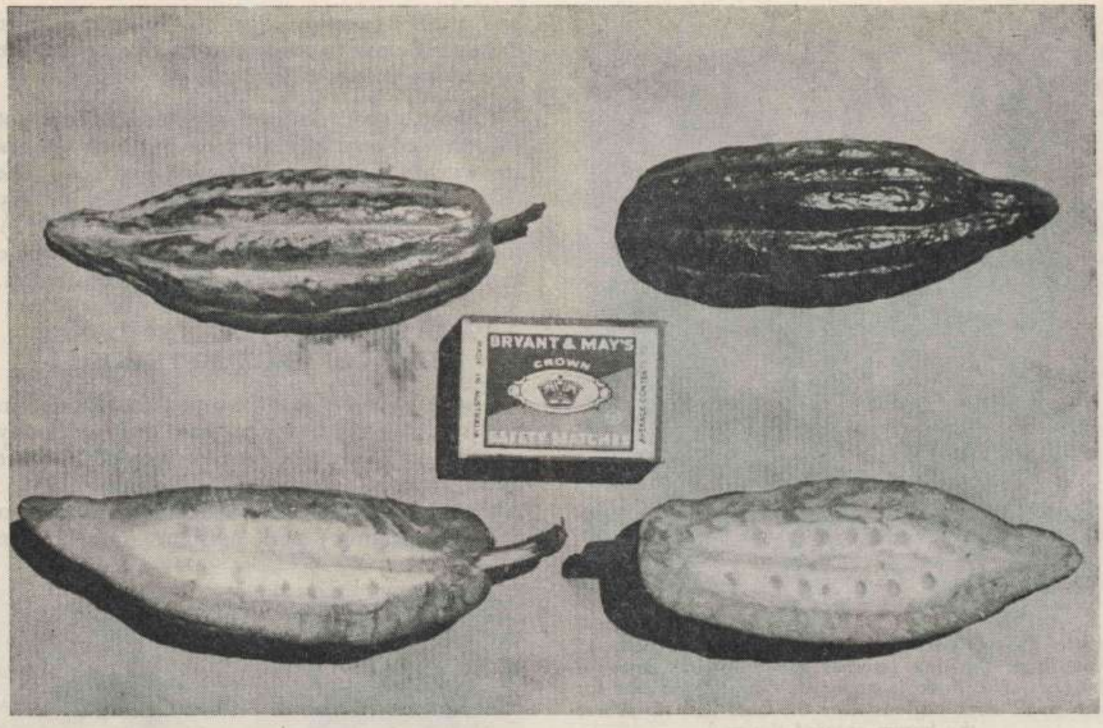


*Plate* VI.—Immature cacao pods from the same tree showing a healthy pod, left, and a wilted pod, right. The whole surface of the wilted pod has darkened while the contents remain pale.

also higher and these are considered important factors minimizing the disease (Hicks unpublished). *P. palmivora* has been controlled successfully in other countries with sprays of copper-containing fungicides (1 to 2 lb. copper per acre) every three weeks or so and by carefully detecting and harvesting the diseased pods (Tollenaar 1958).

Observations at Keravat over the period 1962-1965 have indicated that pod borer infestation per one hundred pods is greater when more pods are on the trees. The Principal Entomologist, Keravat, Mr. G. S. Dun, proposes two sprays of the insecticide Endrin at 0.5 oz. (active ingredient) per acre at fortnightly intervals. Applied when the bulk of the crop is maturing, this may effectively reduce the amount of borer damage and subsequent rot.

No recommendations can be made for the control of wilt or flying fox or bird damage.

## DISCUSSION.

From the foregoing it appears that direct losses of cacao pods from individual causes may not be serious in the Gazelle Peninsula, New Britain, the main cacao growing area in Papua and New Guinea. Losses appeared high in only occasional trees or clones from 1962-1965. In the wetter, cloudier areas of the Territory, losses due to *Phytophthora* pod rot may be higher. Damage by rats, flying foxes and birds may be serious at times. In plantations where trees exceed 20 ft. in height, considerable numbers of pods may not be harvested before their beans have become unfit for fermentation.

The putrefied contents of pods with generally healthy exterior may often escape the attention of the pod breaking supervisor. Although the effect of beans from diseased pods on cocoa quality has not been determined experimentally it is recommended that these beans be fermented separately, if not discarded.

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# *A MOSAIC DISEASE OF* HIBISCUS MANIHOT *IN PAPUA AND NEW GUINEA.*

R. J. VAN VELSEN.*

ABSTRACT.

Hibiscus manihot, *in most areas of Papua and New Guinea, exhibits mosaic leaf symptoms induced by a virus. The virus is transmitted mechanically to* H. esculentus, H. sabdariffa, H. tuberculatus, H. pungens, *and* H. cannabinus. *The virus could not be transmitted by* Planococcus citri, Freesiana *sp., an aleurodid* (Bemisia tabaci), *nor nymphs and adults of* Aphis gossypii *and* Myzus persicae.

*From the host range and insect vector studies, the virus does not appear to be related to any previously described viruses affecting* Hibiscus *spp.*

## INTRODUCTION.

THE fleshy young leaves of *Hibiscus manihot* L. (locally named 'aibika') are eaten as a staple green vegetable by the indigenous people in many coastal regions of Papua and New Guinea. In 1954, Magee noted green mottle symptoms on the leaves of *H. manihot* and Shaw (1963) noted suspected virus symptoms on *H. esculentus* L. and *H. rosa-sinensis* L., in Papua and New Guinea. Throughout the Gazelle Peninsula of New Britain, crops of *H. manihot* are usually affected with mosaic symptoms of the leaves.

A yellow vein mosaic disease of *Hibiscus esculentus* in India was first described by Uppal *et al.* in 1940. This virus disease is restricted to Malvaceae (Capoor and Varma 1950), and is transmitted by grafting and *Bemisia tabaci* (Capoor and Varma 1950, Varma 1952, 1955). Stone (1954) reported that a virus of *H. cannabinus* L. could be transmitted mechanically, and that it appears to be confined to *Hibiscus* spp. Anthocyanosis virus of cotton is reported by Costa (1956) to be transmitted by grafting and *Aphis gossypii* to *H. cannabinus* and *H. esculentus*, but is not transmissible by sap inoculation. Abutilon mosaic virus which is transmitted by *Bemisia tabaci* and sap inoculation produces mosaic symptoms in *H. esculentus* and *H. cannabinus* (Costa 1955, Costa and Carvalho 1960). Tobacco streak virus, for which no insect vector has been recorded, was transmitted by sap inoculation to *H. esculentus* and *H. cannabinus* by Costa and Carvalho (1961).

Costa *et al.* (1959) investigating malva yellows virus recorded *H. esculentus* to be a symptomless carrier of this virus, which is transmitted by *Myzus persicae*, *Aphis gossypii* and *Myzus ornatus* and by grafting, but not mechanically. Cotton leaf curl virus is readily transmitted by *Bemisia tabaci* to *Hibiscus* spp., but the virus is not mechanically transmissible (Tarr 1951). Hibiscus leaf curl (Anon. 1954), and Malva virus (Hein 1956) have also been recorded as infecting *Hibiscus* spp.

The mosaic disease of *Hibiscus manihot* in Papua and New Guinea was investigated to determine whether the symptoms were induced by a virus and if so, to determine its host range and mode of transmission. This paper gives the experimental details and the results of the investigations.

## INVESTIGATIONS.

The mosaic symptoms on the leaves of *H. manihot* were found not to be attributable to fungi, nematodes, bacteria, insects or environmental factors.

### *Symptoms.*

Field infected plants of *H. manihot* exhibit pale mosaic symptoms of the young leaves with clearing of the veins. As the leaves mature, the mosaic symptoms become indistinct. The plants are not stunted and the yield of leaf matter compared with healthy plants is not reduced. The disease does not appear to affect the palatability of the leaves, as they are readily eaten.

* Formerly Senior Plant Pathologist, Lowlands Agricultural Experiment Station, Keravat, New Britain.

*Hibiscus esculentus.*

Severe mosaic symptoms on the leaves appear 7 to 10 days following the inoculation with sap on the first true leaves with cut sections of infected leaves of *H. manihot*. The symptoms are persistent and systemic and the plants are severely stunted.

*Hibiscus sabdariffa* L., *H. tuberculatus, H. pungens, and H. cannabinus.*

The two primary leaves were inoculated with sap from diseased cut leaf sections of *H. manihot* with the aid of 500 grit carborundum powder. Mosaic symptoms appeared five to seven days later on the true leaves, but not on subsequent leaves unless the plants were pruned. The new leaves emerging immediately after pruning had characteristic mosaic symptoms, but subsequent growth was again symptomless. However, *H. esculentus* plants inoculated with sap from symtomless leaves became infected, showing the typical mosaic symptoms. Thus these three *Hibiscus* spp. are systemically infected, but after the initial symptoms appear symptomless.

*Host range studies.*

*Hibiscus esculentus, H. manihot, H. sabdariffa, H. cannabinus* and *H. pungens* were all found to be systemically infected with Hibiscus mosaic virus. The following plants were found to be resistant to the virus :—

*Cucumis sativus* L.
*Pisum sativum* L.
*Vicia faba* L.
*Physalis floridana* Rydb.
*Capsicum annuum* L.
*Chenopodium amaranticolor* Coste et Reyn.
*C. quinoa* Willd.
*Solanum dulcamara* L.
*Zinnia elegans* Jacq.
*Glycine max* Merr.
*Arachis hypogaea* L.
*Lycopersicon esculentum* Mill.
*Nicotiana tabacum* L.
*N. rustica* L.
*N. glutinosa* L.
*Gossypium hirsutum* L.
*Sida rhombifolia* L.
*Althaea rosea* Gav.
*Stizolobium deeringianum* Bort.
*Crotalaria juncea* L.
*C. anagyroides* H.B.K.

Thus the host range of the virus appears to be restricted to *Hibiscus* spp.

*Transmission.*

Due to the inherent viscous nature of the expressed sap from Hibiscus leaves, inoculation experiments were carried out using rolled leaf sections. Diseased leaves were tightly rolled, then a cut was made across the roll and the exposed surface rubbed over the leaves to be inoculated. In this manner, 100 per cent. infection was obtained with the *Hibiscus* spp. tested.

Attempts to transmit the virus by seed collected from infected plants of *H. sabdariffa* and *H. esculentus* were unsuccessful. The virus also was not transmitted through the soil from infected to healthy plants of *H. esculentus* in a series of 40 pots in the glasshouse. However, the virus was readily transmitted from infected to healthy plants of *H. manihot, H. esculentus* and *H. sabdariffa* by both budding and grafting.

*Insect transmission.*

Experiments were carried out to determine whether white flies (*Bemisia tabaci*) were capable of transmitting the virus with acquisition and test feeding periods ranging from five minutes to 24 hours. The time intervals were five minutes, one, three, six, 12 and 24 hours with 30 plants in each test. However, as no transmission was recorded, it is concluded that the white fly (*Bemisia tabaci*) is not a vector. *Planococcus citri* and *Freesiana* spp. nymphs also were unable to transmit the virus from infected *H. esculentus* plants to healthy *H. esculentus* test plants.

*Attempted aphic transmission.*

Nymphs and adults of *Aphis gossypii* and *Myzus persicae*, which were found feeding on young *H. manihot* leaves in the field, were found unable to transmit the virus using acquisition and test feeding times of several minutes to 72 hours.

*Attempted field transmission.*

Healthy *H. esculentus* plants and infected *H. esculentus* plants were planted alternately in the field alongside an established plot of infected *H. manihot* in a search for insect vectors and possible transmission in the field. However, of the 50 healthy *H. esculentus* plants, none became infected at the end of ten months observation, as determined from the absence of symptoms and periodic inoculations onto test seedlings of *H. esculentus* in the greenhouse.

*Vegetative propagation.*

As no vector could be located transmitting the virus, it is probable that the widespread distribution of the disease in the Gazelle Peninsula has resulted from the practice of the local farmers in establishing plants of *H. manihot* from cuttings. Cuttings of *H. manihot* readily root in the pumice soils of the Gazelle Peninsula and provide a quick supply of leaf material.

## CONCLUSIONS.

The host range of the virus studied at Keravat appears to be restricted to *Hibiscus* spp. and is readily transmitted mechanically to other *Hibiscus* spp. However, it could not be transmitted by the white fly (*Bemisia tabaci*), *Planococcus citri*, *Freesiana* sp., nor by *Aphis gossypii* and *Myzus persicae*. Thus the virus is not likely to be related to the yellow vein mosaic disease of *H. esculentus* in India, Anthocyanosis virus of cotton tobacco streak virus, nor malva yellows virus.

From field trials, it appears that the disease is more likely to be spread in the Gazelle Peninsula from the planting of infected cuttings. As the virus does not reduce yield, nor affect the palatability of the leaves, the virus is of little importance in the cultivation of *H. manihot*.

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# *HIPPEASTRUM STREAK, A VIRUS DISEASE OF* HIPPEASTRUM VITTATUM *IN PAPUA AND NEW GUINEA.*

R. J. VAN VELSEN.*

ABSTRACT.

*The streak condition of Hippeastrum plants in the Territory of Papua and New Guinea is due to a virus which appears to be restricted to this host. Although the leaf symptoms are similar to those induced by tomato spotted wilt virus, the virus is not tomato spotted wilt due to dissimilarity in the host range and physical properties. The virus is readily transmitted by mechanical means to Hippeastrum, but no insect vector was located. Attempts to produce virus-free Hippeastrum bulbs by heat treatment were unsuccessful.*

## INTRODUCTION.

*Hippeastrum vittatum* Herb. (syn. *Amaryllis vittata*) is grown throughout the Territory of Papua and New Guinea as an ornamental in house gardens, and the leaves are usually affected by pale and dark green streaks. These streak symptoms are very similar to those described as being induced by tomato spotted wilt virus (Smith 1957). Foliar symptoms induced by viruses on Hippeastrum plants have been reported from the United States of America (Beale 1931), Denmark (Neergaard 1950), the Philippines (Juliano 1951), and the Netherlands (De Bruin-Brink *et al* 1953). To date, the author has not been able to demonstrate the presence of tomato spotted wilt virus in the Territory of Papua and New Guinea, and experimental studies on the streak of *Hippeastrum vittatum* [1] were carried out to determine whether the symptoms are induced by tomato spotted wilt virus and if they are not, what virus is involved. This report gives the experimental details and the results of the investigations carried out on the leaf streak condition of Hippeastrum.

## EXPERIMENTAL STUDIES.

### *Symptoms.*

The emerging leaves from infected bulbs of *Hippeastrum vittatum* at first appear to be symptomless, but later three to five dark green irregular shaped areas are observed near the leaf margin. These areas are usually of greater length than width, ranging from 1 to 100 mm. in length and 1 to 10 mm. in width (*Plate* I).

As the leaves mature, the streaks appear over the whole leaf surface and the leaf tip turns a pale green with the darker green streak areas being quite distinct. The streaking is mainly confined to the top two-thirds of the lamina with little streaking near the leaf base. After the leaf reaches senescence, the symptoms become less distinct. The streak symptoms also occur on the flower stalk, but no symptoms are found on the flower parts. The symptoms appear two to three months after the mechanical inoculation of healthy Hippeastrum plants.

### *Mechanical inoculation.*

In the initial mechanical inoculation trials (Anon. 1963) the first two leaves of healthy *Hippeastrum vittatum* plants were dusted with 500 grit carborundum and the sap from infected leaves smeared onto the leaves with a finger.

* Formerly Senior Plant Pathologist, Lowlands Agricultural Experiment Station, Keravat, New Britain.

[1] The first collection (Accession 2402) of this condition in Papua and New Guinea was made by Dr. D. E. Shaw in 1959 (Shaw 1963).

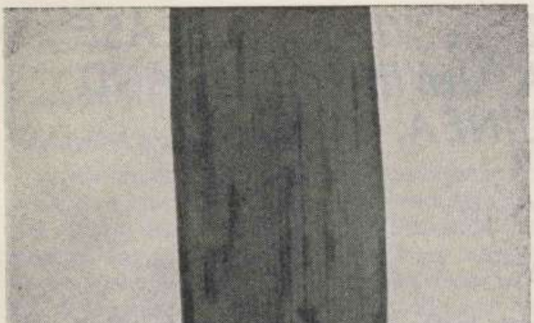

*Plate* I.—Section of a leaf of *Hippeastrum vittatum* showing the longitudinal streaking induced by Hippeastrum streak virus.

The streak symptoms appeared two to three months after inoculation. *Lycopersicon esculentum* variety 'Grosse Lisse' was also inoculated in the same manner, but did not become infected.

Best and Samuel (1936) found that a buffer solution of sodium sulphate, potassium phosphate and sodium sulphite increased the infectivity of crude preparations of tomato spotted wilt virus. Sap from infected Hippeastrum leaves was treated with this buffer and healthy plants of *H. vittata* and *L. esculentum* were inoculated with the suspension. There was no increase in infectivity, and further experiments with sodium sulphite solutions of various molarity and pH were carried out, but only Hippeastrum was found to be infected.

### *Host range.*

The host range of Hippeastrum streak is given in *Table* 1. All plants were inoculated with infectious sap treated with the buffer solution of Best and Samuel (1936), sodium sulphite solutions of various molarity and pH and untreated sap. It is evident that the only plant infected was *Hippeastrum vittatum*. Since the virus did not infect any of the other plants susceptible to tomato spotted wilt virus, it is considered that the virus is not tomato spotted wilt.

*Table* 1.—The host range of Hippeastrum streak virus.

| Species. | Proportion of plants infected. |
|---|---|
| *Hippeastrum vittatum* Herb. .... .... | 87/90 |
| *Petunia hyrida* Vilm. var. 'Rosy Morn' .... | 0/60 |
| *Lycopersicon esculentum* Mill. | |
| var. 'Grosse Lisse' .... | 0/300 |
| var. 'Tatula' .... .... | 0/300 |
| *Datura stramonium* L. .... .... | 0/60 |
| *Nicotiana tabacum* L. .... .... .... | 0/60 |
| *N. glutinosa* L. .... .... .... .... | 0/60 |
| *N. rustica* L. .... .... .... .... | 0/60 |
| *N. clevelandii* Gray. .... .... .... | 0/60 |
| *Hyoscyamus niger* L. .... .... .... | 0/60 |
| *Solanum dulcamara* L. .... .... .... | 0/60 |
| *S. nigrum* L. .... .... .... .... | 0/60 |
| *Capsicum annuum* L. .... .... .... | 0/60 |
| *Tropaeolum majus* L. .... .... .... | 0/60 |
| *Zinnia elegans* Jacq. .... .... .... | 0/60 |
| *Gloxinia* sp. .... .... .... .... | 0/60 |
| *Lathyrus odoratus* L. .... .... .... | 0/60 |
| *Pisum sativum* L. var. 'Greenfeast' .... | 0/60 |
| *Vicia faba* L. var. 'Windsor' .... .... | 0/60 |
| *Freesia* sp. .... .... .... .... | 0/60 |
| *Gladiolus* sp. .... .... .... | 0/60 |
| *Chenopodium amaranticolor* Coste et Reyn. | 0/60 |
| *Allium cepa* L. .... .... .... .... | 0/60 |
| *Allium sativum* L. .... .... .... .... | 0/45 |

### *Physical properties.*

The dilution end point, thermal inactivation point and longevity in vitro were determined using the methods of Bos *et al*, using Hippeastrum as the test plant. The results were recorded six months after treatment. The dilution end point was found to lie between 1 : 500 and 1 : 600, the thermal inactivation point between 40 and 45 degrees centigrade for an exposure of 10 minutes, and longevity in vitro at 25 degrees centigrade between 120 and 144 hours (*Table* 2).

*Table* 2.—Physical properties in crude sap of Hippeastrum streak virus using *Hippeastrum vittatum* Herb. as the test plant.

| THERMAL INACTIVATION. | | DILUTION END POINT. | | LONGEVITY. | |
|---|---|---|---|---|---|
| Temp. (°C.) | Plants infected/ Plants treated. | Dilution. | Plants infected/ Plants treated. | Hours. | Plants infected/ Plants treated. |
| Unheated | 30/30 | Undiluted | 30/30 | 0 | 30/30 |
| 30 | 30/30 | 1 : 10 | 12/30 | 24 | 14/30 |
| 35 | 20/30 | 1 : 100 | 7/30 | 48 | 8/30 |
| 40 | 5/30 | 1 : 400 | 3/30 | 72 | 6/30 |
| 45 | 0/30 | 1 : 500 | 2/30 | 96 | 3/30 |
| 50 | 0/60 | 1 : 600 | 0/90 | 120 | 3/30 |
| 55 | 0/60 | 1 : 700 | 0/90 | 144 | 0/120 |
| 60 | 0/60 | 1 : 800 | 0/60 | 168 | 0/60 |

### *Attempted transmissions.*

No transmission was recorded when healthy Hippeastrum plants were grown in soil collected from around the base of infected field plants. During a period of 12 months, no thrips were collected from Hippeastrum plants growing in the Keravat area. A field planting of healthy and infected Hippeastrum plants was carried out in 1965, in which healthy and infected plants were planted alternately using 50 plants of each. At the end of 12 months, none of the healthy plants was found to be infected. Thus it appears that the main method of dissemination of the virus is by infected planting material.

## CONCLUSIONS.

The streak condition of Hippeastrum plants in the Territory of Papua and New Guinea is due to a virus which appears to be restricted to this host. Although the leaf symptoms are similar to those induced by tomato spotted wilt virus, the virus is not tomato spotted wilt due to dissimilarity in the host range and physical properties. The virus is readily transmitted by mechanical means to Hippeastrum, but no insect vector was located. Attempts to produce virus-free Hippeastrum bulbs by heat treatment were unsuccessful. It is considered that the virus has not been previously described and is confined to *Hippeastrum* spp.

(Received October, 1966.)

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# A REQUIREMENT FOR CHILLING TO INDUCE FLOWERING IN DOLICHOS LABLAB cv RONGAI

G. D. HILL.*

ACCORDING to von Schaaffhausen flowering of *Dolichos lablab* is more dependent on photoperiod than on temperature. This was not found to be the case in extensive acreages of *Dolichos lablab* cv Rongai which were planted in the Morobe District of New Guinea during 1966.

Three hundred and fifty acres were sown in the Markham Valley between Munum and Kaiapit (Latitude 6 degrees south) and fifty acres were planted at Sunshine near Bulolo (Latitude 7 degrees south) between December, 1965, and April, 1966. Differences in photoperiod between the two locations would not have exceeded two minutes per day. It could therefore be assumed that marked differences in time of flowering would be due to factors other than photoperiod.

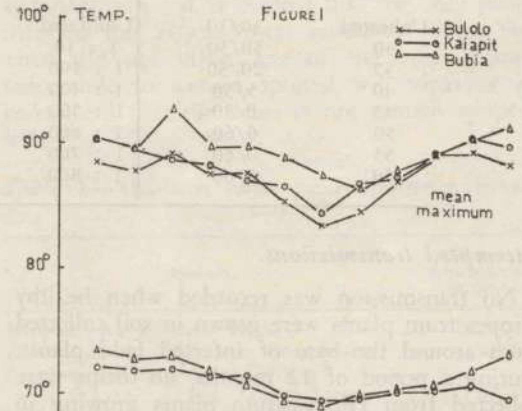
Flowering was first observed at Sunshine (elevation 2,000 ft.) on the 29th April, and generalized flowering had commenced on this site by the end of May.

At all other locations no flowers were observed until the 6th June. Date of planting made little difference to commencement of flowering at any site.

At only three locations in the Markham Valley, which were very dry, was flowering at all extensive. At all other sites, the crop continued to make luxurious vegetative growth producing only occasional flowers in areas where it appeared the plants were water-stressed.

It would appear that as this particular strain of Dolichos was introduced from the Rongai district of Kenya, near the equator, for flowering in low tropical latitudes, one of the two following requirements must be fulfilled :—

1. Low night temperatures, allowing a certain amount of chilling. Mean maximum and minimum temperatures for Bulolo (similar to Sunshine) and two locations in the Markham Valley are shown in *Figure* 1.




It will be seen that although there is little variation in the mean maximum temperatures at the three sites, the mean minimum temperature at the higher altitude is consistently from seven to nine degrees cooler than in the Markham Valley.

Britten has shown that in Hawaii non flowering clones of *Trifolium repens* could be induced to flower if grown in a similar temperature regime to that found at high altitudes. It would appear that a similar mechanism is in operation here.

2. In areas of the Markham Valley where the crop did flower there was a marked dry spell and plants became water-stressed. The setback was evidently sufficient to induce spasmodic flowering.

## IMPLICATIONS.

It would appear that although this plant is an excellent forage legume at low altitudes in the Territory, if seed production is required planting

* Agronomist, Department of Agriculture, Stock and Fisheries, Bubia, Lae.

in areas which have mean minimum temperatures above 64 degrees F. could not be recommended. Successful seed production at low altitudes would depend on the occurrence of an extended dry period sufficient to prevent all vegetative growth.

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# SULPHUR DEFICIENCY IN COCONUTS, A WIDESPREAD FIELD CONDITION IN PAPUA AND NEW GUINEA.

## PART I: THE FIELD AND CHEMICAL DIAGNOSIS OF SULPHUR DEFICIENCY IN COCONUTS.

P. J. SOUTHERN.*

ABSTRACT.

*The paper describes field and chemical work showing that sulphur deficiency is widespread in Papua and New Guinea and is responsible for chlorosis, low yields and poor quality copra. The field symptoms are illustrated by colour photographs.*

*Excellent field responses have been obtained, resulting in increased nut production and frond numbers with improvement in foliage colour and copra quality.*

*The diagnosis of sulphur deficiency by sulphate analysis and quality testing has been developed to a good degree of precision.*

### INTRODUCTION

THE occurrence of widely scattered areas of debilitated and yellow coconut palms in many coconut plantations of Papua and New Guinea has been noted by agricultural workers and plantation managers for many years. Thus Dwyer (1937) referred to chlorotic diseases in coconuts as being very important and likely to be associated with soil deficiency. He referred to conditions at Kokopo and the North Coast of New Britain where 30-year-old palms growing on pumice soil in grassland areas showed severe chlorosis. He also mentioned large chlorotic areas in New Ireland, New Hanover and Bougainville but it has been since shown by Baseden and Southern (1959) that potassium deficiency causes chlorosis and poor production on these coral derived soils. This deficiency produces quite typical bronzing symptoms in the older leaves and the "sickly yellowish green" colour, small number of feathery fronds and low nut production, described by Dwyer as pertaining to New Britain, is clearly a separate condition.

Dwyer also described tapering stem condtion, premature nut fall and leaf droop, in which dead fronds hung around the lower part of the palm head. He considered that these conditions were often associated with poor soil conditions and deficiencies.

In inspections of coconut plantation areas in Papua and New Guinea, the author has observed many small and scattered areas of chlorotic palms, with similar symptoms to those described by Dwyer. Bronzing of older leaves and low potassium contents in tissues and nut waters were not features of the condition. In a few cases severe waterlogging and poor soil physical conditions were apparent but in most areas poor drainage did not appear to be a major limiting factor.

No nutritional investigations on the cause of the condition appear to have been attempted prior to 1958.

This paper and the following part describe the research undertaken to show that sulphur deficiency is responsible for poor growth of coconut palms and low production of copra in these areas. The work also shows that sulphur deficiency is a major cause of defective copra known as 'rubbery copra', which is produced in substantial amounts on many plantations throughout Papua and New Guinea. Dwyer referred to copra which is soft, flexible and leathery, often becoming brown in colour, and of poor appear-

* Senior Chemist, Department of Agriculture, Stock and Fisheries, Port Moresby.

*Plate* I.—Sulphur deficiency, seedling.

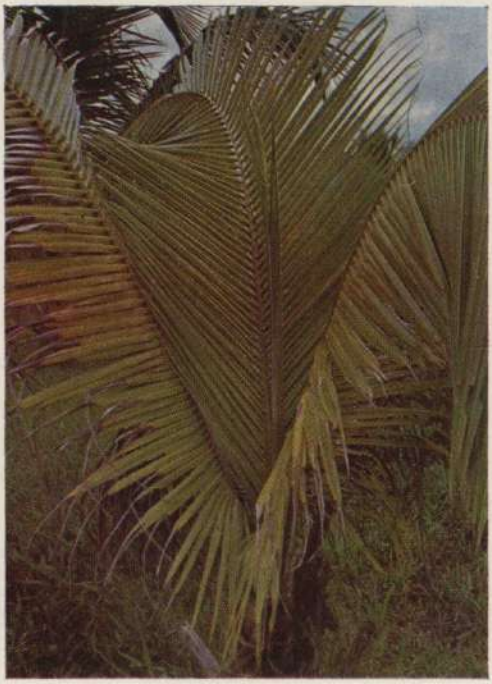

*Plate* II.—Sulphur deficiency, young palm.

*Plate* III.—Older palms displaying sulphur deficiency symptoms.

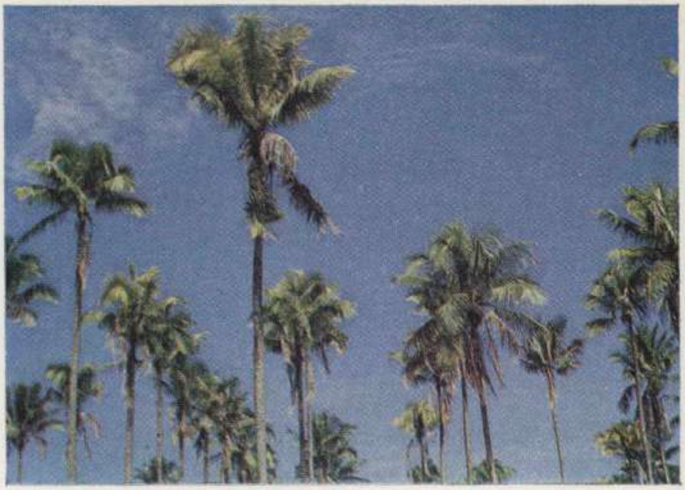

*Plate* IV.—Sulphur deficient area of mature palms.

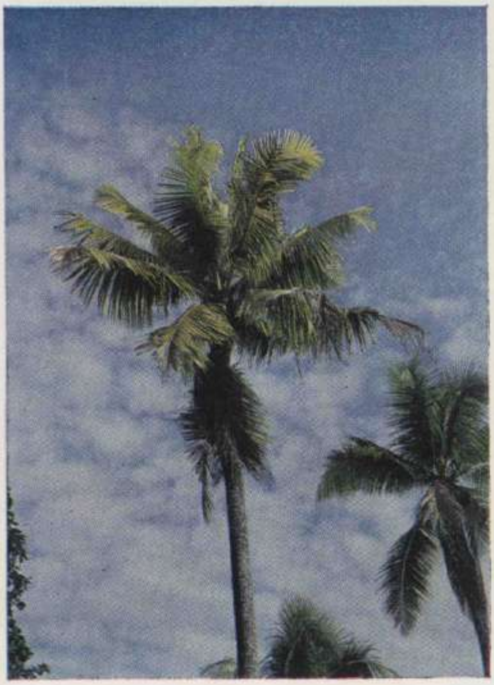

*Plate* V.—Typical symptoms of deficiency in a mature palm.

*Plate* VI.—Coconut leaf from palm with severe deficiency.

*Plate* VII.—Chlorosis and necrosis in leaflets from palms affected with sulphur deficiency.

*Plate* VIII.—Nitrogen deficiency symptoms in palms on coral sand soils low in organic matter.

*Plate* IX.—Response following sulphur treatment. Left, untreated palm; right, seven months after treatment with 2 lb. sulphur.

ance and quality. He attributed this defective copra to soil impoverishment or lack of certain essential elements in the soil. Because of its poor physical and chemical characteristics, such copra is unacceptable to copra buyers and manufacturers if it forms a significant proportion of a consignment.

## DESCRIPTION OF FIELD SYMPTOMS OF SULPHUR DEFICIENCY.

Sulphur deficiency does not appear to have been recorded as a field condition of coconuts. Velasco *et al.* (1960) described deficiency symptoms produced in young palms by omitting sulphur in sand cultures. In general these sulphur deficient palms turned a dirty yellow colour with the second and third leaves becoming chlorotic before the others. Stunting occurred, the petioles were short and there was a tendency for a weakening of the rachis and arching of the leaves to occur, often to almost a semicircle.

*Plates* I and II show sulphur deficiency in young palms in the field in New Guinea. The young fronds are yellow or orange yellow and severely arched. *Plate* III shows a group of older palms in the Markham Valley area affected by sulphur deficiency. All fronds tend to be chlorotic, even the young ones. There is evidence here of weakening of the rachis causing premature bending and the marked tendency of sulphur deficient palms to retain their dead fronds. *Plate* IV shows an area of sulphur deficient mature palms in the Lae area of New Guinea. The symptoms are general yellowing extending to the young leaves, premature bending of the fronds above the normal abscission layer and consequent large numbers of hanging dead fronds. As many as 30 have been observed on one palm. The production of nuts is greatly diminished and severely affected palms produce no nuts. The number of live fronds is much smaller than usual. *Plate* V shows the upright and arched live fronds with a dearth of live fronds in the horizontal or lower positions. The dead fronds hang in a vertical position at the base of the head. There are few nuts and these are small in size and produce poor quality copra. The chlorosis in the palms is clearly seen. This may vary from a pale green colour to a vivid orange. A certain amount of necrosis occurs, spreading from the tips of leaflets towards the midrib.

*Plate* VI shows a typical sulphur deficient leaf with chlorosis followed by necrosis developing at the margins and tip. *Plate* VII shows detail of chlorosis and necrosis in leaflets of palms affected with sulphur deficiency.

The symptoms of sulphur deficiency are distinguishable from those produced by nitrogen deficiency. In the latter the yellowing does not affect the young leaves except in severe cases. The head of the palm retains its normal shape with live fronds still remaining at a horizontal or lower position. *Plate* VIII shows palms growing on a coral sand soil with a noticeable lack of organic matter. They show typical nitrogen deficiency symptoms.

It has been observed also that a large amount of premature nut fall, particularly of button size nuts, occurs in sulphur deficient areas.

Legume cover crops and shade trees growing in association with sulphur deficient palms frequently show characteristic stunting and yellowing symptoms. *Pueraria phaseoloides* plants have small leaves with general chlorosis symptoms similar to those described by Shorrocks (1964). *Leucaena leucocephala*, the leguminous tree grown in Papua and New Guinea for cacao shade, appears sensitive to sulphur deficiency and in the sulphur deficient areas investigated was often stunted and yellow. Its quick response to sulphur containing fertilizers gave early proof of sulphur deficiency in some areas.

## PRELIMINARY CHEMICAL AND FIELD INVESTIGATIONS.

Chemical diagnostic work, particularly foliar analysis and coconut water analysis, has played a major part in the investigation and diagnosis of sulphur deficiency and the assessment of the sulphur status of coconut areas. The first research was carried out by Baseden (1959) on several plantations in the Bainings region in New Britain. Baseden showed that palms displaying chlorosis produced rubbery copra and that frond samples from affected palms had a lower total sulphur content than healthier palms in the same area. There were no consistent differences in the contents of nitrogen, potassium, phosphorus, sodium, calcium, magnesium, manganese, iron and copper. (*Table* 1). Baseden

*Table* 1.—**Analysis of Fronds from Palms yielding Rubbery and Normal Copra (Baseden 1959).**

| Description. | Leaf Position. | N. | P. | K. | Na. | Ca. | Mg. | Mn. | Fe. | Cu. | S. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Palm No. 1, debilitated, | A | 1.50 | 0.202 | 2.40 | 0.08 | 0.15 | 0.38 | 21 | 40 | 10.3 | 0.039 |
| Copra rubbery | B | 1.41 | 0.180 | 2.45 | 0.07 | 0.13 | 0.37 | 26 | 50 | 9.9 | 0.035 |
| | C | 2.09 | 0.160 | 1.25 | 0.07 | 0.23 | 0.43 | 57 | 48 | 3.7 | 0.046 |
| | D | 1.05 | 0.120 | 1.10 | 0.07 | 0.31 | 0.38 | 67 | 47 | 3.9 | 0.043 |
| Palm No. 2, very chlorotic, | A | 1.69 | 0.260 | 2.85 | 0.07 | 0.28 | 0.37 | 17 | 42 | 9.9 | 0.029 |
| Copra very rubbery | B | 1.83 | 0.250 | 2.80 | 0.06 | 0.34 | 0.49 | 49 | 40 | 9.2 | 0.045 |
| | C | 2.11 | 0.212 | 2.20 | 0.06 | 0.28 | 0.45 | 55 | 23 | 6.5 | 0.043 |
| Palm No. 3, some chlorosis, | A | 1.44 | 0.170 | 2.40 | 0.07 | 0.21 | 0.28 | 17 | 42 | 12.2 | 0.036 |
| Copra normal | B | 2.34 | 0.128 | 1.75 | 0.05 | 0.22 | 0.28 | 34 | 46 | 8.5 | 0.062 |
| | C | 2.53 | 0.122 | 1.40 | 0.03 | 0.29 | 0.28 | 55 | 30 | 5.2 | 0.064 |
| | D | 1.72 | 0.130 | 1.00 | 0.05 | 0.47 | 0.29 | 96 | 52 | 3.6 | 0.058 |
| Palm No. 4, healthy, | A | 1.06 | 0.180 | 2.40 | 0.03 | 0.14 | 0.19 | 17 | 30 | 9.5 | 0.065 |
| Copra rubbery | B | 1.52 | 0.170 | 2.15 | 0.02 | 0.14 | 0.24 | 21 | 42 | 6.0 | 0.070 |
| | C | 1.95 | 0.150 | 0.80 | 0.55 | 0.50 | 0.23 | 84 | 54 | 5.5 | 0.138 |
| | D | 1.25 | 0.110 | 0.40 | 0.05 | 0.86 | 0.21 | 140 | 42 | 3.9 | 0.123 |

Note: 1. N, P, K, Na, Ca, Mg and S expressed as per cent. dry matter, Mn, Fe, Cu as p.p.m. dry matter.

2. Leaf Position. A represents youngest unopened 'spear frond', B is youngest fully opened frond, usually the 3rd, C is mature frond in horizontal position, D is oldest frond without necrotic tissue.

did not consider that adverse physical conditions were a likely major cause of the condition in the palms in these areas and considered it a straightforward nutritional problem involving sulphur supply. He observed that palms bordering a drain to which sea water had access were healthy, vigorous and did not produce rubbery copra and considered this to be the influence of the sea water sulphate content.

Unfortunately further confirmatory work and experiments with sulphur were not carried out in this area but a general improvement was observed following removal of heavy grass competition which had probably induced or aggravated the sulphur deficiency.

Following on Baseden's work, further determinations were made of total sulphur in frond samples from other areas displaying symptoms of suspected sulphur deficiency and from healthy areas. These results are summarized in *Table* 2, together with available overseas results tabled by Fremond (1958). At this stage no standardized leaf sampling procedure had been adopted so that results were difficult to compare. However, in general, fronds from healthy palms contained considerably more total sulphur than those with the described condition.

A comprehensive investigation was commenced in 1964, covering nine sites where sulphur deficiency was suspected as being responsible for chlorosis of palms and the associated rubbery type copra. Most of these areas were investigated first by making field observations, chemical analyses and quality tests on copra. This was followed by confirmatory fertilizer trials using various sources of sulphur. The uptake of sulphur was studied by chemical analysis of sulphate in coconut water. Quality tests, nut counts and other observations were made as the trials progressed. Where possible, coconut frond and cocoa leaf samples were collected for analysis.

Early determinations of total sulphur in leaves by Baseden and the author used the precipitation of sulphate with barium chloride following magnesium nitrate or bomb ignition. These were lengthy procedures and in many cases did not differentiate clearly differences in the sulphur status. Efforts to precipitate sulphate with barium chloride in nut water samples produced erratic results due to the high quantities of organic matter present.

The micro methods used by Johnson and Nishita (1952) for the determination of sulphur in plant materials and waters were then examined and found suitable, with minor modifications, for estimating the quantities of sulphur found in coconut leaves and nut waters. These methods determine the easily reducible fraction of sulphur in plants and this is predominantly the sulphate fraction. In this paper the sulphate content refers to this easily reducible sulphur fraction of the total sulphur.

*Table* 2.—Total Sulphur (per cent. Dry Matter) in Coconut Tissues, various Areas.

| Area. | Description. | Copra Quality | Young Fronds (1-3) | Horizontal Fronds (8-16) | Old Fronds (17-24) |
|---|---|---|---|---|---|
| Bainings, New Britain (3 palms) | Chlorotic palms .... .... | Rubbery | 0.035-0.062 | 0.043-0.064 | 0.043-0.058 |
| Bainings, New Britain (1 palm) | Healthy palm in chlorotic area | Normal | 0.070 | 0.138 | 0.123 |
| Gadaisu, Papua, (11 palms) | Generally yellow palms .... | Rubbery tendency | 0.04-0.11 | | |
| Baibara, Papua (2 palms) | Healthy palms .... .... | Normal | 0.11 | 0.19-0.20 | 0.21-0.22 |
| Finschhafen, New Guinea .... | Palms without S Symptoms | Normal | 0.09-0.16 | 0.11-0.16 | 0.10-0.17 |
| New Ireland, (12 palms) .... | ,, ,, | Normal | 0.14-0.22 | | |
| Tahiti, several areas .... | ,, ,, | Not known | | 0.10-0.15 | |
| Tahiti, normal value .... | ,, ,, | ,, | | 0.15 | |
| Dahomey, Africa .... .... | ,, ,, | ,, | | 0.22-0.30 | |

It was found at an early stage that the analysis of sulphate content in the plant material provided a more sensitive index of sulphur status and total sulphur estimations were discontinued.

The physical and chemical characteristics of rubbery copra, its association with sulphur deficiency and its improvement following sulphur applications are discussed in more detail in Part II of this paper (Southern 1967).

The experimental sites are marked 1 to 9 on the map of Papua and New Guinea (*Figure* 1), and descriptions of these areas, together with field and chemical results, are as follows :—

*Experimental Site* 1.

This site is representative of several hundred acres of chlorotic, low yielding palms on a plantation at Lae, New Guinea. There is a very heavy incidence of rubbery copra produced on this plantation, which makes the copra generally unsuitable for marketing. The palms are between 30 and 40 years old and are growing in an alluvial soil under high rainfall conditions.

Preliminary samples of copra collected from a group of yellow palms showed that these palms produced rubbery copra consistently over a number of months.

Initial experiments involving 5 lb. applications of sulphate of ammonia produced spectacular improvement in foliage colour of treated palms, so a comprehensive trial involving various sulphur sources was laid down in July, 1965.

There were four treatments in this trial, as follows :—

1. Control ;
2. Sulphur, 2 lb. per tree ;
3. Sulphate of ammonia, 8 lb. per tree ;
4. Sulphate of potash, 11 lb. per tree.

The amount of sulphur per treatment was approximately the same.

The treatments were replicated four times, with a plot size of five palms. There were adequate guard palms between plots.

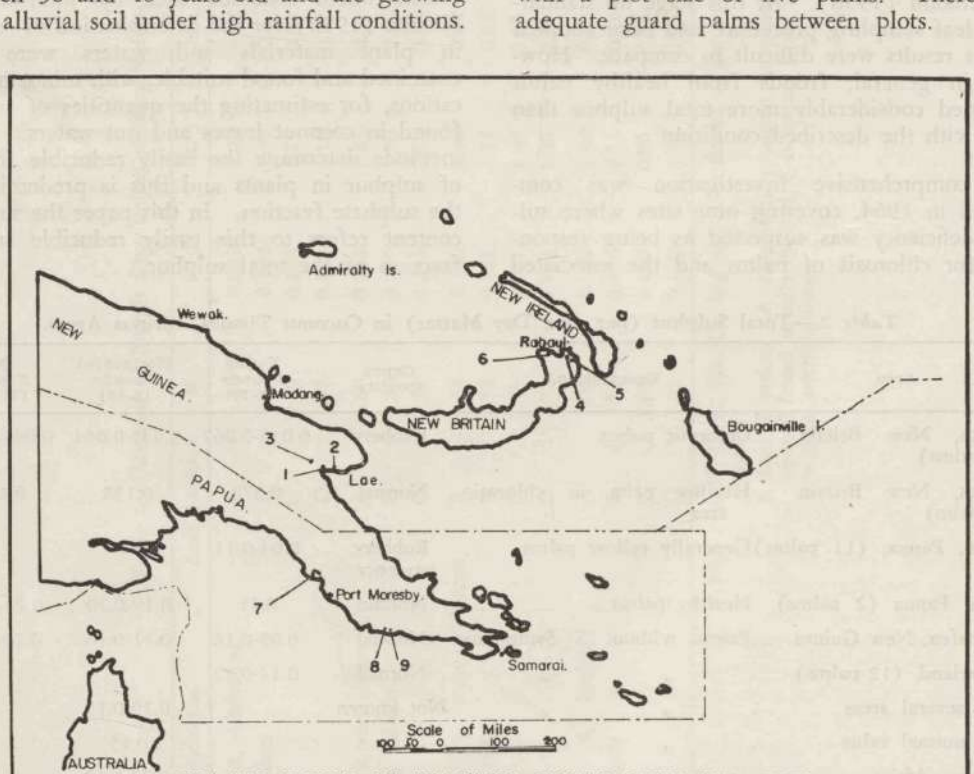


FIG.1. MAP OF PAPUA AND NEW GUINEA SHOWING EXPERIMENTAL SITES.

The following field recordings were made at intervals during the course of the trial :—

(*a*) Foliage colour (according to a points system) ;

(*b*) Frond count, green fronds ;

(*c*) Frond count, dead fronds hanging from palms ;

(*d*) Nut count (above cricket ball size, approximately).

In addition a large number of samples was collected at regular intervals for quality testing and chemical analysis of copra and coconut water. The copra quality grading was carried out on a points system.

There were outstanding responses on all recorded features of this trial. These were obtained with any source of sulphur. There did not appear to be any long term agronomic advantages in using a particular source so that the cheapest source (sulphur) would normally give the most economic results.

The effect of the treatments has been summarized in tables and graphs. All effects due to sulphur are statistically significant and in the case of foliage colour and copra quality assessments significance is at the 0.1 per cent. level. Significance has reached the 1 per cent. level for most other recordings.

(*a*) *Foliage Colour.*

General colour of the palm heads was assessed as follows :—

| | | |
|---|---|---|
| Healthy Green | .... .... | 5 points. |
| Yellowish-Green | .... .... | 4 points. |
| Greenish-Yellow | .... .... | 3 points. |
| Yellow | .... .... .... | 2 points. |
| Orange-Yellow | .... .... | 1 point. |

Improvement in colour for all treatments containing sulphur was noted about three to four months after the fertilizer applications. As might have been expected, the elemental sulphur treatment took a little longer to give results than the sulphate treatments. By January, 1966, six months after treatment, highly significant effects on foliage colour had been obtained. It was noticeable that even older fronds previously yellow or orange became noticeably greener. *Plate* IX shows two adjacent palms ; the one on the left had not been treated, while the palm on the right had been treated with 2 lb. sulphur seven months previously.

A further assessment of foliage colour made in October, 1966, 16 months after treatment, showed that the effects of the treatments were wearing off and the palms were becoming yellow again.

*Table* 3 shows the effects of treatment on foliage colour.

*Table* 3.—**Effect of Treatment on Foliage Colour, Site 1. (Average points score of 20 palms in treatment.)**

| Treatment. | 15.7.1965. | 3.1.1966. | 12.10.1966. |
|---|---|---|---|
| Control .... .... | 3.05 | 3.35 | 2.98 |
| Sulphur .... .... | 3.08 | 4.73 | 4.18 |
| Sulphate of Ammonia .... | 2.88 | 4.90 | 3.95 |
| Sulphate of Potash .... | 2.95 | 4.68 | 3.95 |

(*b*) *Live Frond Count.*

The number of live fronds has been increased significantly by treatments containing sulphur. Controls have remained at an average of about 15 fronds per palm while treated palms' frond numbers have increased to about 21 per palm. *Table* 4 shows the effects of treatment on live frond count.

*Table* 4.—**Effect of Treatment on Live Frond Count, Site 1. (Average fronds per palm for 20 palms.)**

| Treatment. | 15.7.1965. | 3.1.1966. | 12.10.1966. |
|---|---|---|---|
| Control .... .... | 15.7 | 14.1 | 15.6 |
| Sulphur .... .... | 13.9 | 15.7 | 20.9 |
| Sulphate of Ammonia .... | 14.5 | 17.2 | 21.4 |
| Sulphate of Potash .... | 15.5 | 17.1 | 21.0 |

(*c*) *Dead Frond Count.*

Palms throughout this plantation and other sulphur deficient areas have a marked tendency to retain dead fronds. On closer inspection it has been found that these fronds usually bend a few inches above their normal abscission point and then hang in a vertical position. It appears that they may remain in this position for one or two years or even longer. In the Madang district some palms have been observed with the petioles still attached all the way up the stem, giving the palm the appearance of a step ladder. The reason why they do not fall is probably because the leverage force on the abscission layer is very much less and eventually they break off at the original bending point, leaving the leaf bracket and a small portion of petiole behind.

A weakening of the leaf stem due to some physiological upset or nutritional deficiency could quite easily cause this condition and as the abnormality was associated with more definite symptoms of sulphur deficiency, there was a strong possibility that sulphur treatments might decrease this frond hanging tendency. Therefore, counts were made during the course of the trial of the number of dead fronds hanging from palms.

*Table* 5 shows that the average number of dead fronds on sulphur and sulphate treated palms tended to remain fairly constant while the number increased for the controls. The differences were significant at the five per cent. level. It is possible that the fronds counted following sulphur treatment were the same ones counted prior to the treatments being applied. Obviously it would have been preferable to remove all dead fronds from all the palms at the commencement of the trial, but this was impractical.

*Table* 5.—**Effect of Treatment on Dead Frond Count, Site 1. (Average fronds per palm for 20 palms.)**

| Treatment. | 15.7.1965. | 3.1.1966. | 12.10.1966. |
|---|---|---|---|
| Control .... .... | 3.8 | 5.5 | 6.3 |
| Sulphur .... .... | 3.7 | 3.4 | 4.2 |
| Sulphate of Ammonia .... | 5.1 | 3.5 | 5.6 |
| Sulphate of Potash .... | 4.5 | 3.8 | 4.1 |

(*d*) *Nut Count.*

The average number of nuts per palm at the beginning of the trial was in the vicinity of 13. Significant increases in nut counts were obtained as early as six months after the commencement of the trial. This early response could only have been due to a decrease in premature nut fall, which appears to be a feature of sulphur deficient palms. Fifteen months after the commencement of the trial the average treated palm was carrying 70 per cent. more nuts than the average control palm. There appeared to be a lag in the effects of the elemental sulphur treatment and there were large variations over the year in the nut count. Nut counts taken during the course of the trial and effects of treatments are shown in *Table* 6 and *Figure* 2.

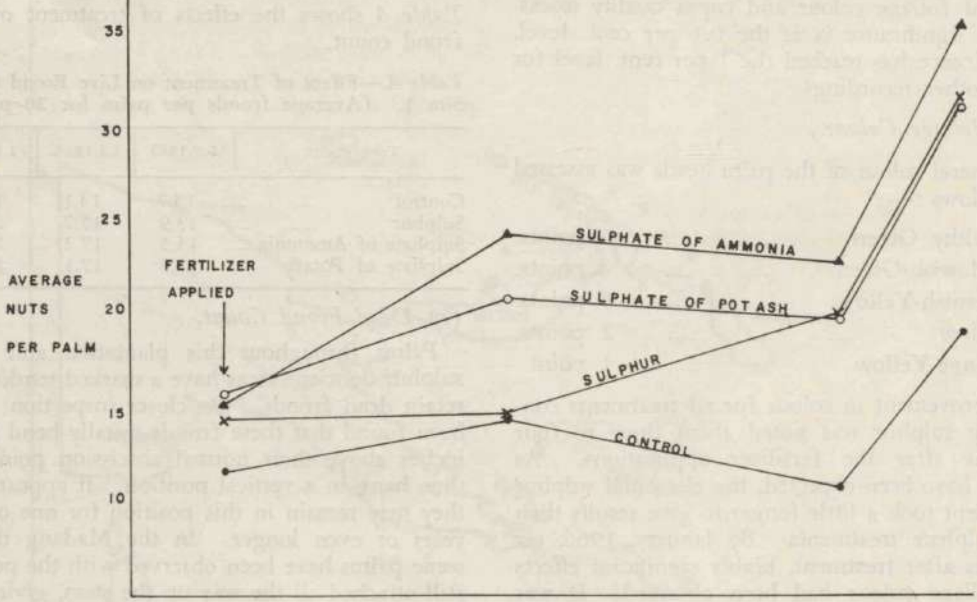


FIG2. EFFECT OF TREATMENT ON NUT COUNT, EXPERIMENTAL SITE I.

*Table* 6.—Effect of Treatment on Nut Count, Site 1. (Average nuts per palm for 20 palms.)

| Treatment. | 15.7.1965. | 3.1.1966. | 6.8.1966. | 12.10.1966. |
|---|---|---|---|---|
| Control .... | 11.6 | 14.4 | 10.8 | 19.0 |
| Sulphur .... | 14.4 | 14.7 | 20.0 | 31.5 |
| Sulphate of Ammonia | 15.1 | 24.1 | 22.6 | 35.3 |
| Sulphate of Potash | 15.7 | 20.8 | 19.8 | 30.9 |

(*e*) *Copra Quality.*

As mentioned earlier, nuts from poor palms in this area consistently produced rubbery type copra. Samples of mature, fallen coconuts from all treatments were collected on 13 occasions during the course of the trial. As on many occasions nuts were unavailable from some palms, samplings have been grouped together, as in *Table* 7.

*Table* 7.—Effect of Treatment on Copra Quality, Site 1. (Average degree of rubberiness for each treatment.)

| Treatment. | Sampling 1-3. | Sampling 4-6. | Sampling 7-9. | Sampling 10-13. |
|---|---|---|---|---|
| Control .... .... | 0.9 | 1.5 | 1.2 | 1.6 |
| Sulphur .... .... | 1.2 | 2.4 | 2.8 | 3.0 |
| Sulphate of Ammonia | 1.3 | 2.9 | 3.1 | 3.3 |
| Sulphate of Potash | 1.3 | 3.4 | 3.5 | 3.3 |

Coconuts were husked and the half kernels washed and then dried in a forced draught oven at 50 degrees—70 degrees C. Samples of coconut water were collected from all nuts and these were bulked for each treatment. They were later analysed.

After drying, the copra was placed into quality categories according to the degree of rubberiness. The categories were given a points score as follows :—

Category 0 Extremely Rubbery 0 point.
Category 1 Very Rubbery 1 point.
Category 2 Rubbery 2 points.
Category 3 Slightly Rubbery 3 points.
Category 4 Normal 4 points.

Typical copra from each of these categories can be seen in *Plate* 2 of the following paper by Southern (1967).

Six to eight months after treatment all copra from sulphur or sulphate treated palms had improved in quality. This improvement was significant at the 0.1 per cent. level. After a further six months there was further improvement and the majority of the palms were producing normal copra. Once again effects from the elemental sulphur treatment were slower to appear than the effects of more soluble fertilizer treatments. *Table* 7 and *Figure* 3 show the effect of treatment on copra quality. Further aspects of the treatment effects on the chemical characteristics of the copra are discussed in Part II of this paper.

(*f*) *Chemical Analysis.*

The main aim of the chemical work in this and succeeding trials was to study the uptake of sulphur and to provide, by frond and nut water analyses, a basis for chemical diagnosis of sulphur deficiency in young and mature palms. Chemical analyses were also used to diagnose any other deficiencies which might have been occurring in the problem areas.

In this trial chemical studies were comprenhensive. Composite samples of coconut waters were collected at 11 periods during the course of the trial and analysed for sulphur and some cations. There was a large amount of variation in sulphate content but nevertheless differences in sulphur uptake between treated and untreated palms are striking and highly significant. *Table* 8 and *Figure* 4 show these results accordingly.

*Table* 8.—Effect of Treatment on the Sulphate Content of Coconut Water, Site 1. (Sulphate content of nut water, p.p.m.S.)

| Sampling Date. | Control. | Sulphur. | Sulphate of Ammonia. | Sulphate of Potash. |
|---|---|---|---|---|
| 10.1.1966 | 1.0 | 1.4 | 7.5 | 3.5 |
| 16.2.1966 | 1.8 | 1.3 | 5.8 | 11.0 |
| 28.2.1966 | 1.5 | 2.5 | 9.5 | 8.0 |
| 14.3.1966 | 1.5 | 8.4 | 23.0 | 23.0 |
| 28.3.1966 | 6.8 | 12.3 | 31.0 | 32.0 |
| 18.4.1966 | 4.0 | 17.0 | 26.0 | 27.5 |
| 2.5.1966 | 7.9 | 33.5 | 38.5 | 51.0 |
| 3.6.1966 | 3.5 | 58.0 | 33.5 | 41.0 |
| 24.6.1966 | 3.5 | 35.0 | 27.5 | 37.5 |
| 5.7.1966 | 5.0 | 15.0 | 13.0 | 17.0 |
| 13.10.1966 | 5.0 | 32.5 | 26.0 | 27.5 |

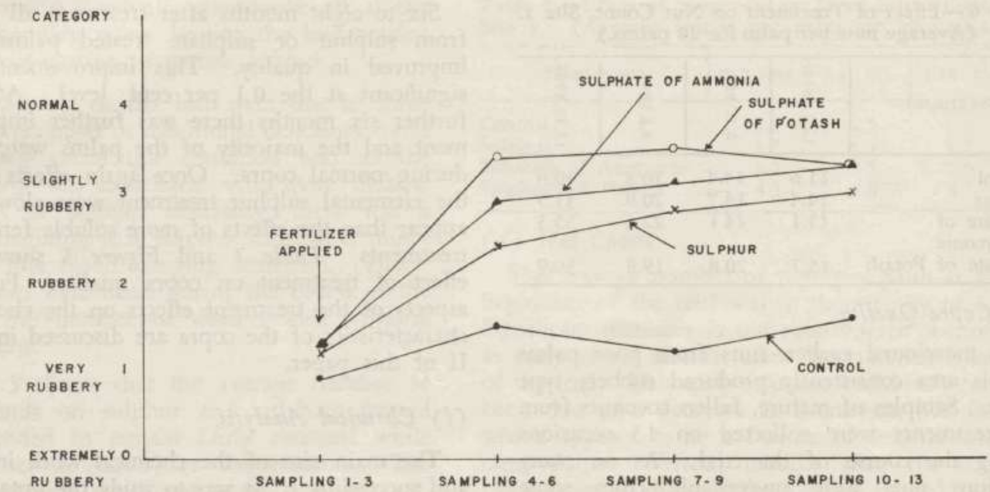


FIG3 EFFECT OF TREATMENT ON COPRA QUALITY, SITE I.

During the whole course of the trial nut waters from untreated palms remained below 8 p.p.m. in sulphate sulphur content and for much of the period the contents were much lower. There was probably uptake of added sulphate by the time of the first sampling, which took place 6 months after the treatments were applied. There was a definite delay in sulphate uptake from the palms treated with elemental sulphur, which explains the slower effects on field and quality measurements. In the period from 9 months to 12 months after treatment, sulphate sulphur contents appeared to reach a maximum. For the period that the palms were green and were producing mainly normal copra, the contents were between 10 and 60 p.p.m.S.

The chemical composition of copra samples obtained from the same nuts as the water samples are given and discussed in Part II.

Coconut waters were also analysed for cations, with particular emphasis on potassium. The potassium content of coconut water gives a good indication of potassium status and has been widely used in this Territory where potassium deficiency is fairly common (Baseden and Southern 1959). It has been found that a content below 30 m.e./litre potassium indicates potassium deficiency, while above 40 m.e./litre potassium deficiency is unlikely.

In the early stages of the trial the nut water potassium content varied between 55 and 65 m.e./litre K, indicating an abundant potassium supply. It is interesting to note that while the control treatment remained at this level, the contents of the treated palms decreased following treatment (*Table* 9).

*Table* 9.—**Effect of Treatment on the Potassium Content of Coconut Waters, Site 1. (K in m.e./litre for composite samples.)**

| Sampling Date. | Control. | Sulphur. | Sulphate of Ammonia. | Sulphate of Potash. |
|---|---|---|---|---|
| 15.7.1965 | 58.0 | 59.9 | 58.9 | 58.3 |
| 26.7.1965 | 59.3 | 61.0 | 58.7 | 60.4 |
| 19.11.1965 | 65.5 | 59.4 | 61.8 | 60.5 |
| 14.3.1965 | 63.0 | 55.0 | 52.0 | 47.0 |
| 28.3.1966 | 62.0 | 56.3 | 49.3 | 51.8 |
| 18.4.1966 | 64.0 | 53.7 | 48.5 | 46.7 |
| 9.5.1966 | 62.6 | 55.5 | 52.3 | 51.3 |
| 3.6.1966 | 63.4 | 52.2 | 51.4 | 50.6 |
| 24.6.1966 | 63.9 | 54.7 | 48.6 | 46.5 |

There is evidence here that sulphur deficient palms have a tendency to absorb potassium in higher than usual amounts. On nearly all other sulphur deficient sites, potassium uptake, as indicated by the nut water content, has been very high.

There were no consistent differences in the sodium, calcium or magnesium contents of the coconut water samples. The range of contents found were as follows :—

Sodium 6.1 — 15.6 m.e./litre.
Calcium 3.4 — 9.3 m.e./litre.
Magnesium 7.7 — 11.6 m.e./litre.

To determine the possiblities of other deficiencies affecting growth or production on this site, leaf samples from young coconuts and from cocoa growing in the area were collected and analysed for all nutrients. The data are presented in *Table* 10. The analyses indicate that most nutrients were in good supply, but that sulphur contents were low.

(*g*) *General Considerations of Treatment Effects.*

The experiment showed that all sources of sulphur were effective in alleviating the sulphur deficiency. The success of the elemental sulphur treatment showed that oxidising bacteria were present and that the deficiency was probably a total one rather than one induced by poor oxidising conditions. Oxidation normally takes a few weeks and this would explain the delay in effects of this treatment.

There are possible side effects of all treatments, but they did not produce significant responses in this trial. Thus there would be a small pH decrease where sulphur or sulphate of ammonia was used and this would tend to release other nutrients. Nitrogen is added with the sulphate of ammonia treatment and potassium as sulphate of potash. There was no change in the potassium content of coconut waters due to sulphate of potash treatment, as is shown in *Table* 9.

The cost of fertilizing palms was approximately as follows :—

Sulphur — 12 cents/palm.

Sulphate of Ammonia — 30 cents/ palm.

Sulphate of Potash — 48 cents/palm.

This is based on the cost of fertilizers landed in bulk in Lae, New Guinea. Obviously the elemental sulphur treatment is the most economic. A yield increase of about six nuts would pay for the fertilizer used and this was easily obtained in the course of the experiment. Residual effects are likely to be considerable and there would be a large improvement in copra quality.

As already pointed out, after the experiment had been in progress 16 months, yellowing of foliage was re-occurring. It is likely that applications of sulphur would have to be repeated after 18 months to maintain or increase the response.

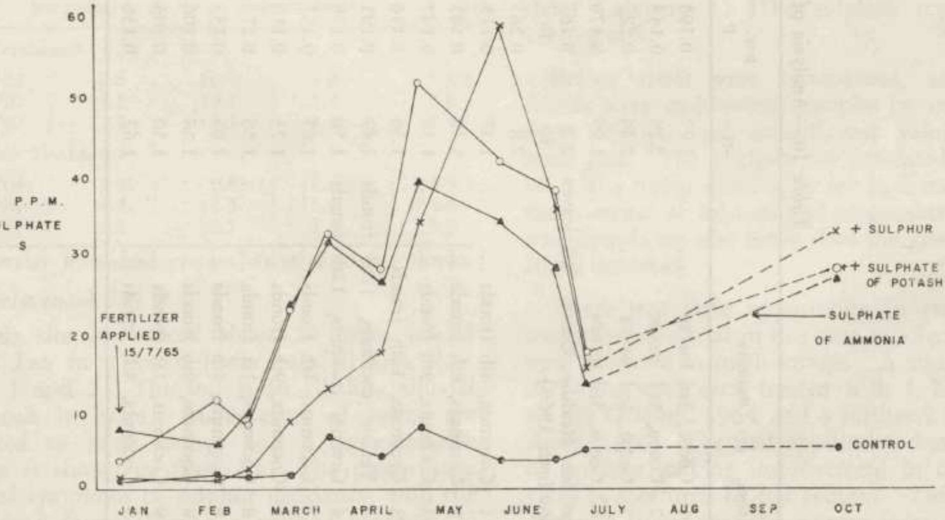


FIG.4 EFFECT OF TREATMENT ON THE SULPHATE CONTENT OF COCONUT WATERS, SITE . 1.

*Table* 10.—Analysis of Cocoa Leaves and Coconut Fronds, Experimental Sites.

| Location. | Sample. | N | P | K | Ca | Mg | S | Mn | Fe | Cu | Zn | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | per. cent., dry basis | | | | | p.p.m., dry basis | | | | | |
| Site 1 | Cocoa, 3rd leaves .... .... | 1.97 | 0.195 | 1.64 | 1.78 | 0.56 | 220 | 123 | 76 | 7.8 | 45 | 27.5 |
| Site 2 | Cocoa, 3rd leaves .... .... | 2.24 | 0.144 | 1.58 | 1.57 | 0.51 | 160 | 203 | 32 | 6.9 | 63 | 24.0 |
| Site 5 | Cocoa, 3rd leaves .... .... | 2.44 | 0.22 | 2.30 | 0.76 | 0.43 | | 47 | | | | |
| Site 6 | Cocoa, 3rd leaves .... .... | 1.99 | 0.170 | 1.48 | 1.83 | 0.80 | | 430 | 42 | 6.4 | 63 | 27.3 |
| Range for Healthy Cocoa, 3rd leaves (Southern 1966). | | 2.2 to 2.8 | 0.16 to 0.26 | 1.8 to 2.6 | 0.7 to 2.0 | 0.35 to 0.70 | over 400? | over 40? | over 60? | over 6? | over 30? | over 20? |
| Site 1 | Coconuts, 4th fronds .... .... | 1.47 | 0.115 | 1.92 | 0.27 | 0.29 | 80 | 28 | 56 | 4.3 | 16.0 | 11.0 |
| Site 1 | Coconuts, 8th fronds .... .... | 1.35 | 0.105 | 1.42 | 0.31 | 0.24 | 65 | 36 | 80 | 4.0 | 21.5 | 11.5 |
| Site 3 | Coconuts, 9th fronds .... .... | 1.36 | 0.147 | 1.13 | 0.21 | 0.10 | 120 | 14 | 32 | 3.1 | 22.4 | 17.0 |
| Site 3 | Coconuts, 14th fronds .... | 1.36 | 0.136 | 0.97 | 0.39 | 0.23 | 130 | 14 | 28 | 2.7 | 26.5 | 20.3 |
| Site 4 | Yellow coconuts, 12th fronds | 1.49 | 0.191 | 1.82 | 0.30 | 0.27 | 45 | 25 | | | | |
| Site 4 | Greener coconuts, 12th fronds | 1.56 | 0.136 | 0.87 | 0.46 | 0.18 | 110 | 33 | | | | |
| Site 7 | Coconuts, 4th fronds .... .... | 1.65 | 0.137 | 1.16 | 0.28 | 0.58 | 90 | 38 | 94 | 3.0 | 13.3 | 8.3 |
| Site 7 | Coconuts, 9th fronds .... .... | 1.23 | 0.110 | 0.75 | 0.42 | 0.73 | 65 | 51 | 90 | 2.6 | 10.5 | 11.5 |
| Site 8 | Coconuts, 1st fronds .... .... | 1.56 | 0.173 | 0.27 | 0.27 | 0.44 | 110 | 23 | 30 | 6.8 | 18.2 | 15.0 |
| Site 8 | Coconuts, 4th fronds .... .... | 1.66 | 0.133 | 0.24 | 0.35 | 0.56 | 115 | 36 | 42 | 2.5 | 16.4 | 13.5 |
| Site 8 | Coconuts, 9th fronds .... .... | 1.58 | 0.106 | 0.22 | 0.39 | 0.65 | 125 | 38 | 52 | 2.6 | 13.8 | 16.9 |
| Site 9 | Coconuts, 1st fronds .... .... | 1.50 | 0.183 | 1.46 | 0.32 | 0.55 | 160 | 34 | 44 | 4.4 | 12.9 | 14.7 |
| Site 9 | Coconuts, 4th fronds .... .... | 1.62 | 0.136 | 0.64 | 0.55 | 0.61 | 100 | 63 | 46 | 3.8 | 11.5 | 18.8 |

*Experimental Site* 2.

This site is located on a coastal plantation about 20 miles north of Lae. The palms are mature and have similar symptoms in every respect to those of the previous site. Several hundred acres are affected with the condition to a greater or less extent.

A small trial was laid down on 5th August, 1966. Forty palms were selected in two blocks of 20 palms each. Ten palms in each block received a 2 lb. application of sulphur.

Nut counts and foliage colour assessments were recorded and nuts from most palms were taken for quality testing and water analysis. All copra made from preliminary samples was rubbery to some extent.

A significant response in foliage colour was obtained within six months from application of sulphur. Within nine months a significant increase in nut numbers had been obtained, while copra quality had improved and there was good evidence of absorption of sulphur from the nut water sulphate estimations. *Table* 11 gives the field and chemical results from this trial.

*Table* 11.—Effect of Sulphur Treatments on Field and Chemical Characteristics, Site 2.

| | Foliage Assessment (Average points score per palm) | Nut Count (Average per palm) | Copra Quality (Average points score per palm) | Nut-Water Sulphate Content (p.p.m. S) |
|---|---|---|---|---|
| *Nil Treatment* | | | | |
| 5/8/66 | 2.8 | 10.4 | 1.6 | 3.5-5.5 |
| 6/2/67 | 3.1 | 10.1 | 1.4 | 2.0 |
| 18/4/67 | 2.7 | 11.3 | 1.1 | 1.3 |
| *Sulphur Treatment* | | | | |
| 5/8/66 | 3.1 | 9.6 | 1.6 | 3.5-5.5 |
| 6/2/67 | 4.4 | 12.5 | 1.6 | 2.0 |
| 18/4/67 | 4.8 | 18.1 | 2.0 | 5.0 |

Nut Water Potassium content, 54-62 m.e./litre (high).

*Experimental Site* 3.

This site is situated about 20 miles inland from Lae in a much lower rainfall area than Sites 1 and 2. The soil is an alkaline alluvial soil rich in bases. Many acres of palms are affected to some degree and a representative group is shown in *Plate* III. The palms have typical symptoms of sulphur deficiency, with the old dead fronds having a marked tendency to be retained, producing an umbrella-like effect.

Frond analysis, *Table* 10, showed low contents of sulphur and fairly normal contents of other nutrients, except nitrogen, which was low. Some of the palms had reached bearing age and the few coconuts which could be found were small in size and produced thin rubbery copra in the 'extremely rubbery category'. The sulphate content of a composite sample of coconut water was very low, being about 3.5 p.p.m.S. The potassium content was high (53 m.e./litre K).

A fertilizer trial with emphasis on sulphur applications was commenced in February, 1967, and early results confirm the sulphur deficiency at this site.

*Experimental Site* 4.

This site is of interest as it is located in a volanic area and is only a few miles from an active volcano containing extensive sulphur deposits and emitting gas with a high sulphur content. Several small areas of mature palms of varying ages are involved and they show severe symptoms of sulphur deficiency. *Leucaena leucocephala* and cocoa in the areas are also rather stunted and yellow. The soil is immature volcanic ash containing large reserves of nutrients and having excellent physical characteristics.

Copra from nuts taken from affected palms was found to be rubbery in nature, generally about Category 2. The sulphate content was 1.0 p.p.m.S.

Before trials were commenced, analysis of fronds were undertaken, samples being collected from affected and non-affected palms in the same area. The analyses are presented in *Table* 10. The major differences are in S content, but the contents of calcium and magnesium of chlorotic fronds are also lower than the green healthy frond contents.

There was little opportunity to carry out a comprehensive trial in this area as affected palms were scattered in small groups. A small number of palms were each treated with 1 lb. sulphur on 8th October, 1964, and a further 2 lb. on 7th April, 1966. The first application was sufficient to produce striking improvement in colour and yield as measured by nut content. *Table* 12 and *Figure* 5 shows that the average increase in yield was over 30 nuts per palm.

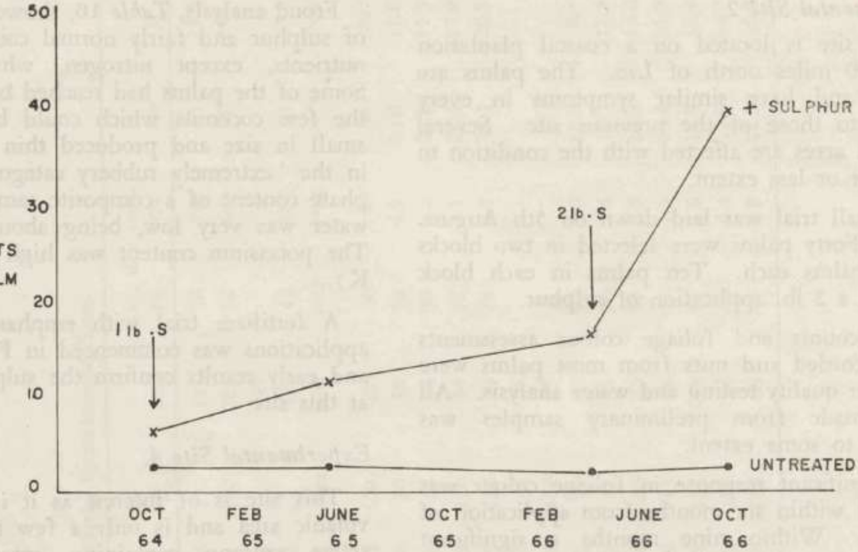


FIG. 5. EFFECT OF TREATMENT ON NUT COUNT, EXPERIMENTAL SITE 4.

*Table* 12.—Effect of Treatment on Nut Count, Site 4. (Nuts per palm.)

| | | 8.10.1964. | 11.5.1965. | 1.4.1966. | 20.9.1966. |
|---|---|---|---|---|---|
| Area A. | | | | | |
| Palm A1, | Treated | 6 | 20 | 16 | 20 |
| A2, | Treated | 3 | 9 | 41 | 40 |
| A3, | Treated | 0 | 4 | 26 | 35 |
| A4, | Treated | 0 | 0 | 13 | 39 |
| A5, | Treated | 8 | 19 | 18 | 47 |
| A6, | Treated | 24 | 31 | 30 | 54 |
| Area B. | | | | | |
| Palm B1, | Treated | 0 | 0 | 9 | 41 |
| B2, | Treated | 18 | 29 | 23 | 38 |
| B3, | Treated | 16 | 22 | 26 | 31 |
| B4, | Treated | 0 | 0 | 30 | 42 |
| B5, | Treated | 0 | 0 | 11 | 52 |
| B6, | Treated | 0 | 0 | 11 | 33 |
| Average— | | | | | |
| Treated | Palms | 6.2 | 11.2 | 16.2 | 39.4 |
| Area B. | | | | | |
| Palm C1, | Untreated | 10 | 8 | 6 | 6 |
| C2, | Untreated | 0 | 0 | 2 | 4 |
| C3, | Untreated | 0 | 0 | 0 | 0 |
| C4, | Untreated | 5 | 1 | 2 | 3 |
| C5, | Untreated | 0 | 8 | 2 | 2 |
| C6, | Untreated | 0 | 0 | 0 | 0 |
| Average— | | | | | |
| Untreated | Palms | 2.5 | 2.8 | 2.0 | 2.5 |

The yield increases and foliage colour improvement were also accompanied by an improvement in copra quality. All treated palms now produce normal copra, while the copra from the untreated sulphur deficient palms remains rubbery. The sulphate content of the nut waters of treated palms has a value over 30 p.p.m. while that from untreated palms has remained at about 1 p.p.m.S.

*Experimental Site* 5.

This area is at Kokopo, about five miles from the previous one, in similar deep pumice soil of good physical characteristics. Here the palms are believed to be over 80 years old. They would appear to have passed their normal productive life but as they had typical symptoms of sulphur deficiency, (in particular, yellowing, low nut count and a small number of upright fronds), it was decided to experiment with sulphur. The area was one where *Leucaena leucocephala* was very stunted in growth and responded immediately to sulphate of ammonia. Cocoa was below average but did not display deficiency symptoms.

Few nuts could be obtained from these trees but those that could were small and produced extremely thin, rubbery copra of Category 0.

A composite sample of coconut water showed a sulphate content of less than 1 p.p.m.S. The potassium content was extremely high (75-92 m.e./litre K).

A trial was commenced on 8th October, 1964. The palms selected were representative of a large area of old yellow palms. One pound of sulphur was applied to each of 12 palms (in two six-palm plots). Another 12 palms were left untreated.

The treatments gave a clear foliage response within six months of application of sulphur while nut count increases of about 20 nuts per palm were obtained after two years. It was considered that the original application of sulphur was too light, so a further application of 2 lb. per palm was made on 7th April, 1966.

The consistent increases in production of single palms are worth recording in detail (*Table* 13), while average increases are shown graphically in *Figure* 6. Despite the small size of the trial, the increases are highly significant.

The copra quality was slower to improve on this site and little improvement was noted after one year. After two years there was a vast improvement in quality in copra from treated

*Table* 13.—Effects of Sulphur on Nut Counts, Site 5. (Nuts per palm at various dates.)

| | 8.10.1964. | 11.5.1965. | 1.4.1966. | 20.9.1966. |
|---|---|---|---|---|
| Area 1. Palm A1, Treated | 5 | 25 | 27 | 27 |
| A2, Treated | 1 | 21 | 20 | 34 |
| A3, Treated | 0 | 4 | 15 | 21 |
| A4, Treated | 2 | 5 | 8 | 21 |
| A5, Treated | 0 | 0 | 3 | 12 |
| A6, Treated | 0 | 0 | 1 | 3 |
| Palm B1, Untreated | 9 | 14 | 4 | 0 |
| B2, Untreated | 8 | 3 | 0 | 1 |
| B3, Untreated | 0 | 0 | 0 | 0 |
| B4, Untreated | 2 | 0 | 1 | 7 |
| B5, Untreated | 0 | 3 | 2 | 7 |
| B6, Untreated | 0 | 0 | 0 | 0 |
| Area 2. Palm C1, Treated | 0 | 0 | 14 | 17 |
| C2, Treated | 8 | 0 | 0 | 25 |
| C3, Treated | 0 | 8 | 9 | 32 |
| C4, Treated | 9 | 16 | 35 | 38 |
| C5, Treated | 9 | 21 | 19 | 23 |
| C6, Treated | 12 | 28 | 21 | 21 |
| D1, Untreated | 1 | 9 | 7 | 5 |
| D2, Untreated | 9 | 14 | 8 | 14 |
| D3, Untreated | 3 | 0 | 0 | 0 |
| D4, Untreated | 3 | 12 | 4 | 11 |
| D5, Untreated | 1 | 0 | 0 | 0 |
| D6, Untreated | 5 | 6 | 0 | 2 |
| Average, Treated palms | 3.8 | 10.7 | 14.3 | 22.8 |
| Average, Untreated palms | 3.4 | 5.1 | 2.2 | 3.9 |

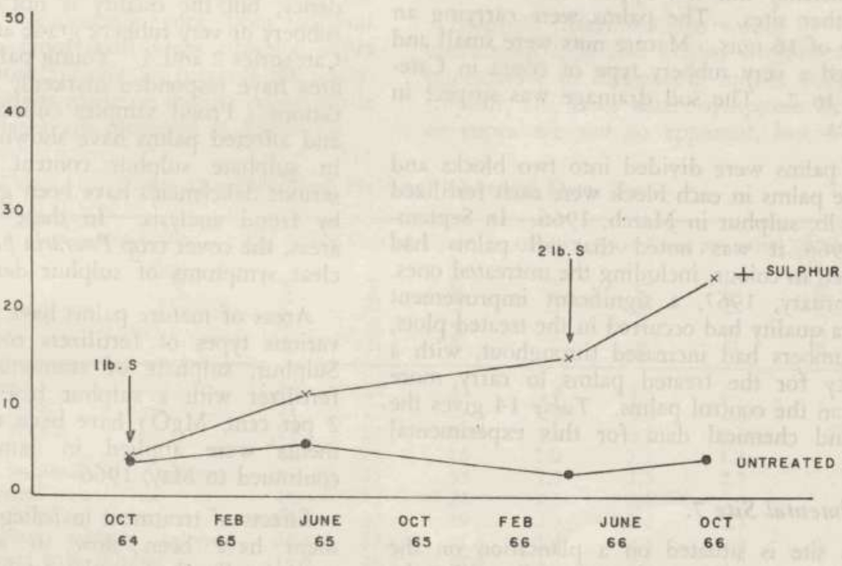


FIG. 6. EFFECT OF TREATMENT ON NUT COUNT, EXPERIMENTAL SITE 5

palms, while nut water sulphate contents had increased in the treated palms to an average figure of 20 p.p.m. There is no doubt that on areas such as this, old palms can be rejuvenated by dressings of sulphur and that economic yield responses can be obtained Most plantation areas in Papua and New Guinea have not reached the age of these palms but it is likely that with the knowledge that widespread sulphur deficiency occurs, the economic life of many palms may be prolonged.

Near this area old palms are being replaced by new plantings and early results show that the seedlings will respond to sulphur applications, although nitrogen deficiency also occurs.

### *Experimental Site* 6.

Rubbery copra is prevalent in some areas of the Bainings District of New Britain. There are extensive areas of chlorotic palms and some of these were examined and sampled by Baseden in his original investigations. Site 6 is representative of areas of poor palms in this district. Typical symptoms of sulphur deficiency were in evidence, while leucaena was difficult to establish and responded well to sulphate of ammonia applications. An area of about 40 mature palms was selected. These palms were generally yellow but deficiency did not appear as severe as on most other sites. The palms were carrying an average of 16 nuts. Mature nuts were small and produced a very rubbery type of copra in Category 1 to 2. The soil drainage was suspect in this area.

The palms were divided into two blocks and half the palms in each block were each fertilized with 3 lb. sulphur in March, 1966. In September, 1966, it was noted that all palms had improved in colour, including the untreated ones. By February, 1967, a significant improvement in copra quality had occurred in the treated plots. Nut numbers had increased throughout, with a tendency for the treated palms to carry more nuts than the control palms. *Table* 14 gives the field and chemical data for this experimental site.

*Table* 14.—Effect of Treatment on Nut Count, Copra Quality and Nut Water Sulphate Content, Site 6.

| | NUT COUNT (Average Nuts/ palm) | COPRA QUALITY (Average points score per palm) | NUT WATER SULPHATE CONTENT (p.p.m. S) |
|---|---|---|---|
| *Nil Treatment* | | | |
| March, 1966 | 18.3 | 1.5 | 2.5 p.p.m. |
| September, 1966 | 20.6 | 1.6 | |
| February, 1967 | 28.9 | 1.6 | 1.0 p.p.m. |
| *Sulphur Treatment* | | | |
| March, 1966 | 15.1 | 1.5 | 2.5 p.p.m. |
| September, 1966 | 21.4 | 1.3 | |
| February, 1967 | 30.3 | 2.9 | 15.3 p.p.m. |

Nut water potassium content was 55-76 m.e./litre K (high).

### *Experimental Site* 7.

This site is situated on a plantation on the coast about 50 miles north west of Port Moresby in Papua. Although only a small area of less than 100 acres in involved, it is likely that many such sulphur deficient areas exist on Papuan coastal plantations. The soils are alluvial and sometimes subject to impeded drainage. The climate is quite different to the areas previously described, having distinct wet and dry seasons and average annual rainfall of about 45 inches.

The mature palms show fairly typical symptoms of sulphur deficiency but are not as severely affected as in many other areas. The copra produced from the palms shows a rubbery tendency, but the quality is not in the extremely rubbery or very rubbery grade and varies between Categories 2 and 4. Young palms in an adjacent area have responded markedly to sulphur applications. Frond samples collected from healthy and affected palms have shown large differences in sulphate sulphur content while no other serious deficiencies have been generally indicated by frond analysis. In these sulphur deficient areas, the cover crop *Pueraria phaseoloides* shows clear symptoms of sulphur deficiency.

Areas of mature palms have been treated with various types of fertilizers containing sulphur. Sulphur, sulphate of ammonia and compound fertilizer with a sulphur base (12 : 12 : 17 : 2 per cent. MgO) have been used. First treatments were applied in January, 1966, and continued to May, 1966.

Effects of treatment in foliage colour improvement have been slow to appear. This is undoubtedly due to the prolonged dry season from April to November, 1966, when only 7.4

in. of rain were recorded. Elemental sulphur applied in March, 1966, was still quite visible in January, 1967, which marked the beginning of the wet season. Little oxidation had thus occurred and soil moisture content was low enough to limit uptake of nutrients, even when applied as soluble fertilizers.

By April, 1967, all treatments containing sulphur had produced a distinct improvement in foliage, nut count and copra quality, while uptake as determined by nut water sulphate content was considerable. *Table* 15 lists the details of the various experiments at this site and the observations and analyses made.

### *Experimental Sites 8 and 9.*

These sites consist of two small areas on adjacent plantations at Cape Rodney, about 100 miles south east of Port Moresby. Both areas show typical symptoms of sulphur deficiency but the situation is more complex than in areas previously described, as a serious potassium deficiency is also operating, characterized by pronounced bronzing of leaves and very poor uptake as measured by chemical analysis.

No experiments have yet been carried out on these two areas. Mature and young palms are involved. Analyses of nut waters show low sulphate contents and frond samples from the young palms demonstrate very poor sulphur uptake. Nuts from both areas produce copra of rubbery nature. *Table* 16 presents the analysis and observations made on mature palms while the frond analyses are included in *Table* 10.

*Table* 16.—**Analysis of Coconut Waters, Sites 8 and 9.**

| — | Copra Quality. | K (m.e./litre). | $So_4S$ (p.p.m.). |
|---|---|---|---|
| Site 8, sulphur deficient | Rubbery | 5.7 | 1.0 |
| Site 8, healthy, adjacent | Normal | 9.9 | 23.3 |
| Site 9, sulphur deficient | Rubbery | 24.3 | 2.0 |

## THE DIAGNOSIS OF SULPHUR DEFICIENCY BY COCONUT WATER ANALYSES AND QUALITY TESTING OF COPRA.

It is clear that the sulphate content of coconut water collected from the various sites bears a strong relationship to the absence or presence of field symptoms and to the quality of the copra produced. These methods are therefore important aids to diagnosis of sulphur deficiency and could be used to locate sulphur deficient areas in the Territory. Thus any plantation producing significant amounts of rubbery copra should be investigated. While it is not certain that this abnormal copra is only produced by sulphur deficient palms, certainly it was so for the nine experimental sites chosen.

Sulphate determinations would be valuable in confirming field and quality diagnoses but more importantly in diagnosing milder deficiencies of sulphur, i.e., cases where symptoms in the palms or copra are not so apparent, but where yield

*Table* 15.—**Details of Field and Chemical Data, Site 7.**

| Trial | Treatment | Nut Count, nuts per palm | | | Quality, Point Score per palm | | | Sulphate Content, p.p.m.S | |
|---|---|---|---|---|---|---|---|---|---|
| | | 19.5.1966 | 20.1.1967 | 27.4.1967 | 19.5.1966 | 29.1.1967 | 27.4.1967 | 19.5.1966 | 20.1.1967 |
| A | Control .... .... .... | 23 | 24 | 33 | 2.8 | 2.4 | 2.7 | | 4.5 |
| | + NPK .... .... | 21 | 27 | 24 | 2.2 | 2.0 | 2.3 | | 3.5 |
| | + NPKS .... .... | 12 | 26 | 39 | 1.9 | 3.0 | 3.0 | | 6.5 |
| B | Control .... .... .... | 16 | 25 | 26 | 2.0 | 2.2 | 1.8 | | 4.5 |
| | + Sulphate of Ammonia | 15 | 21 | 34 | 2.5 | 2.5 | 2.7 | | 6.0 |
| C | Control .... .... .... | 11 | 17 | 20 | 2.7 | 2.7 | 2.5 | | 1.5 |
| | + Sulphur .... .... | 16 | 32 | 39 | 2.5 | 2.3 | 2.5 | | 7.5 |
| Average, treatments without sulphur | | 19.0 | 27.1 | 31.8 | 2.4 | 2.3 | 2.3 | 2 | 3.5 |
| Average, treatments with sulphur .... | | 14.5 | 26.7 | 37.4 | 2.3 | 2.6 | 2.7 | 2 | 6.7 |

Potassium Content of Nut Waters 58-90 m.e.K/litre (high)

*Table* 17.—Sulphate Contents of Coconut Waters, Deficient and Non-deficient Areas.

| Location. | Deficiency Symptoms. | Copra Quality. | S.p.p.m. |
|---|---|---|---|
| Site 1 | Present | Rubbery | 1.0—8.0 |
| Site 1 | Not Present (Treated) | Slightly rubbery to normal | 13-58 |
| Site 2 | Present | Rubbery | 3.5 |
| Site 2 | Present | Slightly rubbery | 3.5—5.5 |
| Site 3 | Present | Very rubbery | 1.0 |
| Site 4 | Present | Rubbery | 1.0 |
| Site 4 | Not Present (Treated) | Normal | 30 |
| Site 5 | Present | Very Rubbery | 1.0 |
| Site 5 | Not Present (Treated) | Normal | 19.8 |
| Site 6 | Present | Rubbery | 1.0—3.0 |
| Site 6 | Not Present (Treated) | Slightly Rubbery | 15.3 |
| Site 7 | Present | Slightly Rubbery | 1.0—5.5 |
| Site 8 | Present | Rubbery | 7.0 |
| Site 8 | Not Present | Normal | 23 |
| Site 9 | Present | Rubbery | 2.0 |
| Bainings | Not Present | Normal | 80-100 |
| New Britain | Not Present | Not Reported | 70-100 |
| New Ireland | Not Present | Not Reported | 70-80 |
| Papua | Not Present | Normal | 44-100 |
| Bougainville | Not Present | Not Reported | 50 |
| New Britain (South) | Not Present | Not Reported | 35-80 |
| Markham Valley | Not Present | Normal | 60 |

may be affected. *Table* 17 presents the sulphate contents of coconut waters from all the experimental sites chosen and also from a number of healthy areas producing normal copra. There are marked differences in the sulphate content between deficient and non-deficient areas.

To summarize, symptoms of sulphur deficiency and presence of rubbery copra are mainly associated with sulphate contents of less than 10 p.p.m.S. There have been no indications of palm or copra symptoms above 20 p.p.m.S. and generally these palms are producing well.

It appears likely that in the intermediate range, i.e., 10 to 20 p.p.m., mild sulphur deficiency could occur and yields may be affected. These levels will provide a good working basis for chemical diagnosis of sulphur deficiency in mature palms and it should be possible, with further experimental trials and chemical analyses, to increase the precision of diagnosis.

### *Diagnosis of Sulphur Deficiency in Young Palms.*

The sulphate sulphur content of the fronds of young palms can be used as a criterion for diagnosis of sulphur deficiency. The method could probably be extended to tall mature palms but the coconut water method is more convenient.

Samples of fronds have been obtained from young palms in areas where sulphur deficiency has been established by responses to sulphur in either mature or young palms. Various frond positions have been used, depending on the age of the palms. Sampling is carried out by selecting six leaflets from the mid portion of the fronds and discarding the midribs.

There are large differences between the sulphate sulphur contents of deficient and non-deficient palms. It is also clear that frond position has a large effect on sulphate content, the contents in the younger fronds being higher under both deficient and non-deficient conditions. *Table* 18 shows the sulphate contents of fronds from various coconut experimental areas.

Critical levels of 200 and 150 p.p.m. sulphate sulphur respectively are suggested for young (1st to 4th) and older (9th to 14th) fronds.

## GENERAL DISCUSSION.

It has been shown that sulphur deficiency exists in all of the nine areas of chlorotic palms. It is known that a large number of other areas of coconuts, which show similar symptoms, exist in Papua and New Guinea. The wide occurrence of defective nuts producing rubbery copra gives support to the view that sulphur deficiency

*Table* 18.—**Foliar Sulphate Contents (p.p.m.S) of Deficient and Non-deficient Palms, various areas.**

| Location | Age | Deficiency | 1st Fronds | 4th Fronds | 9th Fronds | 14th Fronds |
|---|---|---|---|---|---|---|
| Site 1 .... .... .... | Mature .... .... | Severe .... .... | | 80 | 65 | |
| Site 3 .... .... .... | Mature .... .... | Severe .... .... | | | 120 | 130 |
| Site 4 .... .... .... | Mature .... .... | Severe .... .... | | | | 45 |
| Site 4 .... .... .... | Mature .... .... | Slight .... .... .... | | | | 110 |
| Site 7 .... . .... .... | Young .... .... | Severe, nil treatment .... | 70-190 | 40-180 | | |
| Site 7 .... .... .... | Young .... .... | Severe, N treatment .... | 80-130 | 90-120 | | |
| Site 7 .... .... .... | Young .... .... | Nil, S treatment .... | 220-640 | 240-290 | | |
| Site 7 .... .... .... | Young .... .... | Nil, NS treatment .... | 240-750 | 230-420 | | |
| Site 7 .... .... .... | Mature .... .... | Severe, untreated .... | | 90 | 65 | |
| Site 7 .... .... .... | Mature .... .... | Slight, untreated .... | | 170 | 100 | |
| Site 7 .... .... .... | Mature .... .... | No deficiency .... .... | | 455 | 380 | |
| Site 8 .... .... .... | Young .... .... | Severe .... .... | 110 | 115 | 125 | |
| Site 8 .... .... .... | Mature .... .... | No deficiency .... .... | | | 160-230 | 180-230 |
| Site 9 .... .... .... | Young .... .... | Severe .... .... | 160 | 100 | | |
| Papua .... .... .... | Young .... .... | No deficiency .... .... | 30-170 | 460-640 | 270-560 | |
| Finschhafen .... .... | Mature .... .... | No deficiency .... .... | | 240-330 | 160-220 | |
| Kokopo .... .... .... | Young .... .... | Severe, nil treatment .... | | | | |
| Kokopo .... .... .... | Young .... .... | Severe, N treatment .... | 50-160 | | | |
| Kokopo .... .... .... | Young .... .... | Nil, S treatment .... | 370-750 | | | |
| Kokopo .... .... .... | Young .... .... | Nil, NS treatment .... | 200-420 | | | |
| Lae .... .... .... | Mature .... .... | Slight .... .... .... | | | 150 | 130 |
| Range of Values .... .... .... .... .... | | Severe .... .... | 70-190 | 40-180 | 65-125 | 45-130 |
| Range of Values .... .... .... .... .... | | Slight .... .... .... | | 170 | 100-150 | 130 |
| Range of Values .... .... .... .... .... | | No deficiency .... .... | 220-750 | 230-420 | 160-560 | 180-230 |

is a major limiting factor to the high production of good quality copra in this Territory. It is of consequence also to note that many cases of sulphur deficiency have occurred in other crops throughout Papua and New Guinea. Coffee, tea, tobacco and legumes have been affected both in lowland and highland areas.

New Guinea has a wide variety of soil types derived from volcanic and sedimentary rocks; they vary from deep mature tropical latosols to immature volcanic and alluvial soils. Sulphur deficiency has been found to exist in most types, but perhaps more frequently on the younger soils. The reasons for the widespread occurrence of this deficiency are thus more likely to be ecological than pedological. Some contributing factors are likely to be :—

(*a*) The extremely high rainfall and heavy leaching in most areas.

(*b*) The practice of burning grassland and forests periodically. Much sulphur would be converted to gas and lost to the atmosphere and subsequently the sea.

(*c*) The lack of industrialization, contributing sulphur in waste gases.

(*d*) Only small use of fertilizers until recent years. There is now wider use of fertilizers, but many, such as urea and a large range of compound fertilizers, do not contain sulphur. It has been observed that use of fertilizers containing nitrogen but no sulphur will induce or aggravate sulphur deficiencies in most tropical crops.

(*e*) The competition of other plants having an affect on sulphur availability. Kunai grass (*Imperata* sp.) competition is often associated with sulphur deficiency. The wide practice in Papua and New Guinea of interplanting coconuts with cocoa would increase sulphur requirement.

An interesting feature of some of the experimental work has been the apparent seasonal change in the severity of the condition. This has been observed in foliage improvement and also in quality improvement of the copra. Such changes are consistent with changes in the availability of sulphur, which could occur as a result of very dry or very wet periods. On one occasion, at least, the improvement of palms in New Britain coincided with a volcanic eruption in Bougainville and it is believed that sulphur rich dust carried by the prevailing winds temporarily alleviated the condition.

Plantation managers who have been fertilizing their interplanted cocoa with sulphate of ammonia have observed an improvement in the condition of coconuts and a decrease in the amount of rubbery copra produced. It is also worthy of note that for years some big companies have been carrying out a policy of fertilizing coconut palms with ferrous sulphate. This procedure was considered to produce beneficial results but it now appears likely that any response obtained was probably due to the sulphur content of the ferrous sulphate and that a much more economic treatment would be elemental sulphur.

It is likely that sulphur deficiency exists in many plantation areas in Papua and New Guinea and that extensive use of sulphur is warranted. Large increases in production have been obtained on individual areas and quality improvement is an added benefit. The identification of sulphur deficient areas is possible by using field and chemical diagnosis and surveys should be undertaken to determine the areas affected. The records held by the Department of Agriculture, Stock and Fisheries on the incidence of rubbery copra on individual plantations will prove valuable in these surveys.

The author is of the opinion that sulphur might be the forgotten essential nutrient as far as coconuts are concerned. While more developed copra producing countries like Ceylon, India and the Philippines have probably been using sulphur containing fertilizers for many years and may therefore not encounter deficiency problems, there must be many other areas, particularly Indonesia and the Pacific Islands, where sulphur deficiency may be occurring, perhaps causing some undiagnosed growth or production problem.

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# SULPHUR DEFICIENCY IN COCONUTS, A WIDESPREAD FIELD CONDITION IN PAPUA AND NEW GUINEA.

## PART II : THE EFFECT OF SULPHUR DEFICIENCY ON COPRA QUALITY.

P. J. SOUTHERN.*


### ABSTRACT.

*Sulphur deficiency causes coconut palms to produce defective 'rubbery' copra which has poor physical and chemical qualities. The copra has a low oil content, high moisture absorbing properties, high sugar, ash and nitrogen contents. The oil extracted contains high amounts of unsaturated fatty acids causing high iodine values and low saponification values. It is shown that this is probably due to the high proportion of testa to kernel.*

*Rubbery copra contains lower amounts of sulphate than normal copra and can be improved in quality by ameliorating the sulphur deficiency. At present it forms a significant proportion of the copra production of Papua and New Guinea.*


References have been made in the preceding paper (Southern 1967) to the occurrence in Papua and New Guinea of abnormal copra, locally termed 'rubbery copra'. There are few reports of such material being found in manufactured copra in other coconut growing countries.

Cooke (1937) described the properties of rubbery copra as found in Malaya, as follows :—

"Defective nuts produce rubbery copra, the copra obtained from such nuts, even if ripe, being heavily wrinkled, yellow, distorted and plastic after drying under the best conditions possible, and such copra is particularly liable to deteriorate. Copra from defective nuts can be distinguished from copra of similar texture which is obtained from unripe nuts because the testa or brown skin of such copra is thick, dark brown and adhering. Copra from unripe nuts presents a bald appearance as much of the skin is retained by the shell.

"In certain districts of Malaya, there is a pronounced tendency for nuts to be defective which, coupled with unfavourable climatic conditions, seems to explain the particular difficulty of producing good copra in Malaya. The physiological aspect of the problem, which is very complex, is under investigation by the Soils Chemist."

* Senior Chemist, Department of Agriculture, Stock and Fisheries, Port Moresby.

Cooke also describes the chemical and physical properties of rubbery copra :—

"While the moisture content of the wet, raw meat from defective nuts is exceptionally high, the oil content (wet basis) is exceptionally low. Nevertheless, when the large amount of contained moisture is evaporated, the average oil content (dry basis) of the resulting rubbery copra is normal, i.e., the average oil —tissue ratio is not abnormal.

"Individual pieces of rubbery copra, however show wide variations as regards oil content and the following may be quoted as typical :—

58.0, 62.1, 63.8, 66.2, 67.4, 69.4, 69.6 per cent.

Average oil content (dry basis) ;—65.46 per cent.

"Since the average oil content is normal, it might appear surprising that the oil millers should regard rubberiness as one of the worst defects of copra on the grounds that rubbery copra gives a poorer yield of oil. The reason is that such copra does not break up easily, but gives a coarse meal which is elastic, which does not part with its oil readily and which, moreover, being spongy, can reabsorb oil when the pressure is removed. A further serious objection to such copra is that it will jam the conveying machinery and clog the silos and hoppers."

Dwyer (1937) reported the presence in the Bismarck Archipelago of defective coconuts showing a thin, leathery, soft kernel, which did not dry out properly when dried in the normal manner. The resultant copra was described as soft, flexible and leathery, often becoming brown

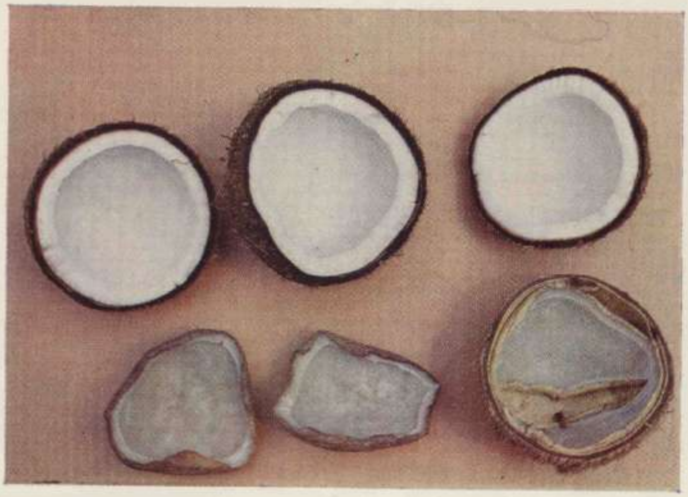

*Plate* I.—Rubbery copra produced from apparently normal nuts from sulphur deficient palms.


*Plate* II.—Pieces of copra showing varying degrees of rubberiness and being typical of the categories selected.


*Plate* III.—The improvement in copra quality following treatment of palms with sulphur.

in colour, and being of poor appearance and quality. Dwyer also considered the occurrence as having a nutritional or physiological cause.

There is no doubt that in this Territory, copra of rubbery quality, similar to that described by Cooke and Dwyer, is found throughout all major copra producing areas. Unpublished data by Murty (1958) showed that an estimated 2,000 tons of copra containing an admixture of rubbery material passed through inspection centres from July, 1957, to June, 1958. This was over two per cent. of the total production. Over 100 plantations had reports of rubbery copra occurring in their shipments. When it is considered that much of the rubbery copra produced is hand sorted on plantations and is not included in copra prepared for export, it is likely that this defective copra represents a significant proportion of the total production.

It has now been shown that rubbery copra is produced by coconut palms affected by sulphur deficiency and that copra quality can be improved by treating affected palms with sulphur (Southern 1967). Some of the effects of sulphur deficiency on the physical and chemical characteristics of copra are outlined in this paper.

## THE PHYSICAL NATURE OF RUBBERY COPRA.

Fresh coconut meat from sulphur deficient palms cannot be distinguished from that obtained from healthy palms. The meat often has a rather wrinkled inside surface but this abnormality is also found in nuts from potassium deficient palms and even in some nuts from apparently healthy and productive palms. The nuts themselves are generally small in size while they may be any shape.

All the nuts examined in these investigations had the appearance of fully mature nuts ; in fact the embryo had commenced to develop in many cases. They were all collected on the ground and husks were well dried out. There was therefore no possibility that the rubbery copra obtained was due to nut immaturity, which can produce a thin type of leathery copra. *Plate* I shows that the affected nuts have normal meat thickness. However, when they are dried the meat collapses into thin, rubbery or leathery copra, often darker in colour than usual. The copra frequently splits and becomes distorted in shape. In severe cases the testa becomes very wrinkled. The coloured photograph clearly shows the type of copra produced from apparently normal nuts.

The loss in weight on drying is much more than in normal manufacture, a property also observed by Cooke. From tests carried out on copra from an experimental site it was found that 100 lb. of coconut meat from sulphur deficient palms would produce only about 38 lb. of rubbery copra, compared to the production of about 58 lb. of normal copra from non-deficient palms.

Tests have also shown that different drying techniques have little or no influence on the nature and quality of the final product. Thus halves of the same nut dried in the oven or the refrigerator produced copra of similar characteristics.

In the usual hot humid atmosphere of the tropics, this defective copra will absorb moisture rapidly and its physical characteristics become more obvious. It becomes flexible and almost elastic, giving rise to the term 'rubbery copra'. It is these adverse physical properties which cause milling and extraction problems. The texture of this copra, its distorted and cracked shape and its generally thinner nature enable it to be readily differentiated from normal copra.

## THE CHEMICAL CHARACTERISTICS OF RUBBERY COPRA.

To examine the chemical properties of various degrees of rubbery copra, representative samples of rubbery and normal copra were selected from a large amount of copra collected from the Experimental Site 1 described in the previous paper. These were placed in five categories as follows :—

Category 0 .... Extremely Rubbery.
Category 1 .... Very Rubbery.
Category 2 .... Rubbery.
Category 3 .... Slightly Rubbery.
Category 4 .... Normal.

Typical pieces of copra in each of these categories are shown in *Plate* 2. The grades are mainly distinguished by thickness and texture and differences are not clearly brought out by the illustration.

All copra was dried at 50° to 60°C in a forced draft hot air oven. Prior to this samples were washed thoroughly to remove traces of coconut water from the surface of the meat.

Following rapid comminution in a blendor, determinations were made of moisture, oil content, total sugars, nitrogen, sulphur and ash. The results of these analyses are shown in *Table* 1.

Some more detailed comments on the determination and results are as follows :—

(*a*) *Moisture Content.*

The dried ground samples were left for a short time exposed to a humid atmosphere before any determinations were carried out. Moisture determinations showed that rubbery copra had a greater tendency to absorb moisture than normal copra. This is a well known property of rubbery copra and has been remarked upon by Cooke. It has been generally observed in these investigations that fungus and bacterial growth would form on the surface of pieces of rubbery copra long before normal pieces of copra were affected. This is a serious disadvantage in that shipments of copra containing rubbery material would deteriorate much faster than those of normal copra.

The affinity for moisture of rubbery copra may be due to the higher content of nonfatty material, in particular the higher content of minerals.

(*b*) *Oil Content.*

The oil was determined by extracting five grams of ground material with petroleum ether in a soxhlet extraction unit. The material was reground three times in a stainless steel mill until the total oil content was almost constant. Less than 0.3 per cent. oil was recovered in the final grinding and extraction.

The oil content of pieces of rubbery copra is very much less than that of normal copra and *Table* 1 shows that the oil content is well correlated with the degree of rubberiness. Other samples of rubbery copra have invariably given low oil contents, as *Table* 2 shows. These results were the analyses of a number of nuts rather than single nuts.

*Table* 2.—Oil Contents of Copra, Rubbery and Non-Rubbery.

| Location. | Category. | Description. | Oil Content (Per Cent. Dry Basis). |
|---|---|---|---|
| Site 4 .... | 2 | Rubbery .... | 53.6 |
| Site 5 (*a*) | 0 | Extremely Rubbery | 39.1 |
| Site 5 (*b*) | 0 | Extremely Rubbery | 41.6 |
| Site 6 (*a*) | 1 | Very Rubbery | 47.8 |
| Site 6 (*b*) | 1 | Very Rubbery | 46.6 |
| Site 6 (*c*) | 1 | Very Rubbery | 51.7 |
| Site 6 (*d*) | 1 | Very Rubbery | 42.8 |
| Site 7 .... | 1 | Very Rubbery | 47.7 |
| Site 7 .... | 2 | Rubbery .... | 56.5 |
| Site 7 .... | 3 | Slightly Rubbery | 61.8 |
| Kokopo | 1 | Very Rubbery | 47.5 |

*Figure* 1 shows that the oil contents obtained correlate well with the categories of quality determined by visual and physical examination. The diagram is a summary of results presented in *Tables* 1 and 2.

While Cooke (1937) considered that Malayan 'rubbery copra' had a fairly normal oil content (expressed on a dry basis), it is evident that the Papua and New Guinea material has a very low oil content. Shipments which contain significant proportions of rubbery copra are therefore likely to have a lower oil content than usual. Moreover, the difficulty in extracting oil from rubbery pieces because of their adverse physical nature would make rubbery copra, with its lower oil content, even more unattractive to coconut oil manufacturers.

*Table* 1.—Analysis of Various Grades of Rubbery Copra.

| Category. | Description. | Moisture Per Cent. | Oil Per Cent Dry Basis | Total Sugars Per Cent Dry Basis | Ash Per Cent. Dry Basis. | Nitrogen Per Cent. Dry Basis. | Sulphate p.p.m.S Dry Basis. |
|---|---|---|---|---|---|---|---|
| 0 | Extremely Rubbery .... | 4.8 | 38.4 | 29.5 | 4.0 | 2.52 | 31 |
| 1 | Very Rubbery .... .... | 4.8 | 47.0 | 32.4 | 3.2 | 1.95 | 37 |
| 2 | Rubbery .... .... .... | 4.3 | 51.6 | 32.9 | 2.8 | 1.65 | 22 |
| 3 | Slightly Rubbery .... .... | 2.5 | 64.4 | 20.0 | 2.5 | 1.32 | 107 |
| 4 | Normal .... .... .... | 2.4 | 64.9 | 21.5 | 2.3 | 1.19 | 141 |

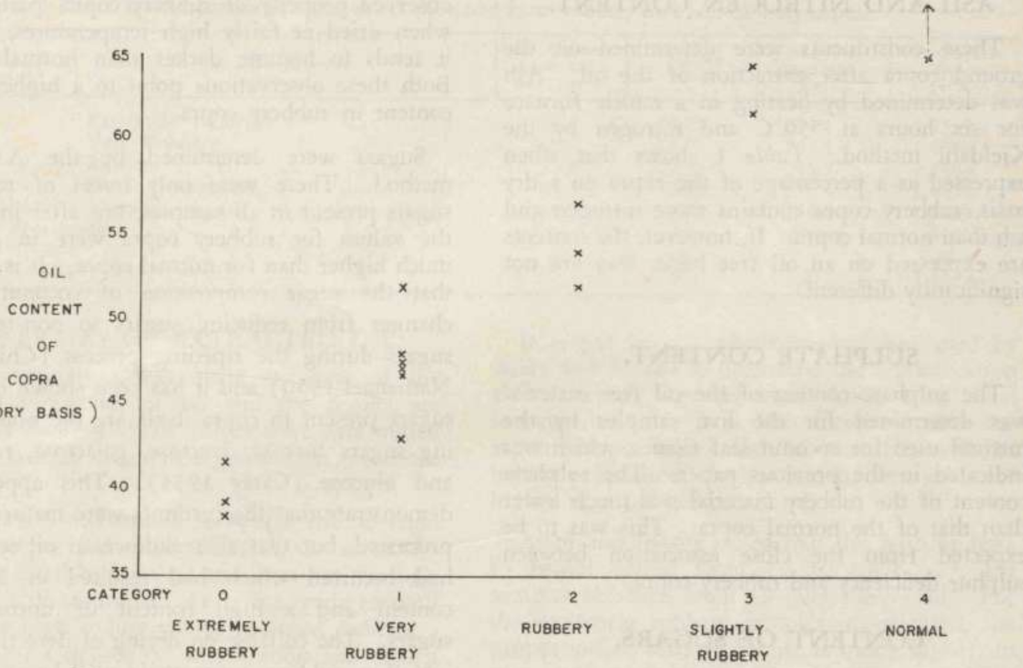


FIG I. OIL CONTENT OF COPRA, VARIOUS CATEGORIES.

It has been shown in the previous paper how copra quality can be improved by the use of sulphur or sulphate fertilizers. An outstanding example of the improvement gained is shown in *Plate* III. Two years after application of 2 lb. sulphur the quality improved from Category 0 (extremely rubbery) to Category 4 (Normal). This example occurred at Kokopo on Experimental Site 5. The oil content of samples increased from 40 per cent. to 65 per cent. on a dry basis.

In Experimental Site 1, oil contents of copra samples were determined at frequent intervals during the course of the fertilizer trial. With the improvement in copra quality it would be expected that the oil content of the copra would increase for the sulphur treated palms and this is strikingly shown in *Table* 3 and *Figure* 2.

It is surprising to note that significant increases in oil content were obtained six months following treatment with sulphate fertilizers. The action of elemental sulphur was slower than that of the soluble sulphate fertilizers although the end result was the same. The increase in oil content is thus associated with quality improvement, foliage colour improvement, frond increases and sulphate content as shown in the previous paper.

*Table* 3.—**Effect of treatment on oil content of Copra, Site 1. (Per cent. oil on dry basis.)**

| Sampling. | Date. | Nil Treatment. | Sulphur. | Sulphate of Ammonia. | Sulphate of Potash. |
|---|---|---|---|---|---|
| 1 | 19.7.1965 | 43.7 | 46.8 | 45.4 | 48.7 |
| 2 | 11.10.1965 | 41.4 | 46.8 | 51.1 | 49.9 |
| 3 | 10.1.1966 | 46.6 | 54.4 | 59.4 | 57.2 |
| 4 | 16.2.1966 | 48.9 | 53.7 | 64.0 | 64.8 |
| 5 | 28.2.1966 | 51.0 | 59.9 | 62.6 | 63.0 |
| 6 | 14.3.1966 | 54.3 | 61.0 | 64.3 | 62.7 |
| 7 | 28.3.1966 | 53.3 | 64.4 | 65.2 | 65.2 |
| 8 | 18.4.1966 | 48.8 | 62.1 | 63.8 | 64.5 |
| 9 | 2.5.1966 | 49.5 | 62.9 | 65.3 | 66.7 |
| 10 | 3.6.1966 | 53.0 | 63.3 | 64.7 | 63.8 |
| 11 | 24.6.1966 | 47.4 | 62.8 | 64.3 | 63.6 |
| 12 | 5.7.1966 | 46.7 | 60.4 | 61.5 | 60.6 |

## ASH AND NITROGEN CONTENT.

These constituents were determined on the ground copra after extraction of the oil. Ash was determined by heating in a muffle furnace for six hours at 550°C and nitrogen by the Kjeldahl method. *Table* 1 shows that when expressed as a percentage of the copra on a dry basis, rubbery copra contains more nitrogen and ash than normal copra. If, however, the contents are expressed on an oil free basis, they are not significantly different.

## SULPHATE CONTENT.

The sulphate content of the oil free material was determined for the five samples by the method used for coconut leaf tissues, which was indicated in the previous paper. The sulphate content of the rubbery material was much lower than that of the normal copra. This was to be expected from the close association between sulphur deficiency and rubbery copra.

## CONTENT OF SUGARS.

It has been observed that defective nuts, either as green meat or as the dried rubbery copra, are noticeably sweeter to the taste. Another observed property of rubbery copra, particularly when dried at fairly high temperatures, is that it tends to become darker than normal copra. Both these observations point to a higher sugar content in rubbery copra.

Sugars were determined by the A.O.A.C. method. There were only traces of reducing sugars present in all samples, but after inversion the values for rubbery copra were in general much higher than for normal copra. It is known that the sugar composition of coconut water changes from reducing sugars to non-reducing sugars during the ripening process (Child and Nathanael 1950) and it has been shown that the sugars present in copra itself are the non-reducing sugars sucrose, fructose, galactose, raffinose and glucose (Caray 1934). This appears to demonstrate that the coconuts were mature when processed, but that a breakdown in oil synthesis had occurred which had resulted in low oil content and a high content of unconverted sugars. The collapse on drying of defective nuts into thin, rubbery copra could well be attributed to the fact that the cells did not contain their normal quota of oil.


FIG.2. EFFECT OF TREATMENT ON OIL CONTENT OF COPRA , EXPERIMENTAL SITE I.

*Table* 4.—Properties of coconut oil extracted from rubbery and non-rubbery copra.

| Category. | Description. | Oil Content (per cent. dry basis). | Iodine Value. | Saponification Value. | Refractive Index (40°C). |
|---|---|---|---|---|---|
| 0 | Extremely rubbery .... .... | 38.4 | 20.25 | 234.1 | 1.4519 |
| 1 | Very Rubbery .... .... | 47.0 | 14.77 | 243.1 | 1.4508 |
| 2 | Rubbery .... .... .... .... | 51.6 | 12.63 | 245.7 | 1.4504 |
| 3 | Slightly Rubbery .... .... .... | 64.4 | 9.03 | 258.4 | 1.4490 |
| 4 | Normal .... .... .... .... | 64.9 | 7.40 | 264.6 | 1.4489 |
| Required Specification .... .... .... .... .... Range, B.S. 628 (1950) .... .... .... .... | | | 7.0 to 9.5 | Above 255 | 1.4485 to 1.4492 |

## PROPERTIES OF EXTRACTED OIL.

An examination was made of some of the chemical properties of oil and the results are shown in *Table* 4. The values were determined by the British Standards Institution Methods (1950).

The values determined show that the oil from rubbery copra has quite different characteristics from the usual coconut oil and does not conform to the specifications laid down for crude coconut oil. The high iodine values obtained indicate a much greater degree of unsaturation and thus a different composition of fatty acids.

It is considered that the abnormal values obtained for these oil characteristics are likely to be due to the much greater proportion by weight which the brown testa (seed coat) represents in rubbery copra. Early work by Allan and Moore (1925) showed that testa oil had quite different characteristics and fatty acid composition from kernel oil. The resultant mixed whole oil therefore had intermediate values and composition. Thus the following results were obtained for saponification values and iodine values (*Table* 5).

Further work by Armstrong, Allan and Moore (1925) showed that the testa (or parings) oil contained 23.0 per cent. and 10.0 per cent. respectively of the unsaturated oleic and linoleic acids, compared to only 5 per cent. and 1 per cent. for the kernel oil. This would account for the higher iodine values obtained for the former oil.

It is not known which method was used by Allan and Moore to determine the saponification values, which are very much lower than usual for coconut oil. It is also surprising that the saponification values for the testa oil, with its higher proportion of oleic and linoleic acids are higher than for the kernel oil.

Allan and Moore noted that the ratio of testa to kernel varied from 1 : 10 to 1 : 25, for samples obtained from all over the world. For the extremely rubbery samples investigated, the proportion of testa to kernel is much higher, in some cases probably as high as 1 : 2 or even 1 : 1. The testa oil with its much higher proportion of unsaturated fatty acids would therefore have a great influence on the characteristics of the mixed oil and could well be responsible for the abnormal values obtained from oil from rubbery copra.

Further investigations confirmed this hypothesis. Testa free pieces of rubbery copra were analysed and these were found to have more normal oil characteristics, although their oil content was still low. Results on three samples were as shown in *Table* 6.

## GENERAL DISCUSSION.

The presence of rubbery copra in shipments has been shown to have a number of deleterious effects on the physical qualities of the copra and would tend to lower the oil content, reduce its saponification value and raise the iodine value

*Table* 5.

| — | Kernel Oil. | Testa Oil. | Whole Oil. |
|---|---|---|---|
| Saponification Value .... .... | 213.4-219.3 | 232.5-253.5 | 214.2-221.0 |
| Iodine Value .... .... .... | 5.7- 9.3 | 21.5- 59.7 | 7.1- 10.5 |

*Table* 6.—Characteristics of oil obtained from testa free pieces of rubbery copra.

| Category. | Description. | Oil Content (Dry Basis). | Saponification Value. | Iodine. Value. | Refractive Index. |
|---|---|---|---|---|---|
| 1 | Very Rubbery | 43.4 | 248.4 | 7.99 | 1.4489 |
| 1 | Very Rubbery | 43.7 | 250.1 | 7.74 | 1.4489 |
| 3 | Slightly rubbery | 59.7 | 262.2 | 5.66 | 1.4480 |

and refractive index. If rubbery copra is present in significant quantities, the quality of the oil may be changed so that it does not meet the required specifications.

The occurrence of sulphur deficiency and rubbery copra is so widespread in Papua and New Guinea that the general use of sulphur containing fertilizers could increase total copra production substantially and improve the quality of the final product.

The present investigation did not proceed further in examining the biochemical processes which obviously are affected by a deficiency of sulphur and do not pursue their normal course. The literature does not appear to contain references to the role of sulphur in the formation of fats and oils in plants and this may be the first account of the effect of sulphur deficiency on oil synthesis. There is clearly an interesting and fruitful avenue of research open to bio-chemists and plant physiologists working in the tropics.

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# Book Review.

## FISH AND FISHERIES.

HUGH ANDERSON. LOTHIAN PUBLISHING COMPANY PTY. LTD., MELBOURNE—SYDNEY.

This is a small, handy volume, useful as a brief guide to Australian fisheries; one of a series on Australian Primary Industries from Lothian.

There is a brief history of fisheries and an outline of Australia's place in world fishing, including gross production, and a review of the important species, processes and methods used. The most important individual fisheries are reviewed along the same lines—historically first, followed by notes on current trends and production. Unfortunately the headings do not quite keep pace with the text, and some important sections are not indicated by headings.

Some of the statistics are not quite accurate—for example, it is stated that there are less than 20,000 square miles of trawling grounds off the Australian Coast, but this includes only Territorial waters, and excludes very large areas off the northern and western coasts. These are available to Australian fishermen as much as the North Sea is available to British boats. However, any brief exposition in simple style is likely to lose a little in accuracy. Most of the catch statistics are reliable although in one place Australia is supposed to catch 'nearly 100,000,000 ton' per year; in another, the record catch (1963-1964) is '89½ million pounds'. The latter is correct.

Biology is clearly not the author's strong point—for example sharks are by no means the only fishes without swimbladders (the flatheads, to which a section is devoted, also lack this organ, to name one group). However, this booklet is not intended as a biology treatise.

These minor criticisms aside, the book is a satisfactory introduction to its subject, packed with information and covering all the important aspects of a very large field. Max Coward's illustrations are rather fuzzy, especially the fish—but fish are among the most demanding of subjects for any artist. Retail price in Australia $1.15.

L. W. C. FILEWOOD

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Port Moresby: G. W. Reid, Acting Government Printer.—A3238/1.68.

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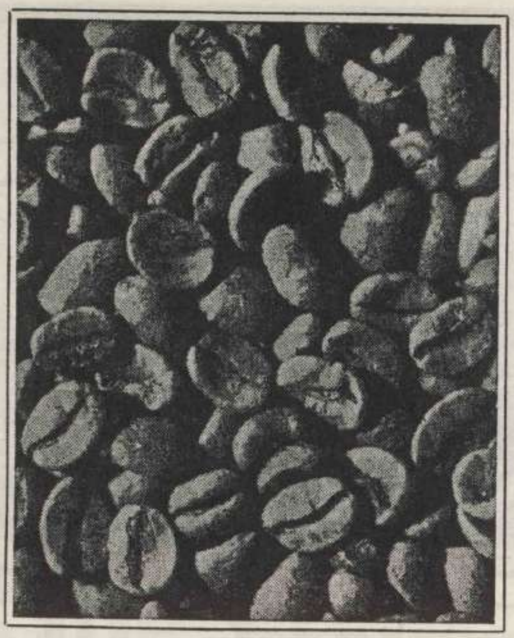

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