COCONUT NUTRITION IN THE MARKHAM VALLEY OF NEW GUINEA

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ABSTRACT

The poor growth and production of coconuts in the Markham Valley of New Guinea is associated with a condition of sulphur deficiency. A twice-yearly application of sulphur and in some areas sulphur with nitrogen markedly improved the growth of seedlings and increased the production of nuts from mature palms. In trials the annual production of copra was increased from a low 200 *to* 500 *kg per ha to* 1 700 *kg per ha. This is equivalent to a net return of about* K65 *per ha if sulphur alone is used but only* K43 *per ha if nitrogen in addition is necessary.*

INTRODUCTION

Coconuts have been widely grown in the Markham Valley by the indigenous population for many years. Plantings consisted solely of small groves around village sites and were utilized in the subsistence food economy of the area. Early this century several large plantations were planted to coconuts on the coast, in the vicinity of Lae, and in later years coconuts were also established on a plantation scale within the valley itself.

By the early 1960s the production of coconuts from the region near Lae, notably at Malahang and Singaua Plantations, had markedly decreased. Although many of the palms were quite old, having been planted prior to 1914, and were past the age of optimum production, work by Southern (1967) indicated that a major factor influencing the yield was a widespread sulphur deficiency.

Amelioration of this deficiency resulted in a much improved frond colour and significantly increased nut numbers.

During 1966 a survey of coconuts in the Markham Valley was completed by Sumbak (unpublished report). He concluded that a definite sulphur deficiency existed in the vicinity of Lae with probable deficiencies extending up the Markham Valley to Munum and Valley View Plantations. On Narakapor Plantation the old palms appeared healthy while seedlings and young palms showed yellowing of the fronds. It was thought that nitrogen may also be limiting growth in some areas.

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Chlorosis of coconut palms has also been noted at Maralumi Plantation, in the vicinity of Kaiapit and as far west as the base of the Kassam Pass. Village groves in grassland areas that are periodically burnt often show severe yellowing of the fronds and poor yield while palms in well-maintained areas around the villages are healthy. After a particularly wet season it has also been noted that palms apparently healthy at other times were now chlorotic.

Fertilizer trials on seedling and young mature palms were established on Narakapor and Munum Plantations in the Markham Valley. These were designed to examine the sulphur and nitrogen nutritional status of the coconuts.

EXPERIMENTAL METHODS AND RESULTS

Trial 1—*Seedling palms, Narakapor Plantation*

Site Description—Site 1

The area is flat and near the Markham River. During periods of heavy rains it is subject to water-logging and occasional flooding. Soils are deep, alluvial in origin, of a dark clay-loam grading into clay at depth. Supplies of phosphorus, calcium, magnesium and potassium in the soil would appear to be adequate while nitrogen is very low. The soil is slightly alkaline. A soil analysis of samples from this site is given in *Appendix* 1.

Rainfall in the area is about 2 500 mm per annum distributed throughout the year.

Method

Coconut seedlings had been field-planted six months prior to commencement of the trial.

The area was planted with *Brachiaria ruziziensis* and *Calopogonium mucunoides* pasture which competed with the coconut seedling growth. All seedlings were showing varying degrees of frond yellowing. Fertilizer treatments applied in February and October, 1967 comprised—

(*a*) Control,
(*b*) Sulphur,
(*c*) Sulphur + urea, and
(*d*) Sulphur + urea + Rainamina trace element mix *.

Sulphur and urea were applied at rates of 110 and 170 g respectively per seedling and the Rainamina at 80 g per seedling per application.

In May, 1968 treatments *b*, *c*, and *d*, were changed to—

(*b*) Urea (230 g every 3 months),
(*c*) Urea (450 g every 6 months), and
(*d*) Urea (450 g) + sulphur and Rainamina (each at 230 g) applied per palm every 6 months.

Every treatment was applied to 16 seedlings in each of three blocks. Fertilizers were evenly spread around the base of the seedling over the area of canopy cover. A single guard row of seedlings was left between adjacent plots.

Recordings on the rate of frond production, colour of crown and height of seedling were made every 6 months.

At each recording the newest opened frond was marked. The number of fronds between consecutive marked fronds represented the number produced over the period between recordings. Colour of the crown was rated on a scale where 5 = dark green, 4 = pale green, 3 = yellowed, 2 = bright yellow or orange, 1 = orange with necrosis. Height of the seedlings was from ground level to the tip of the tallest frond.

Results

Recordings of height, frond production and colour of fronds were compiled over 33 months and are tabulated in *Table* 1. Fertilization with urea produced a small increase in frond production but no significant increase in height. When both sulphur and urea were applied together there was a major response in growth and height of the seedlings and also in frond colour.

In 1969 it was noted that fertilizer treatment affected the susceptibility of the seedlings to fungal leaf spot (on which various fungi were present) and to damage by *Brontispa longissima* (*Table* 2). The application of nitrogenous fertilizer by itself usually resulted in increased leaf spot damage. This did not occur if sulphur was added with the urea (nitrogen). The healthy, vigorous seedlings were not damaged by leaf spot disease but they suffered the greatest infestation by *Brontispa* sp.

During the conduct of this trial cattle were rotationally grazed amongst the coconuts. Many of the seedlings were extensively damaged and sometimes killed by the cattle and only those treated with both sulphur and urea successfully matured. Palms treated with sulphur and nitrogen were bearing an average of 4.1 spadices and 3.6 nuts at 5 years from germination (*Plate* I).

A summary of the foliar analysis results for nitrogen and sulphur is given in *Table* 3. There is little difference in nitrogen concentration between treatments. However, all treatments except that in which sulphur is added show a very marked decline in sulphur concentration in the fronds over the period of the trial. The Kjeldahl nitrogen/sulphate-sulphur ratio (N/S) indicates a normal balance of these nutrients only in the suphur + urea treatment. With the exception of nitrogen and sulphur all other nutrients were present in concentrations within the normal range.

Trial 2—*Young Bearing Palms—Narakapor Plantation*

Site Description

As for Site 1.

Method

A block of 6-year old palms was selected for trial with the following fertilizer treatments—

(*a*) Control,
(*b*) Sulphur,
(*c*) Sulphur + urea, and
(*d*) Sulphur + urea + Rainamina trace element mix.

*Refer to *Appendix* 2 for composition.

Table 1.—Recordings on seedling coconuts at Narakapor Plantation (*Trial* 1)

Treatment and recording date	Height m	Frond production	No of green fronds	Colour
Treatment *a* (control)—				
October, 1967	2.50	5.8		4.5
May, 1968	2.77	3.6		
December, 1968	3.20	4.1		3.9
June, 1969	2.96	4.1		4.1
November, 1969	3.14	3.2	8.1	3.8
Total frond production		20.8		
Treatment *b**—				
October, 1967	2.53	5.8		4.6
May, 1968	2.83	3.5		
December, 1968	3.93	5.2		3.9
June, 1969	3.81	5.6		3.9
November, 1969	3.96	4.0	7.1	4.5
Total frond production		24.0		
Treatment *c**—				
October, 1967	3.02	6.4		4.6
May, 1968	3.05	3.5		
December, 1968	3.50	5.3		3.8
June, 1969	3.41	4.4		4.0
November, 1969	3.78	4.0	7.7	3.9
Total frond production		23.6		
Treatment *d* (sulphur + nitrogen + tracest†)—				
October, 1967	3.08	6.4		4.7
May, 1968	3.14	3.4		
December, 1968	4.33	5.2		4.9
June, 1969	5.61	5.2		5.0
November, 1969	5.88	4.1	13.0	5.0
Total frond production		24.3		

*Treatment changed May, 1968.

†Rainamina trace element mix (see *Appendix* 2).

Fertilizers were applied every 6 months, sulphur and Rainamina at the rate of 450 g per palm and urea at 900 g palm. In November, 1968, rates of all fertilizers were increased to 900 g per palm.

Each treatment was applied to 3 plots of 9 palms, arranged in 3 randomized blocks. Palms were planted on a 9.1 m square, interplanted with hedgerows of *Leucaena leucocephala.* Rotational grazing of the leucaena and calopo under the palms was practised.

Recordings on nut yield, crown colour and frond number per palm were made at 6-monthly intervals. Nut yield was recorded as the number of nuts of diameter > 10 cm present on the palm. It is considered that these nuts would normally mature within the following 6 months and they therefore represent the production over that period.

Leaf samples were regularly collected for chemical analysis.

Table 2.—Incidence of fungal leaf-spot and *Brontispa* infestation of coconut seedlings under different fertilizer treatments during 1969 (*Trial* 1)

Treatment and recording date	% of fronds affected with fungal leaf spot	% of palms infested with Brontispa
Control—		
June, 1969	21	22
November, 1969	18	26
Nitrogen 4 application per annum—		
June, 1969	38	46
November, 1969	16	50
Nitroge 2 applications per annum—		
June, 1969	42	33
November, 1969	24	41
Sulphur + nitrogen + traces—		
June, 1969	0	68
November, 1969	0	57

Table 3.—Chemical analysis of the first and fourth fronds of coconut seedlings from *Trial* 1 at Narakapor

Frond and sampling date	% N*				ppm S†				N/S			
	Treatment				Treatment				Treatment			
	a	b	c	d	a	b	c	d	a	b	c	d
1st frond—												
February, 1967	1.32	1.33	1.49	1.39	670	748	760	753	20	18	20	19
October, 1967	1.10	1.11	1.03	0.96	460	563	407	455	24	20	25	21
December, 1968	0.77	1.12	0.99	0.91	222	192	335	503	35	58	30	18
June, 1969	1.35	1.55	1.37	1.37	162	113	122	630	83	140	110	22
November, 1969	1.09	1.33	1.30	1.03	42	60	45	482	260	220	290	21
4th frond—												
October, 1967	1.16	1.15	1.25	1.14	425	540	320	476	27	21	39	24
December, 1968	0.93	1.29	1.22	1.25	235	401	347	567	40	32	35	22
June, 1969	1.35	1.72	1.53	1.36	123	73	98	478	110	240	160	29
November, 1969	1.15	1.20	1.46	1.35	67	102	68	607	170	120	220	22

*Nitrogen by Kjeldahl method.

†Reducible sulphur by Johnson and Nishita method.

Plate I.—Markham Valley palm at five years from germination, fertilized with sulphur and nitrogen in *Trial* 1 (Site 1)

Results

Twenty-two months after the first application of fertilizer there was a marked increase in nut yield of the young bearing palms. The average yield over the next three years of those palms treated with sulphur and nitrogen was significantly greater than those not fertilized or fertilized only with sulphur (*Table* 4). A summary of recordings on number of fronds and frond colour, in *Table* 4, showed only minor differences between treatments.

Foliar concentration of nutrients was recorded but as there was little difference between the treatments for most nutrients results were averaged (*Table* 5). Sulphur and nitrogen concentration within the fronds, however, varied considerably between treatments. The application of urea produced a consistent small increase in the nitrogen concentration within fronds. While the concentration of sulphate decreased markedly in the unfertilized plots a high concentration was achieved and maintained in the fronds of palms fertilized with sulphur. The nitrogen/sulphate-sulphur ratio was reduced from a high value in the control plots to a more normal value by the addition of sulphur. A summary of these results is given in *Table* 6.

Nutwater samples collected at the different recording periods from mature nuts were analysed for sulphur content and the results are shown in *Table* 7. In spite of some fluctuation the unfertilized control palms revealed a consistently lower concentration of sulphur in the nutwaters.

On several occasions copra was made from nuts in the trial area and the number of nuts needed to produce 1 tonne of copra was calculated. These estimates (given in *Table* 8) indicate the large size of Markham Valley coconuts and show no size response to fertilizer treatment.

Within the trial several palms died from a disease of unknown etiology. Death ocurred over a period of about 14 months. First symptoms were the premature death of the lowest fronds. Six months later only six to eight green fronds remained at the top of the crown, the dead fronds hanging as a skirt. After a further 6 months only the spear and perhaps one frond remained alive. Some time after the death of a palm one or more of the adjacent palms would start to show the initial symptoms. In two places in the trial this resulted in small groups of dead palms. The number lost were small and did not affect the trial significantly.

Foliar samples collected from the affected palms did not indicate any abnormality nor was any disease organism isolated. The occurrence of this disease was not related to any treatment as it occured on the fully fertilized plots as well as on the unfertilized areas.

Trial 3 *Young Bearing Palms. Munum Plantation*

Site Description—Site 2

The trial at Munum Plantation was on the flat outwash alluvial plains of the Saruwaged Range. The topsoil is a medium-textured loam overlying, at shallow depth, beds of gravel with very low water retention capacity. In this area of the Markham Valley the rainfall is about 1 800 mm with a fairly even distribution throughout the year. Nevertheless, periods without rain can result in a condition of drought on these free-draining soils.

Table 4.—Mean nut yield, frond numbers and colour ratings per palm on coconuts at Narakapor Plantation, *Trial* 2

Date	Control			Sulphur			Sulphur + nitrogen			Sulphur + nitrogen + traces		
	Nuts	Fronds	Colour	Nuts	Fronds	Colour	Nuts	Fronds	Colour	Nuts	Fronds	Colour
February, 1967	0.5			0.1			0.7			1.0		
October, 1967	7.8		5.0	4.0		5.0	6.4		5.0	10.9		5.0
May, 1968	7.5			5.2			6.9			9.3		
December, 1968	11.3		4.9	9.8		5.0	18.3		5.0	17.8		5.0
May, 1969	3.2	24.3	4.9	3.6	25.7	5.0	8.2	28.7	5.0	4.8	28.3	5.0
November, 1969	7.6	27.9	4.8	8.7	29.7	5.0	18.4	32.8	5.0	21.0	32.2	5.0
June, 1970	2.2	26.6	4.8	3.2	29.7	5.0	18.0	31.0	5.0	15.8	29.6	5.0
November, 1970	6.5			7.5			19.8			21.4		
June, 1971	6.2	28.7	4.7	6.7	29.1	4.9	11.4	29.5	4.7	12.7	28.4	5.0

Table 5.—Average nutrient content of the 14th frond, collected from *Trial* 2 and *Trial* 3

Site and sampling date	Nutrient								
	%P	%K	%Ca	%Mg	ppm Mn	ppm Fe	ppm Zn	ppm Cu	ppm B
Narakapor—									
February, 1967	0.17	1.52	0.45	0.41	40	19	22	2.8	22
December, 1968					34	56	31	5.9	24
June, 1969					34	47	26	3.0	24
June, 1970	0.17	1.28	0.46	(0.74*)	33	37	31	8.2	22
June, 1971	0.16	1.42	0.38	0.17	50	57	27	3.7	20
January, 1972	0.13	1.45	0.24	0.18	49	50	24	4.2	19
Munum—									
February, 1967	0.14	0.97	0.39	0.23	14	14	27	1.7	20
November, 1969					15	65	25	8.4	14

*Value queried.

Table 6.—Nitrogen and sulphur concentrations in frond samples from mature palms, *Trial* 2

Frond and sampling date	%N				ppm S				N/S			
	Treatment				Treatment				Treatment			
	a	b	c	d	a	b	c	d	a	b	c	d
4th frond—												
February, 1967*	1.39				270				52			
December, 1968	1.23	1.20	1.30	1.35	206	250	267	186	60	48	49	73
Average of June & November, 1969	1.35	1.40	1.48	1.52	152	263	280	208	89	53	53	73
June, 1970	1.42	1.23	1.46	1.49	85	150	228	280	170	82	64	53
June, 1971	1.62	1.53	1.54	1.55	124	169	231	217	130	91	67	71
January, 1972	1.57	1.64	1.47	1.55	128	227	154	186	120	72	96	83
14th frond—												
February, 1967	1.20				325				37			
December, 1968	1.05	1.00	1.13	1.14	330	448	385	550	32	22	29	21
Average of June & November, 1969	1.17	1.20	1.29	1.37	188	310	251	350	62	39	51	39
June, 1970	1.32	1.62	1.40	1.75	108	435	460	403	120	37	30	43
June, 1971	1.47	1.36	1.44	1.43	215	443	406	487	68	31	36	29
January, 1972	1.38	1.39	1.41	1.50	167	359	333	363	83	39	42	41

*The 9th frond was sampled instead of the 4th frond at this period.

Table 7.—Sulphur content (ppm SO_4 S) in nutwater samples, *Trial* 2

Sampling date	Control	Sulphur	Sulphur + nitrogen	Sulphur + nitrogen + traces
November, 1967	14.2	15.7	11.2	(1.0)*
December, 1968	18.4	20.9	20.8	25.0
June, 1969	12.3	14.3	16.9	22.8
November, 1969	7.0	8.6	11.4	10.9
June, 1970	14.7	16.5	25.6	24.1
June, 1971	2.6	10.6	8.3	9.5

*Value queried.

Table 8.—Estimated number of nuts to produce one tonne of copra. Nuts collected from *Trial* 2 and dried in a forced-air-draught oven

Date	Control	Sulphur	Sulphur + nitrogen	Sulphur + nitrogen + traces	Average
November, 1969					3 120
June, 1970	2 720	2 910	2 870	3 350	2 963
June, 1971					3 460
June, 1972	2 910	2 870	2 970	3 030	2 945
Average					3 122

Coconut palms were growing poorly with low yield and marked chlorosis of the fronds. Premature senescence and death of fronds was widespread and many palms had a characteristic skirt of dead fronds hanging beneath the crown.

Method

An area of poor-yielding chlorotic palms about 11 years old was marked into plots of 9 palms, each with a common guard row between plots, in 2 randomized blocks. Four fertilizer treatments were applied, these being—

(*a*) Control
(*b*) Sulphur,
(*c*) Sulphur + urea, and
(*d*) Sulphur + urea + Rainamina trace element mix.

All fertilizers were applied at the rate of 900 g per palm every 6 months, commencing in February, 1967, and continued through until June, 1971. Fertilizers were evenly spread around the base of each palm over the area of canopy cover.

Rotational grazing of the area by beef cattle was practised but this did not affect the conduct of the trial.

Periodic nut counts were made to assess yields, and frond and nutwater samples were collected.

Results

Not only was there a marked decline in condition of the unfertilized palms but 13 per cent of them died and some others were almost dead at the conclusion of the trial (*Plate* II). All treatments containing sulphur showed a very marked improvement in frond colour and number of green fronds per palm and a significant increase in the nut yield. A summary of these recordings is given in *Table* 9.

Kjeldahl nitrogen and sulphate-sulphur concentration of foliar samples are summarized in *Table* 10. The unfertilized palms showed an increase in nitrogen concentration and a progressive decline in sulphate concentration to a very low level. This resulted in a very large N/S ratio in the fronds. The addition of urea caused only a very small increase in nitrogen concentration. Sulphate concentration in the fronds fluctuated markedly when sulphur was applied but the level was usually much higher than in unfertilized palms.

With the exception of nitrogen and sulphur there was no marked variation in the nutrient content of fronds between treatments and the averaged results are tabulated in *Table* 5.

The sulphur concentration present in nutwater samples from the different treatments is shown in *Table* 11. These confirm a severe sulphur deficiency in the unfertilized palms but an adequate nutrition where elemental sulphur has been applied.

DISCUSSION

Site 1

In *Trial* 1 initial recordings on the seedlings indicated no response to sulphur fertilizer. This resulted in treatments being changed to look more closely at nitrogen response. Whereas there was no significant response to urea applied at 6-monthly intervals there was a small but significant increase in height in response to urea when it was applied every 3 months.

It is probable that this initial response was not solely due to the nitrogen treatment but to the combination of nitrogen and residual sulphur. When sulphur was applied together with urea the growth response was very marked, the height increase being six times that of the "urea only" treatment.

Plate II.—Fertilizer trial at Site 2. Palms on the left were fertilized with sulphur, those on the right remained unfertilized. Palms in the centre are in the guard row

Seedings with the "nitrogen only" treatments showed no consistent improvement in frond colour. Total frond production was marginally increased but fewer fronds per plant indicated an earlier senescence and dying of the fronds. This may in part have been influenced by the higher incidence of fungal leaf spot (Gallasch 1974).

The only seedlings which appeared healthy and were growing vigorously were those treated with elemental sulphur and urea. These contained a full complement of fronds. No leaf spotting was recorded on these plants but they had the highest incidence of insect attack, *Brontispa longissima* being common on the young fronds.

The young bearing palms (*Trial* 2) gave no response to the addition of sulphur alone but when sulphur was added together with nitrogen the yield was significantly increased. No additional response was noted when trace elements were also added. Although there was no marked response to fertilizer in either crown colour or frond number per crown, the fronds on the control plots appeared shorter and gave a less dense canopy. However, there may have been some poaching from adjacent fertilized plots as unfertilized palms outside of the trial area were quite debilitated and very chlorotic, symptomatic of severe sulphur deficiency.

Over the period of the trial there was a marked reduction in the sulphate-sulphur concentration in both the 4th and 14th fronds of the bearing palms (*Table* 6). This indicated an increasing sulphur deficiency in all treatments not including sulphur. The application of elemental sulphur tended to maintain the sulphate concentration in the fronds at pre-treatment levels but did not increase it.

In the seedlings, sulphate concentrations at the December, 1968 recordings were still above the nominal critical level (100 to 200 ppm depending on the age of the frond). Nevertheless, the seedlings were exhibiting severe

Table 9.—Mean nut yield, frond numbers and colour ratings per palm on coconuts at Munum, *Trial* 3

Date	Control			Sulphur			Sulphur + nitrogen			Sulphur + nitrogen + traces		
	Nuts	Green/dead fronds	Colour of fronds	Nuts	Green/dead fronds	Colour of fronds	Nuts	Green/dead fronds	Colour of fronds	Nuts	Green/dead fronds	Colour of fronds
February, 1967	1.9	16/10	4.0	0.4	14/12	3.5	1.2	19/6	4.1	0.1	14/12	4.3
October, 1967	1.4	15/10	4.0	2.0	12/11	4.3	2.8	16/7	4.4	2.2	13/8	4.5
May, 1968	0.4	-/13	3.3	0.5	-/11	4.0	1.4	-/7	4.1	0.2	69/9	4.5
December, 1968	0.3	11/5	3.2	0.8	16/2	5.0	1.3	21/1	5.0	1.3	16/2	5.0
June, 1969	0.6	15/4	4.1	1.2	22/1	5.0	5.7	25/2	5.0	1.8	22/2	5.0
November, 1969	3.2	16/4	4.0	8.5	27/2	5.0	22.6	29/1	5.0	11/9	28/1	5.0
June, 1970	1.6	12/-	3.7	5.1	25/-	5.0	9.8	28/-	5.0	5.9	26/-	5.0
November, 1970	3.2	-	-	18.6	-	-	25.9	-	-	16.2	-	-
July, 1971	2.6	14/	2.4	19.8	26/-	5.0	26.0	27/-	4.9	15.9	27/-	4.9

— Not recorded

Table 10.—Chemical analysis of the 4th, 9th* and 14th fronds of coconut palms at Site 2, Munum Plantation

Frond and sampling date	%N				ppm S				N/S			
	Treatment				Treatment				Treatment			
	a	b	c	d	a	b	c	d	a	b	c	d
4th frond—												
February, 1967*	1.29				120				108			
December, 1968	1.34	1.39	1.30	1.39	240	340	430	350	56	41	30	40
June, 1969	1.67	1.47		1.47	100	268	415	345	167	55		43
November, 1969	1.68	1.55	1.66	1.54	45	138	50	153	373	112	332	101
July, 1971	1.88	1.42	1.56	1.55	25	230	220	125	752	62	71	124
14th frond—												
February, 1967	1.16				130				89			
December, 1968												
June, 1969	1.31	1.32	1.38	1.38	125	268	440	428	105	49	31	32
November, 1969	1.33	1.38	1.37	1.42	60	188	113	203	222	73	121	70
July, 1971	1.90	1.31	1.50	1.42	55	240	180	250	345	55	83	57

*9th frond sampled.

Table 11.—Sulphur content (ppm SO_4 S) in nutwater samples, *Trial* 3, Munum

Date	Control	Sulphur	Sulphur + nitrogen	Sulphur + nitrogen + traces
February, 1967	3.5	*	*	*
December, 1968	*	21.4	*	*
November, 1969	1.5	10.5	6.4	13.4
June, 1970	1.0	18.6	21.0	23.2
July, 1971	<1	>20	>20	>20

*Insufficient nuts for sample.

sulphur deficiency symptoms, notably stunted growth and yellowed fronds. At the final recording in November, 1969 there was a linear correlation ($r = 0.86^{***}$) between height and sulphur content for both the first and fourth fronds up to values of at least 600 ppm S (*Figure* 1).

The nitrogen concentration in fronds of seedlings and bearing palms showed greater fluctuation with the recording period than with the treatments. There was no trend over the period of the trial as there was with sulphate-sulphur concentration. On the average the application of nitrogen resulted in an increase in nitrogen concentration of only about 0.1 per cent. There was no correlation between nitrogen concentration and either height of seedlings or nut yield of palms.

Notwithstanding the application of 1.8 kg of urea per annum the foliar nitrogen concentration remained at a low level and considerably less than the nominal critical value of 1.70 per cent. Unless the nitrogen availability after fertilizing was still much below the optimum it must be that this critical value is not relevant to the situation.

An examination of the nitrogen/sulphate-sulphur ratio indicated a linear correlation between this ration and growth of the seedlings as measured by height ($r = 0.77^{***}$ for 1st frond and $r = 0.60^{**}$ for 4th frond) (*Figure* 2). No correlation existed between nut yield and either

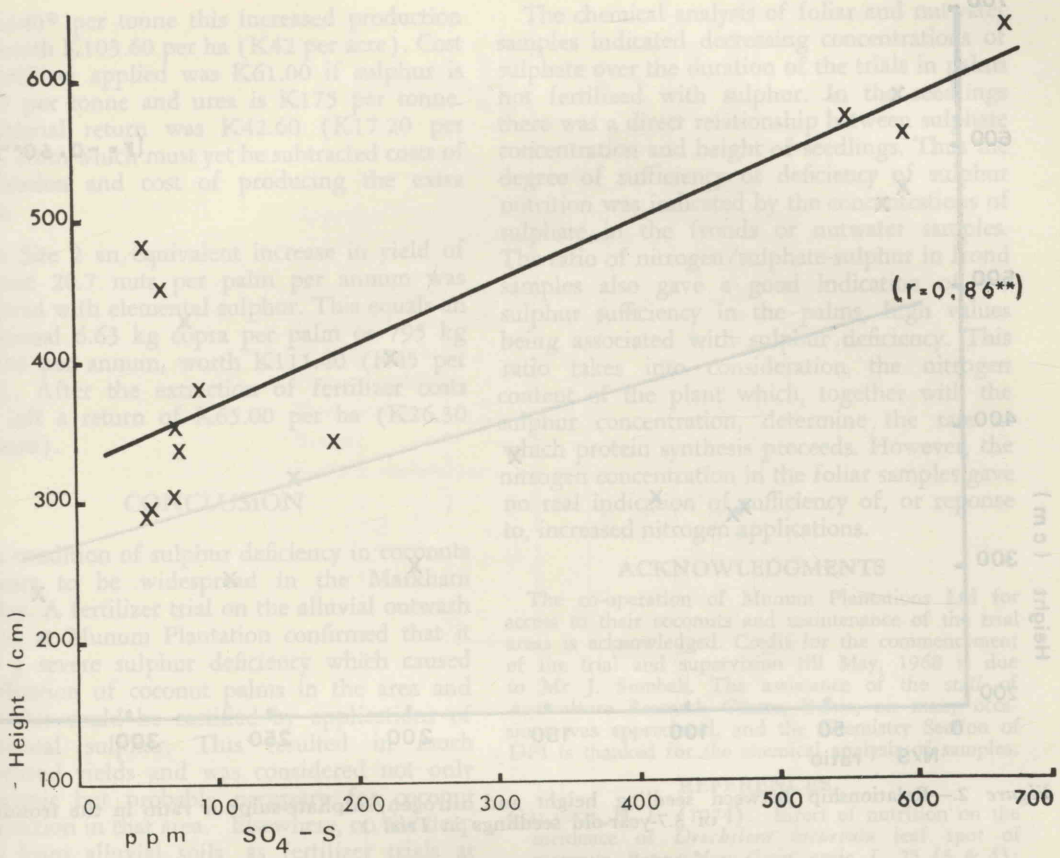

Figure 1.—Relationship between seedling height and sulphate-sulphur concentrations in the fronds of 3.7-year-old seedlings in *Trial* 1

the N/S ratio or sulphur concentration in the fronds of the mature palms.

The average magnesium concentration in the 4th frond (*Table* 5) decreased over the trial period. This decrease in concentration occured even on those palms which were treated with Rainamina and would be receiving 1 kg magnesium sulphate each per year. It may be that ammonia released by the urea restricted the absorption of magnesium (Jacob and von Uexkull 1958).

Sulphur content of nutwater samples collected from treatment plots indicated a marked variation in concentration between recording periods. This could be a seasonal effect. The concentration of sulphur in nutwaters from the control plots was usually a little and occasionally markedly lower than from treated plots. When the concentration is less than 10 ppm sulphur is usually considered deficient. There is no apparent correlation between nutwater sulphur concentration and the concentration of sulphate-sulphur in the fronds.

As *Table* 8 indicates, there was no marked effect of fertilizer on copra yield of nuts, the average yield being 320 g per nut (3 120 nuts per tonne).

Site 2

A somewhat different situation pertained at Site 2 (*Trial* 3). In this area a significant response was obtained to elemental sulphur without nitrogen and the use of urea gave no additional benefit. An initial response was noted after 28 months and this had increased significantly by 45 months after the first application. The eventual nut yield per palm in *Trial* 3 was of the same order as the per palm

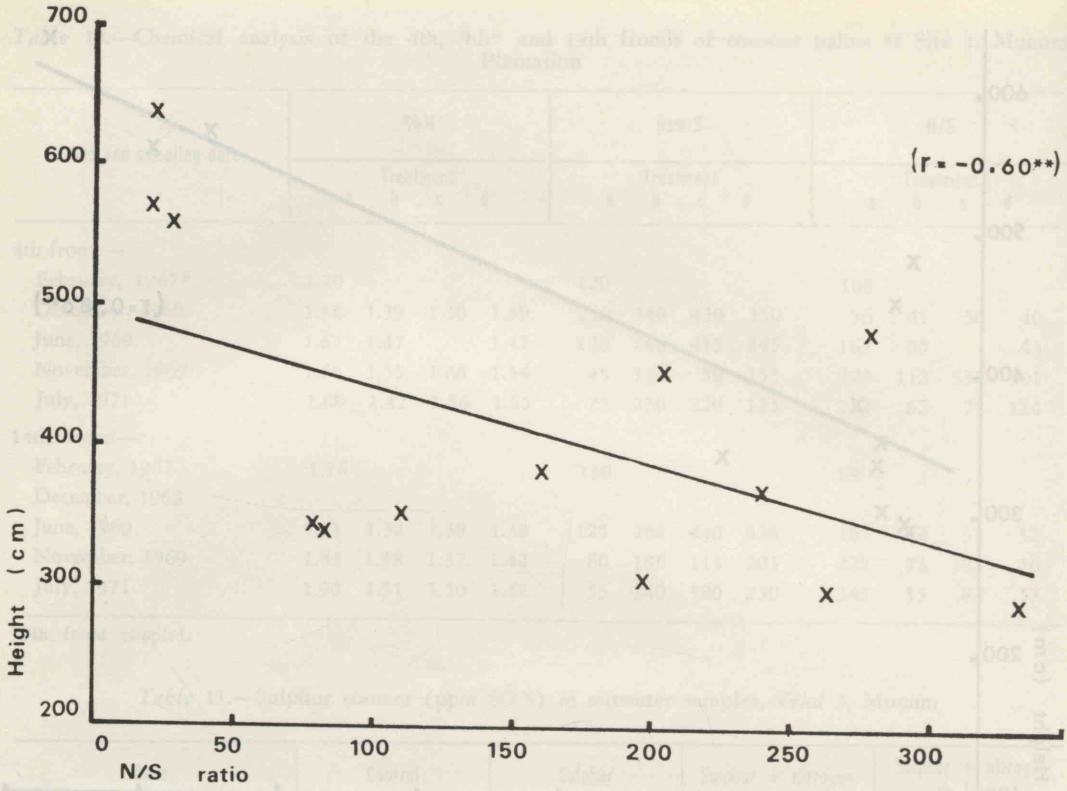

Figure 2.—Relationship between seedling height and nitrogen/sulphate-sulphur ratio in the fronds of 3.7-year-old seedlings in *Trial* 1

yield at Site 1, on treated plots; however the response was much greater at Site 2 where the control palms had deteriorated very markedly. Palms that were not fertilized with sulphur were very low-yielding, the fronds were extremely chlorotic and oranged and the crown reduced to about half the normal number of fronds; in addition several palms had died. Palms treated with 1.8 kg elemental sulphur fertilizer per year were very healthy.

Sulphur concentrations in the fronds reacted similarly as at Site 1. The sulphate-sulphur concentration showed a progressive decline in most plots but was more pronounced in the control treatment. Sulphate concentration in fronds of the treated palms was much higher than in the controls.

The last samples collected indicated extreme sulphur deficiency in the unfertilized palms. Unaccountably, even the fertilized palms revealed occasional below-normal sulphate-sulphur concentrations.

Nitrogen concentrations were similar to those at Site 1 with the exception of higher levels under severe sulphur deficiency. The nitrogen/sulphate-sulphur ratios indicated a marked imbalance of these nutrients in the control plots but this was much reduced by the sulphur treatments. No significant correlations of nut yield with either the N/S ratios, sulphate-sulphur concentrations or nitrogen concentration were found.

The sulphur contents in the nutwater samples from Site 2 indicated that adequate levels were reached after several years' application of elemental sulphur. Only traces of sulphur were present in the control plots, confirming a severe deficiency of that nutrient.

At Site 1 there was an average annual increase in nut yield of 19.2 nuts per palm per annum with the application of urea + sulphur. This was equivalent to 6.15 kg of copra per palm or 740 kg copra per ha at the density of 120 palms per ha at this site. At a market price

of K140* per tonne this increased production was worth K103.60 per ha (K42 per acre). Cost of fertilizer applied was K61.00 if sulphur is K215 per tonne and urea is K175 per tonne. Additional return was K42.60 (K17.20 per acre) from which must yet be subtracted costs of application and cost of producing the extra copra.

At Site 2 an equivalent increase in yield of at least 20.7 nuts per palm per annum was achieved with elemental sulphur. This equals an additional 6.63 kg copra per palm or 795 kg per ha per annum, worth K111.40 (K45 per acre). After the extraction of fertilizer costs this left a return of K65.00 per ha (K26.30 per acre).

CONCLUSION

A condition of sulphur deficiency in coconuts appears to be widespread in the Markham Valley. A fertilizer trial on the alluvial outwash plains at Munum Plantation confirmed that it was a severe sulphur deficiency which caused debilitation of coconut palms in the area and that this could be rectified by applications of elemental sulphur. This resulted in much improved yields and was considered not only economic but probably necessary for coconut production in that area. Elsewhere, on the deep clay loam alluvial soils, as fertilizer trials at Narakapor Plantation indicated, nitrogen must be added in conjunction with sulphur. In addition to a more economic production from the bearing palms the use of these fertilizers brought the seedlings into bearing at five years of age. Unfertilized seedlings, if they survived, were delayed in coming into bearing.

The chemical analysis of foliar and nutwater samples indicated decreasing concentrations of sulphate over the duration of the trials in palms not fertilized with sulphur. In the seedlings there was a direct relationship between sulphate concentration and height of seedlings. Thus the degree of sufficiency or deficiency of sulphur nutrition was indicated by the concentrations of sulphate in the fronds or nutwater samples. The ratio of nitrogen/sulphate-sulphur in frond samples also gave a good indication of the sulphur sufficiency in the palms, high values being associated with sulphur deficiency. This ratio takes into consideration the nitrogen content of the plant which, together with the sulphur concentration, determine the rate at which protein synthesis proceeds. However, the nitrogen concentration in the foliar samples gave no real indication of sufficiency of, or reponse to, increased nitrogen applications.

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*K1 = $1.05 Australian.

Appendix 1—Soil analysis from Site 1, Narakapor Plantation

Sample depth	pH	Specific conductivity mho x 10^3	P ppm (Olsen)	Exchangeable Ca m-e %	Exchangeable Mg m-e %	Exchangeable K m-e %	Exchangeable Na m-e %
0-15 cm	7.3	0.111	26	52	10.3	1.80	1.5
15-45 cm	7.5	0.108	13.5	31	6.2	0.63	1.21

Sample depth	Total metal ions m-e %	Total salts %	Carbon %	Nitrogen %	C/N ratio	Loss on ignation %
0-15 cm	86.8	0.033	1.2	0.14	8.6	9.0
15-45 cm	90.8	0.032	0.47	0.07	6.7	7.6

Appendix 2.—Composition of Rainamina trace element mixture

Magnesium sulphate	56 %
Manganese sulphate	14 %
Copper sulphate	9 %
Ferrous sulphate	7 %
Zinc sulphate	7 %
Borax	6 %
Sodium molybdate	1 %