

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 condition, 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.

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

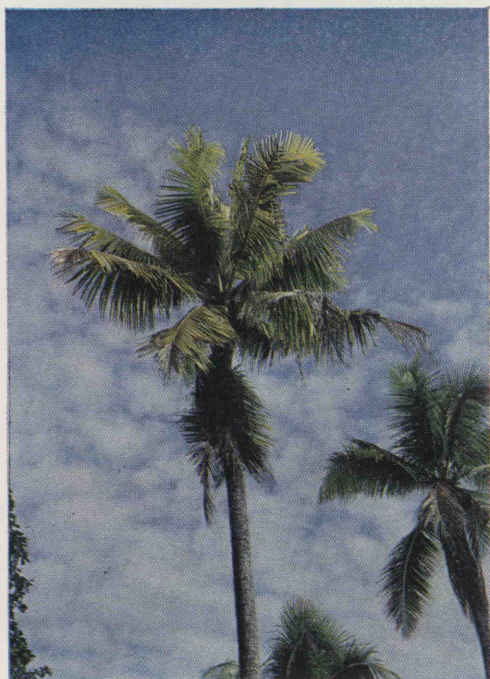


Plate VI.—Coconut leaf from palm with severe
deficiency.



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 Baining 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, Copra rubbery	A	1.50	0.202	2.40	0.08	0.15	0.38	21	40	10.3	0.039
	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, Copra very rubbery	A	1.69	0.260	2.85	0.07	0.28	0.37	17	42	9.9	0.029
	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, Copra normal	A	1.44	0.170	2.40	0.07	0.21	0.28	17	42	12.2	0.036
	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, Copra rubbery	A	1.06	0.180	2.40	0.03	0.14	0.19	17	30	9.5	0.065
	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.

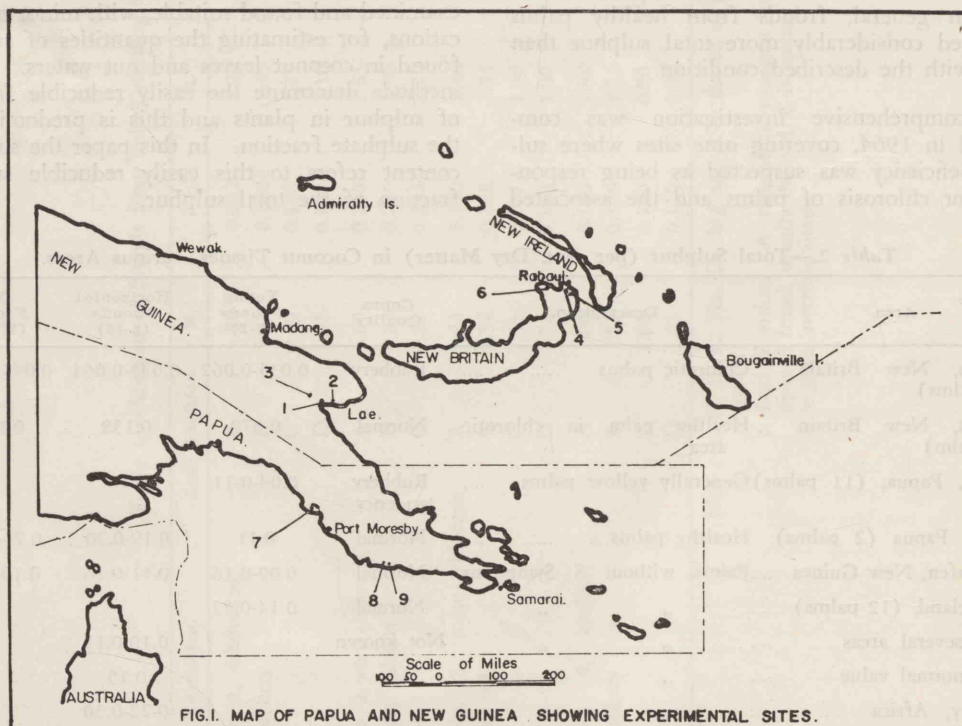


FIG.1. MAP OF PAPUA AND NEW GUINEA SHOWING EXPERIMENTAL SITES.

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.

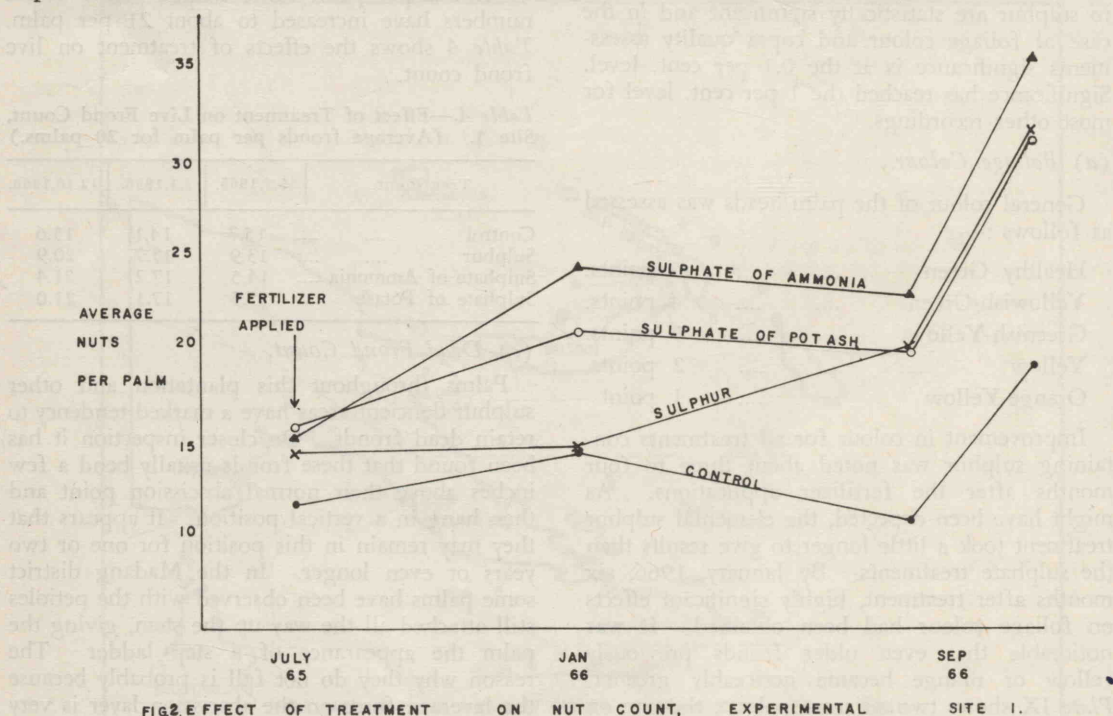


Table 6.—Effect of Treatment on Nut Count, Site 1.
(Average nuts per palm for 20 palms.)

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 comprehensive. 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

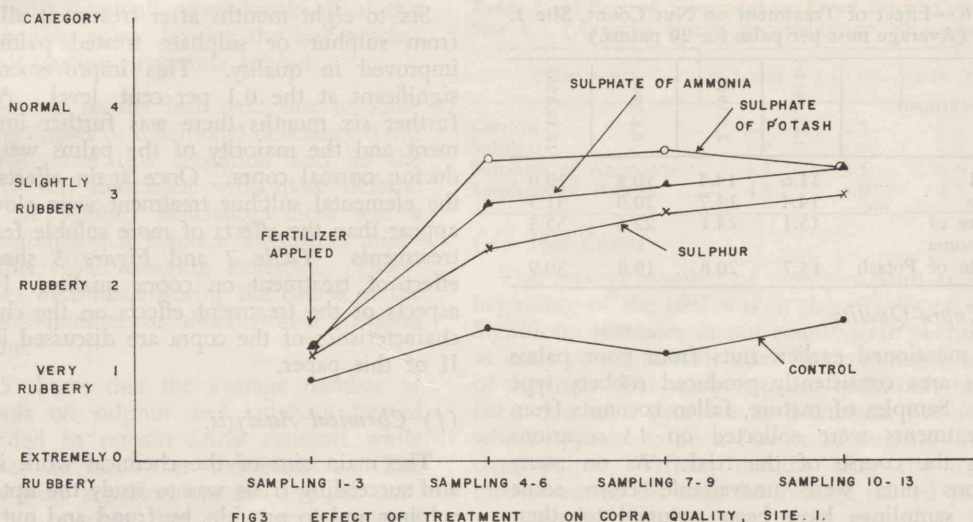


FIG 3 EFFECT OF TREATMENT ON COPRA QUALITY, SITE 1.

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
14.3.1966	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 possibilities 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.

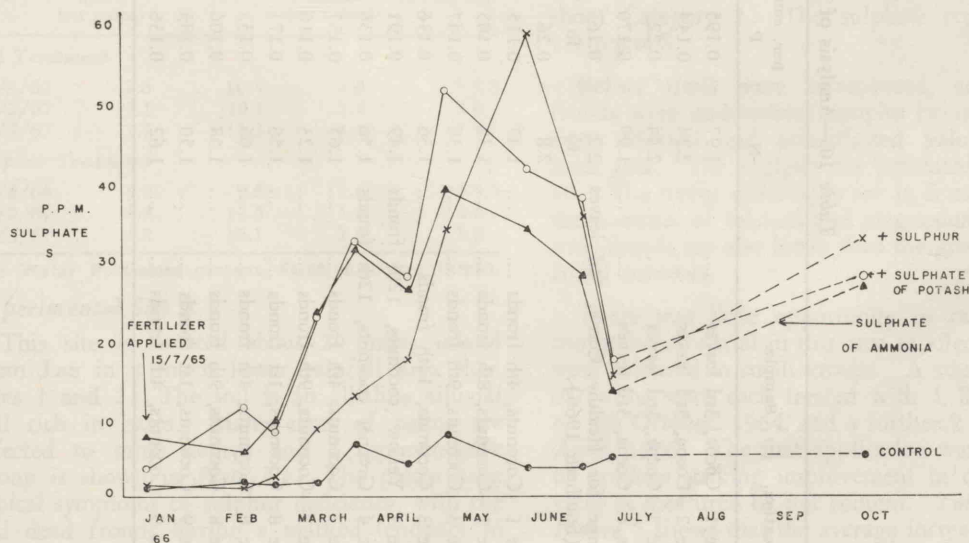


FIG. 4. EFFECT OF TREATMENT ON THE SULPHATE CONTENT OF COCONUT WATERS, SITE 1.

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

Location.	Sample.			N	per. cent., dry basis			Ca	Mg	S	Mn	p.p.m., dry basis			Zn	B
					P	K						Fe	Cu			
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)
<i>Nil Treatment</i>				
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
<i>Sulphur Treatment</i>				
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 volcanic 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.

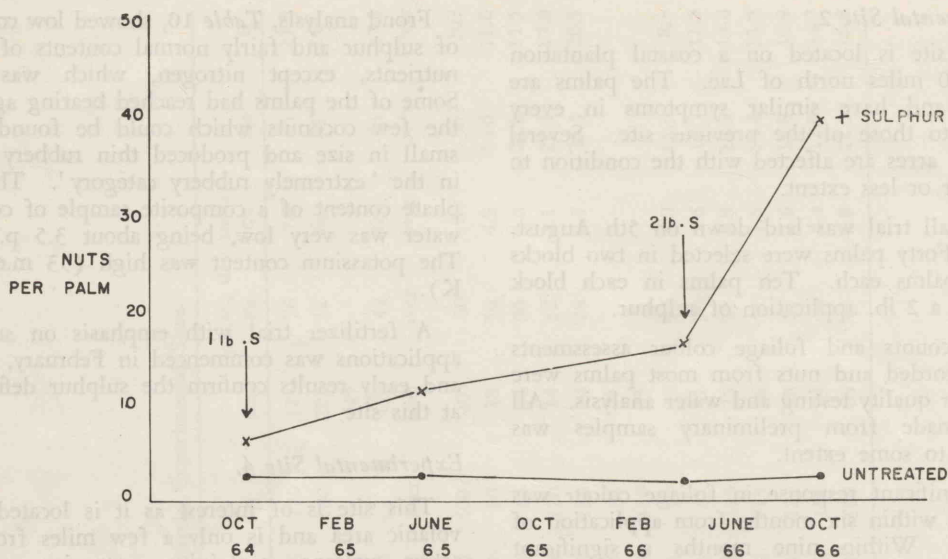


FIG. 5. EFFECT OF TREATMENT ON NUT COUNT, EXPERIMENTAL SITE 4.

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

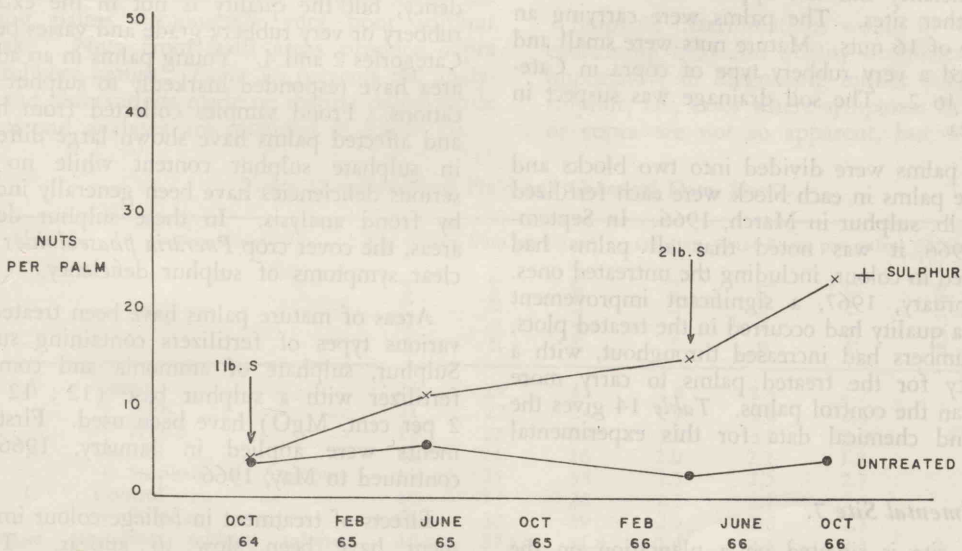


FIG. 6. EFFECT OF TREATMENT ON NUT COUNT, EXPERIMENTAL SITE 5

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 Baining 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.

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

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)
<i>Nil Treatment</i>			
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.
<i>Sulphur Treatment</i>			
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).

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).	SoS (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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