

EVIDENCE OF POTASSIUM DEFICIENCY IN COCONUT PALMS ON CORAL-DERIVED SOILS IN NEW IRELAND FROM ANALYSIS OF NUT WATERS, HUSKS, FRONDS AND SOILS.

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THE analysis of soil and plant materials from areas where coconut palms are in various stages of decline, shows that the potassium status of the palms and soil is closely related to the degree of decline and the severity of the deficiency symptoms.

There is evidence that the potassium reserves of large areas of the coral-derived soils in New Ireland are inadequate for the satisfactory growth of coconut palms.

Introduction.

The area investigated involves nearly 150 miles of the coastal fringe of the east coast of New Ireland, extending from Kavieng to south of Namatanai. It embraces about 50 plantations with a total area of some 30,000 acres, or approximately 1.5 million palms. It is estimated that one-third to one-half of this area carries palms which are chlorotic, bearing few nuts, and in the more extreme cases are dying prematurely.

In general, there is a very marked decrease in the productiveness of the palms with increasing distance from the shore, which coincides with a change in soil characteristics.

The decline of coconut palms in New Ireland has been evident for some time, and was the subject of a report by Dwyer (1940).

A soil survey carried out in 1955 (Van Wijk) outlined the main soil types, and, subsequently, samples for analysis were collected by the writers from 15 plantations, which were considered representative of the main problem.

The diagnostic work was based mainly on a comparison of the analysis of soil and plant materials taken in September, 1957, from sites where palms were healthy and in various stages of decline. The age of palms in the areas investigated was estimated at 30-45 years.

Description of the Soils.

The main soil types of the east coast of New Ireland have been described by Van

Wijk. The coastal areas from which samples were taken on the writers' survey consisted chiefly of red-brown clay-loams over raised coral and brown-yellow clays. In addition, one alluvial soil and two coral sand areas were examined. The soils were all derived from calcareous material except the alluvial soil, which appeared to have been formed from volcanic material. The occurrence of small quantities of magnetite in the sand fractions of the soils further inland, indicated that some volcanic material from the high ranges, which form the backbone of New Ireland, probably had been washed down. There was no evidence that this material was associated with the formation of the coastal soils.

On a typical plantation, palms are planted from the edge of the coastal limestone cliffs to the foothills, which may lie from one mile to four miles inland. The soil on the coast is a shallow red-brown loam over raised coral, varying in depth from a few inches to two or three feet. The fissured nature of the parent coral leads to large variations in soil depth over a short distance. Free coral limestone occurs on the surface and throughout the profile, ensuring the soil is kept in a lime-saturated flocculated condition. Drainage of excess water proceeds rapidly through holes in the limestone into underground streams. Palms on this soil type are usually, but not always, in a healthy condition. They suffer occasionally from overdrainage in dry periods. However, the symptoms on chlorotic palms are similar to those further inland on the slower-drained soils.

Progressing inland, the soil increases in depth and there is much less influence of the underlying coral on the soil characteristics. The soil colour changes to orange or yellow due to the substitution of the clay bases by hydrogen, slower drainage conditions and consequently hydration and reduction of the iron minerals. The palms on these more acid soils are very often declining in pro-

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duction and showing chlorosis varying in degree from slight to very severe. From examination of the soils after heavy rain it did not appear that impeded drainage was a primary cause of the decline of palms on this type of soil.

There is seldom an abrupt change either in the field characteristics of the soils or in the degree of chlorosis of the palms but changes occur gradually through intermediate stages. Occasionally healthy productive palms are to be found growing well inland on alluvial and volcanic soils and also on soils derived from soapstone. On some parts of the coast there exists a coral sand fringe where coconut growth is usually satisfactory, providing palms have access to the moving water table.

Descriptions of the Visual Symptoms.

The symptoms of nutrient disorder in coconut palms are evident on substantial areas of almost all plantations between Kavieng and Namatanai, and in general, they are in their severest form on those parts of the plantations furthest from the beach. The majority of plantations employ a cover crop, usually *Pueraria*, which invariably displays symptoms where palms are unthrifty. Symptoms are apparent also in some areas in *Leucaena glauca* seedlings, *Centrosema*, *Tephrosia candida*, corn and cacao.

Coconut Palms : In the earlier stages the symptoms occur as a slight yellowing of the margin and tips of leaflets of the lower fronds. The lengths of the fronds and leaflets are less than those of healthy palms, and there are noticeably fewer fronds and nuts.

At the severest stage, the leaflets of the old and some young fronds are almost completely yellow to orange-yellow, and even leaflets of the most recent fully-expanded fronds show some chlorosis. Leaflets and fronds are much reduced in size, being a third to a half of those of healthy palms, and older fronds are prematurely shed, leaving a small number of upright fronds. Numerous small necrotic spots cover the chlorotic tissues of the leaves. Palms so affected are stunted and generally two-thirds or less than the height of healthy palms. The number of nuts carried ranges from nil to 10. Typical chlorosis symptoms of coconut palms and fronds are illustrated in Plates 1 to 4.

Pueraria : The symptoms show as a marginal and interveinal yellowing of the leaves, the extent of the chlorosis increasing with the age of the leaf, the oldest sometimes showing marginal scorching. The leaves are much smaller than normal and tough in texture. The growth of *Pueraria* is greatly restricted in areas where the palms are very poor, and in some instances is barely adequate to cover the soil. Plate 5 shows a general view of *Pueraria* cover crop with severe chlorosis. A chlorotic *Pueraria* leaf is shown in Plate 6.

Leucaena glauca : Symptoms occur in *Leucaena* seedlings only in areas where palms are very unthrifty. They show as a marked stunting in growth and a tip scorch of the leaflets. No scorching was evident on *Leucaena* which was more than four feet tall.

Centrosema and Tephrosia : A marginal yellowing, particularly of the older leaves, was observed in these legumes when found growing in poor areas (see Plate 8).

Corn : In one area where corn was grown, the symptoms of marginal leaf scorch, interveinal chlorosis, undeveloped deformed ears, decaying root and nodal tissue were clearly evident.

Cacao : Marginal leaf scorch in cacao is widespread, but unlike the symptoms appearing in palms, *Pueraria* and *Leucaena*, it is more severe and prevalent near the coast than inland. The scorch takes the form of a grey to almost white necrosis of the marginal tissues of about the sixth leaf from the terminal and increasing in severity down the branch. A slight yellow mottle occurs in the area between the necrotic margin and healthy centre tissue of the leaf. A typical example of cacao leaf scorch is shown in Plate 9.

Methods of Sampling and Analysis.

(a) SAMPLING.

Selection of Sampling Sites : Where possible, palms of uniform appearance were chosen as sites suitable for sampling. Five ratings of productivity based on an estimate of the average number of nuts carried were made, and 23 sites spread over the five groups were selected for sampling.

	Productivity Rating.	Nuts/palm.
1	High	60 +
2	Fairly high	40 — 60
3	Medium	20 — 40
4	Low	5 — 20
5	Very low	0 — 5

Nut Waters : At each site, mature fallen nuts from 10 palms were collected, and a sample from each nut preserved with a few drops of formaldehyde in a specimen tube.

Husks : Samples of husks from the above nuts were bulked into one sample.

Fronds : About 20 leaflets from the mid-portion of the youngest fully-expanded frond were taken from a single palm representative of the site.

Pueraria : The third leaf from the terminal was taken and collection made over an area of 10 yards square.

Leucaena : Terminal leaves were collected.

Cacao : The third leaf from the terminal of hardened flushes was selected. Twenty leaves from five trees represented one sample.

Soil : At each site, samples of 0.4 in., 4-8 in. were taken.

(b) ANALYSIS.

Nut Waters : Samples were diluted and K, Na, Ca were determined on a Beckman D.U. Flame Spectrophotometer by the method of Southern (1956). The concentration of P was determined colorimetrically on the diluted solution with an E.E.L. absorptiometer. The concentration of Cl was found by titration of a 10 ml. aliquot of the undiluted nut water with N/10 AgNO_3 .

Leaves and Husks : Samples were oven-dried, ground, ashed at 500°C . and extracted with 1 + 4 HCl on a water bath. After dilution, analysis for K, Na, Ca, P was made as above. Analysis for N was made by the Kjeldahl method. Mn was determined by the permanganate method.

Soils : Samples were air-dried and passed through a 2 mm. sieve; pH and conductivity were determined on a 1 : 5 soil water extract. The exchangeable cations were determined directly on a Beckman Flame Spectrophotometer after leaching with normal ammonium acetate. Total exchange capacity was determined by the ammonia absorption method. The Olsen and Truog (modified) methods using 0.5 M NaHCO_3 and 0.01N H_2SO_4 respectively to extract phosphorus gave an indication of the phosphate status of the soil. Total N was determined by the Kjeldahl method. Further fractionation of the potassium in the soil was made by boiling separate portions of the soil with N HNO_3 and concentrated HCl. Mechanical analyses were carried out by utilizing a plummet balance after pre-treatment of the soils.

Experimental Results.

The 23 sites sampled between Kavieng and Namatanai were located on coral-derived soils with the exceptions of Site 3 (an alluvial of volcanic origin), Site 12 (coral sand), Site 20 (slightly-raised coral sand). Samples from palms making vigorous growth on immature volcanic ash soils, Sites 1 and 2, have been analyzed to give comparative data in the high-producing categories.

The summary of the analysis of nut waters, fronds, husks and soils is given in Tables I, II and III.

TABLE I.—PLANT ANALYSIS

Location Site No.	PRODUCTIVITY RATING nuts/palm	NUT WATER (p.p.m.)				No. of Analyses	FROND (Per cent, dry basis)					HUSK Per cent, in ash		Per cent, Ash	APPEARANCE
		K	Na	Ca			K	Na	Ca	N	P	K	Na		
1.	High	3000	78	231		5	2.10	.02	.16	...	...	35.7	.66	4.21	Palms healthy in appearance making vigorous growth.
2.	60+	2380	82	171		25	...	...	...	...	...	...	...	...	
3.	...	2531	159	204		10	...	...	...	...	...	35.3	10.1	3.71	
4.	...	2503	218	272		10	...	...	...	...	...	36.9	7.3	3.43	
5.	Fairly high 40-60	2065	422	313		10	...	...	...	...	...	...	...	...	Palms healthy.
6.	Medium	1378	631	361		10	1.10	.42	.11	1.67	.16	11.8	25.4	2.95	Palms generally healthy in appearance, some have signs of chlorosis.
7.	20-40	1316	673	200		10	.83	.54	.11	2.02	.12	13.3	20.1	3.11	
8.	...	1268	676	177		10	.46	.45	.22	2.10	.18	11.5	25.8	2.66	
9.	...	1225	1005	272		12	...	...	...	...	...	...	...	...	
10.	...	1215	1065	235		10	.68	.55	.13	1.99	.13	...	...	...	
11.	...	1063	1034	232		10	...	...	...	...	...	...	...	...	
12.	...	1088	865	342		10	...	...	...	...	...	5.6	30.5	2.66	
13.	...	820	954	218		10	...	...	...	...	...	7.1	24.5	2.80	
14.	...	607	976	199		10	...	...	...	...	...	6.0	28.4	2.86	
15.	Low	840	689	186		10	.52	.65	.25	2.11	.17	11.7	22.6	3.60	Palms unthrifty, fronds small and sparse, older fronds chlorotic.
16.	5-20	998	785	286		10	...	...	...	...	...	16.4	18.2	2.75	
17.	...	752	977	223		10	...	...	...	...	...	5.3	25.3	2.97	
18.	...	687	902	284		8	...	...	...	...	...	...	...	...	
19.	...	681	904	212		9	.46	.47	.16	2.16	.18	3.8	29.4	3.40	
20.	...	672	926	227		10	...	...	...	...	...	5.8	30.0	3.12	
21.	...	380	1080	255		10	.49	.43	.24	2.18	.15	5.2	26.7	3.51	
22.	Very low	530	858	236		18	.28	.47	.20	2.05	.15	19.7	15.2	2.89	Palms very unhealthy, some dying. Palms are stunted, fronds very small and few in number, severe chlorosis.
23.	0.5	393	956	232		13	.26	.72	.13	2.04	.12	3.8	24.7	2.78	
24.	...	366	753	176		11	.10	.47	.25	1.74	.13	7.6	21.4	2.62	
25.	...	364	795	201		14	.24	.29	.21	1.71	.11	...	...	...	

TABLE II—ANALYSIS OF SOILS

Location Site No.	Productivity Rating Nuts/Palm	Depth Ins.	pH	Soluble Salts per cent.	Exchangeable Cations m.e. per cent.				Cation Exchange Capacity m.e. per cent.	Rate Satur- ation per cent.	P ₂ O ₅ Olsen Throg. p.p.m.	Total N per cent.	Clay per cent.	Description
					Ca++	Mg++	K+	Na+						
3	High 60 +	0-4 4-8	5.6 6.0	.029 .021	25.0 24.3	8.0 8.9	.52 .30	.50 .46	34.0 34.0	38.8 36.8	88 92	.38 ...	29 33	Alluvial soil volcanic origin.
6	Medium 20-40	0-4	7.4	.078	*	2.4	.58	.60	*	25.8	100	.92	36	Shallow red-brown clay loam.
8		0-4	6.1	.063	19.9	6.2	.54	.53	27.2	27.0	100	.44	45	Deep red-brown clay loam.
9		4-8	6.1	.065	16.1	3.6	.51	.59	20.8	21.6	96	...	60	
10		0-4	6.2	.072	32.5	3.3	.57	.80	37.2	...	...	.52	63	Shallow red-brown clay loam.
		0-4	6.5	.057	31.6	10.6	.65	.50	43.4	...	...	.66	55	Shallow red-brown clay loam.
		4-8	6.9	.059	40.0	5.3	.37	.51	46.4	...	...	...	60	
15	Low	0-4 4-8	5.3 5.2	.034 .012	19.9 14.7	3.6 0.9	.47 .25	.57 .53	24.5 16.4	30.0 ...	82 ...	.46 ...	63 71	Red brown-yellow clay.
16	5-20	0-4	5.7	.038	19.8	2.6	.44	.64	23.5	25.9	91	.54	70	Shallow red-brown clay.
		4-8	5.7	.028	14.4	1.3	.26	.60	18.8	21.1	79	...	72	
26		0-4	5.8	.059	13.8	4.0	.54	.48	16.6	21.4	88	...	...	Red brown-yellow clay.
		4-8	5.7	.040	9.0	2.1	.34	.40	11.8	...	...	...	78	
19		0-4	5.9	.029	17.8	3.0	.28	.50	21.6	23.5	92	.37	67	Shallow red-brown clay loam.
		4-8	5.7	.023	13.3	1.6	.30	.59	15.8	18.6	85	...	72	
22	Very low 0-5	0-4 4-8	5.3 5.1	.032 .016	21.9 16.2	2.8 1.0	.32 .20	.57 .59	25.6 18.0	32.3 29.0	79 62	.66 ...	62 67	Red brown-yellow clay.
		0-4	5.5	.045	17.2	3.4	.43	.64	21.7	25.5	85	.41	67	Red brown-yellow clay.
		4-8	5.6	.041	13.0	1.3	.37	.46	15.1	18.9	80	...	73	

1. All results are expressed on an air dry basis.

2. As no preliminary leaching for soluble salts was carried out, these figures include small amounts of Soluble Salts.

* Calcium carbonate present.

TABLE III—POTASSIUM CONTENTS OF SOILS

Location Site No.	Productivity Nuts/Palm	Depth ins.	K. Soluble in conc. HCl, m.e./100g	K Soluble in HNO ₃ , m.e./100g	Exchangeable K m.e./100g
3.	High	0-4	4.40	1.90	.52
	60 +	4-8	4.55	1.40	.32
6.	Medium	0-4	1.65	1.15	.58
8.	20-40	0-4	1.50	.75	.54
		4-8	1.40	.75	.51
9.		0-4	1.35	.65	.57
10.		0-4	1.45	.95	.65
		4-8	1.20	.60	.37
15.	Low ...	0-4	1.45	.65	.47
	5-20	4-8	1.40	.55	.25
16.		0-4	1.35	.55	.44
		4-8	1.15	.35	.26
26.		0-4	1.25	.75	.54
		4-8	1.35	.60	.34
19.		0-4	1.20	.50	.28
		4-8	1.25	.55	.30
22.	Very low	0-4	1.05	.45	.32
	0-5	4-8	1.20	.50	.20
24.		0-4	1.25	.60	.43
		4-8	1.30	.50	.37
Average 0-4 inches.—					
High Productivity			4.40	1.90	.52
Medium Productivity			1.49	.90	.58
Low Productivity			1.31	.61	.43
Very Low Productivity			1.15	.52	.37

TABLE IV

Location Site No.	Distance Inland (Yds.)	NUT WATER (ppm)				No. of Analyses	FROND (Per cent. dry basis)					HUSK (Per cent. in ash)			PUERARIA (Per cent. dry basis)					
		K	Na	Ca	P		Cl	K	Na	Ca	N	P	Mn (ppm)	K	Na	Per cent. Ash	K	Na	Ca	P
7.	10	1316	674	200	84	2177	10	.83	.54	.11	2.02	.12	50	13.3	20.1	3.11	1.64	.02	1.40	.20
13.	140	820	954	218	121	2147	10	...	...	...	...	...	...	...	...	...	...	...	...	...
21.	200	380	1080	255	125	2080	10	.49	.43	.24	2.18	.15	74	5.2	26.7	3.51	1.44	.02	1.40	.28
23.	350	393	956	232	143	1896	13	.26	.72	.13	2.04	.12	85	3.8	24.7	2.78	.52	.01	1.28	.30
25.	800	364	795	201	128	1952	14	.24	.29	.21	1.71	.11	350	...	...	...	.44	.01	1.31	.25

For comparison—health palms on volcanic soil.

1.	400	3000	78	231	104	1900	8	2.1	.02	.16		60	35.7	.66	4.21
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FIELD DESCRIPTIONS.—

7. Palms fairly good, up to 40 nuts/palm, fronds large, no chlorosis.

Pueraria and grass cover showing no symptoms.

13. Palms variable, 20-40 nuts/palm, little to no chlorosis in older fronds.

No symptoms in *Pueraria*.

21. Palms very variable, 15-30 nuts/palm, distinct yellowing of lower fronds.

No symptoms in *Pueraria*.

23. Palms very poor, 0-5 nuts/palm, severe chlorosis of old and young fronds, fronds small and sparse.

Pueraria very chlorotic and stunted.

25. Palms extremely poor, some dying, 0-5 nuts/palm, severe chlorosis of all fronds, palms stunted, fronds very small and sparse.

Pueraria very chlorotic, inadequate soil cover.

To investigate the marked increase in the debilitation of the palms with increasing distance from the shore, a traverse was run along a line of palms from the shore to 800 yards inland. The topography and soil changes of the plantation chosen for the traverse were typical of many East Coast plantations. At the shore a raised coral terrace, some 60 feet above sea-level, gradually slopes down away from the sea for a distance of about a mile to the foothills. The soil near the shore is shallow, slightly-acid to neutral red-brown clay-loam, changing to a deep, acid, yellow-brown clay further inland. Five sites on the traverse were selected for sampling. The results and field descriptions are given in Table IV.

A study of the data set out in Tables I to IV shows that the potassium level in the palms and soil is closely related to palm productivity and the deficiency symptoms.

(a) NUT WATER ANALYSIS.

Potassium: Under conditions of an abundant potassium supply as in the soils derived from volcanic ash (3 to 6 m.e. per cent. exchangeable K^+) (Graham and Baseden 1956) the potassium content in mature fallen nuts from very productive palms ranges from 2300 to 3000 p.p.m. K. This appears to be about the maximum level that occurs under natural conditions. As would be expected, a higher level occurs in actively-

Between these two extremes, the productivity of the palms, measured as the number of nuts carried, bears a close relationship to the level of potassium in the nut water.

In Graph I, the potassium concentration in the nut water is shown plotted against the productivity of palms at each of the 25 sites. The average productivity of the 60+ nuts per palm group has been arbitrarily set at 70.

The regression line for these data is:

$$Y = .0281 X - 4.86$$

where Y = average number of nuts per palm at each site,

X = p.p.m. K in the nut water (average of approximately 10 nuts from each site).

The correlation coefficient is 0.95.

From the data summarized in Graph I, a tentative scale has been drawn up to indicate the potassium status of palms in the areas investigated.

Sodium: A striking feature of the nut water analysis is the substantial uptake of sodium when there is a deficiency of potassium.

On the potash-adequate volcanic ash soils, the sodium in nut waters is generally less than 100 p.p.m. Na, regardless of proximity to the sea. Where potash is deficient on

K (p.p.m.) (in mature nuts)	PRODUCTIVITY (nuts per palm)	SYMPTOMS	POTASSIUM STATUS INDICATED
2,300-3,000	60+	None	High.
1,600-2,300	40-60	None	Sub-optimal.
900-1,600	20-40	Chlorosis of lower fronds in some cases.	Deficient.
350-900	5-20	Fronds small and sparse, older fronds chlorotic.	Very deficient.
0-350	0-5	Palms stunted, some dying. Fronds very small and sparse. Severe chlorosis of old and young fronds.	Extremely deficient.

developing nuts and rises to 4000 p.p.m. K in the smallest nuts on the palm.

On the acid soils derived from coral (0.2 to 0.4 m.e. per cent. exchangeable K^+) where palms are carrying from nil to five nuts each, the average potassium level in the water of mature fallen nuts is less than 400 p.p.m. K, some individual nuts being as low as 50 p.p.m. K.

the acid coral-derived soils and the level in the nut water falls below 1,000 p.p.m. K, sodium rises to 800-900 p.p.m. Na.

In New Ireland, where the more deficient soils are further inland, the situation arises that palms nearer the sea have a lower sodium content in the nut water.

Plate 1.—A typical declining plantation on the east coast of New Ireland.



Plate 2.—Coconut Palm showing chlorosis caused by potassium deficiency. Note the short fronds and low nut production.

Plate 3.—Chlorosis symptoms on a coconut palm frond.



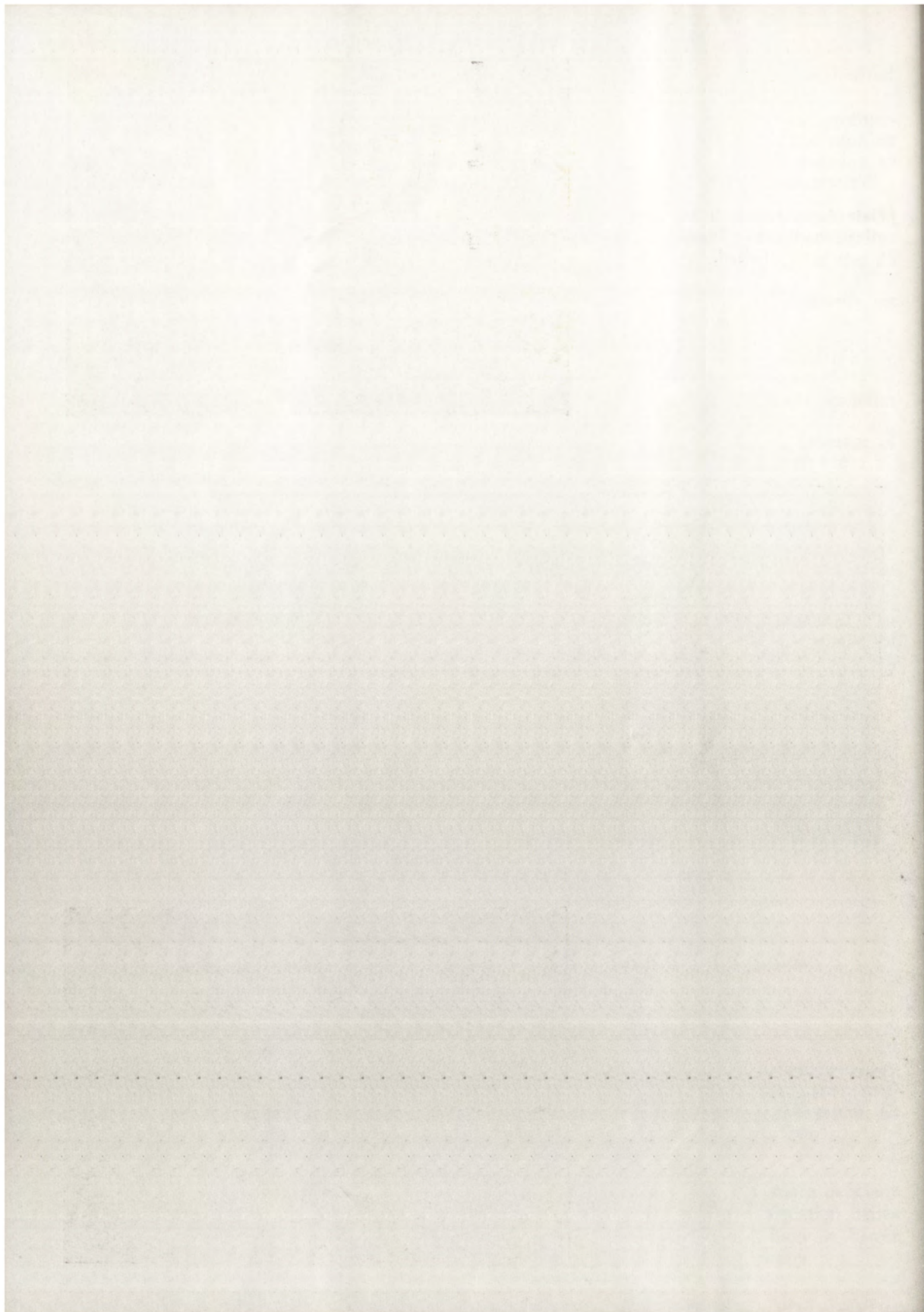


Plate 4.—Close-up view of typical chlorosis symptoms on a coconut palm frond.

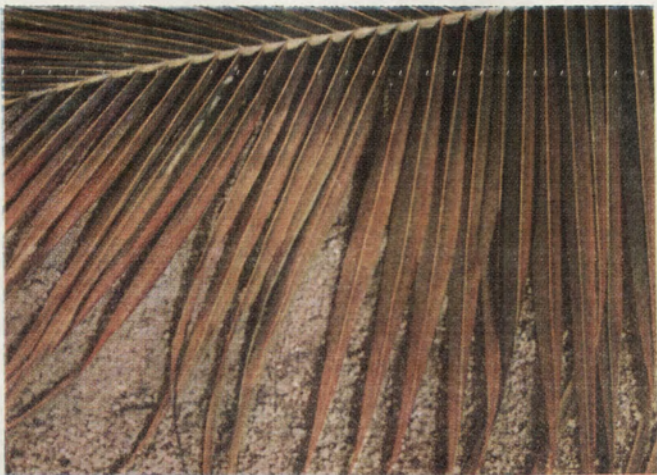


Plate 5.—General view of Pueraria cover crop showing severe chlorosis in the older leaves.

Plate 6.—Pueraria leaf from the field showing marginal chlorosis caused by Potassium deficiency.



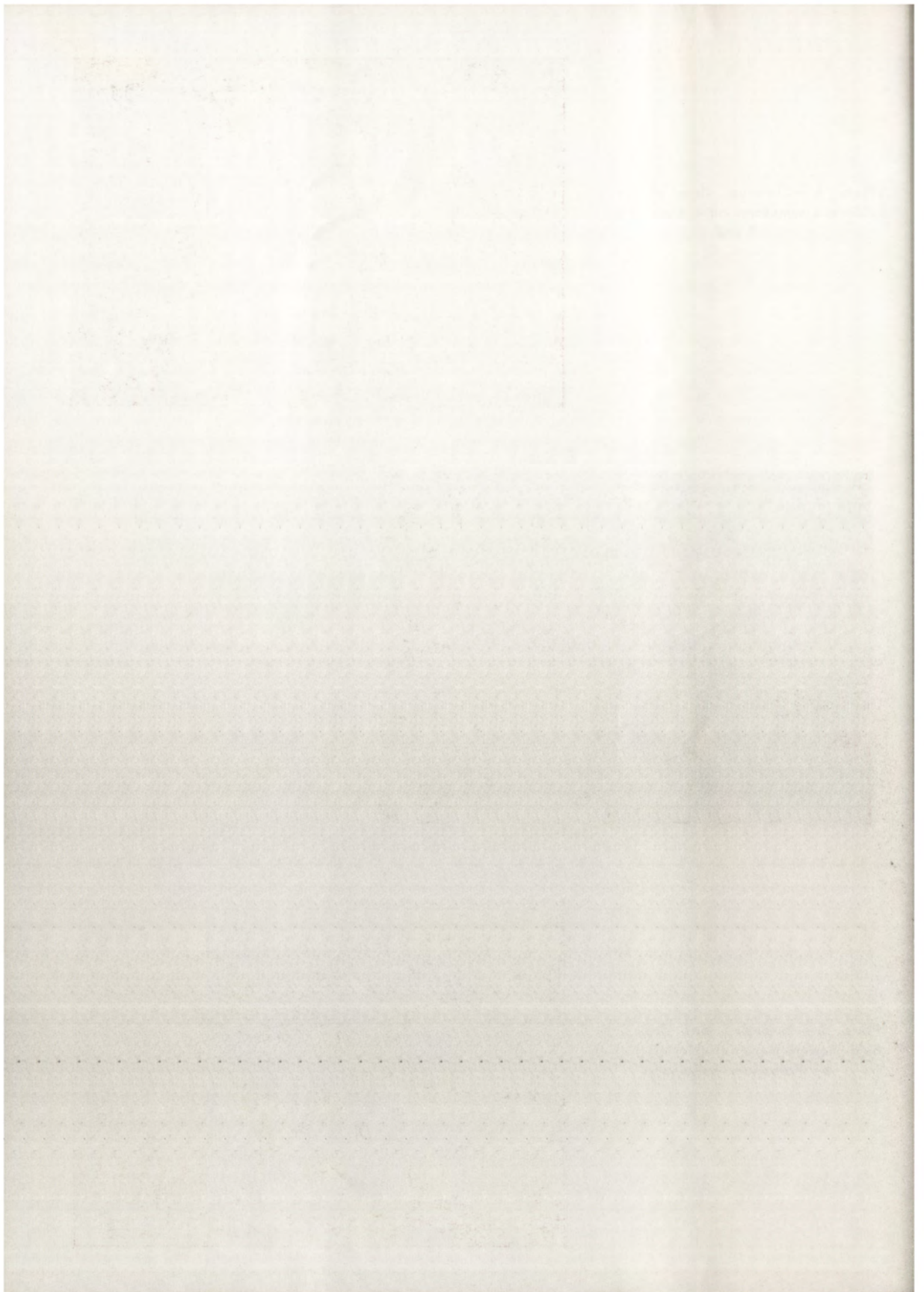


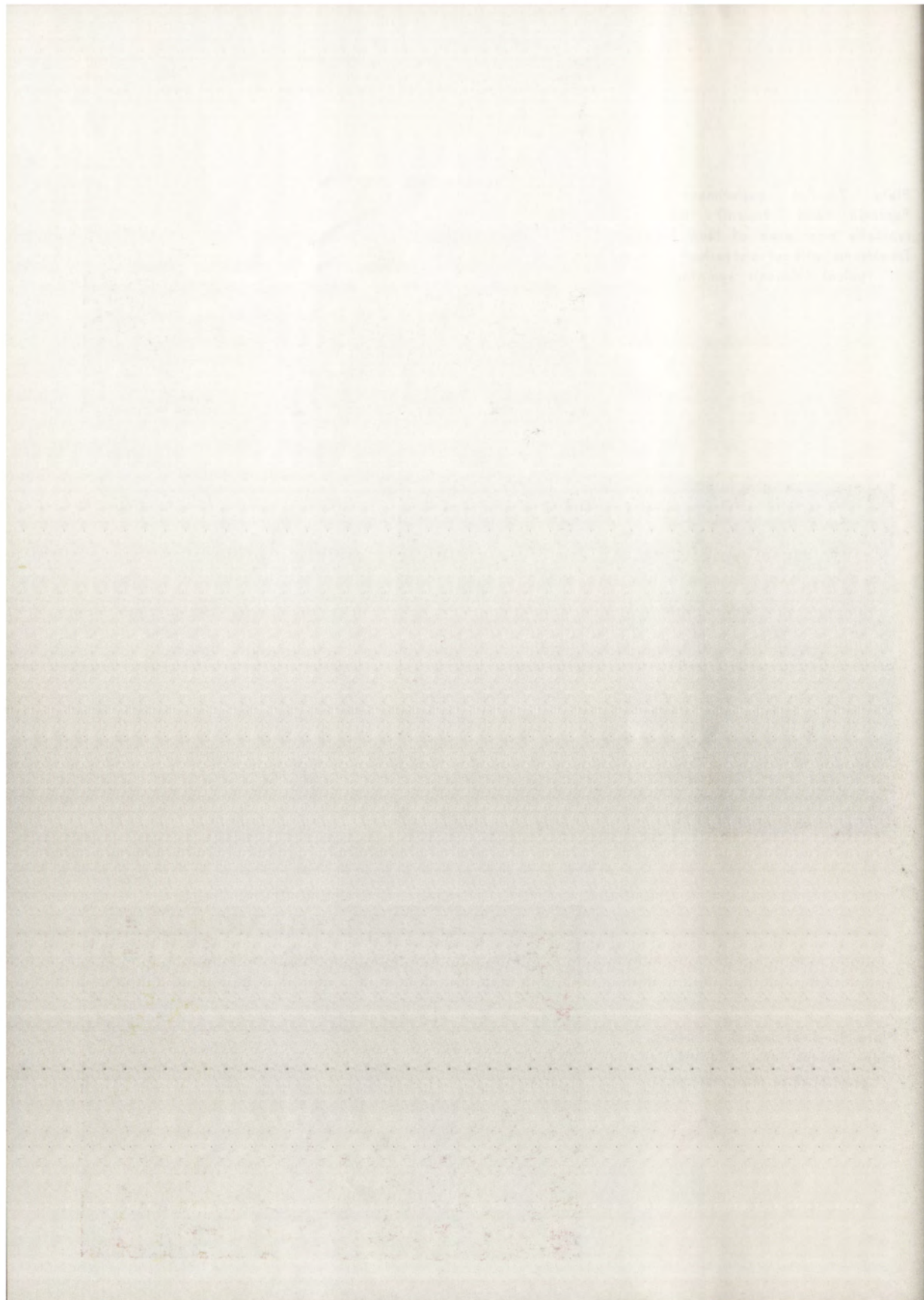
Plate 7.—Pot experiment using Pueraria and topsoil from a typically poor area of New Ireland. Treatments without potassium showed typical chlorosis symptoms.



Plate 8.—General view of cover crop predominantly Centrosema, with marginal chlorosis.

Plate 9.—Leaf scorch in cacao. The older leaves are affected with a greyish-white marginal necrosis.





The relationship between sodium and potassium is shown in Graph II, where each point represents the average of the analysis of approximately 10 nuts from a site.

The line of regression is given by the equation :

$$Y = 1158 - .360 X$$

where Y = p.p.m. Na in the nut water

X = p.p.m. K in the nut water

The coefficient of correlation is -0.88 .

It is noticeable that the summation of the chemical equivalents of sodium and potassium tends to be constant in the medium to high productivity groups, indicating the ability of mutual replacement. However, there is no evidence that sodium can replace potassium in its function as a plant nutrient.

The following figures show the average potassium and sodium contents of nut waters in each of the five productivity groups, converted to milliequivalents per litre.

Productivity (nuts per palm)	K+	Na+	K+ plus Na+
60+	66.7	5.8	72.5
40-60	52.8	18.4	71.2
20-40	28.4	42.4	70.8
5-20	18.3	39.0	57.3
0-5	10.5	36.6	47.1

From the foregoing it would appear that a high sodium content (800-900 p.p.m. Na) may be taken as indirect evidence of a potassium deficiency.

Calcium: The calcium concentration of nut water tends to be constant, regardless of whether samples come from palms on coral sand (pH 8.4) or acid coral-derived soil (pH 5.0).

Chloride: The main inorganic anion present in nut water is chloride (approximately 2,000 p.p.m. Cl) and the level varies very little according to the distance from the sea. The chloride content is quite unrelated to sodium content. On volcanic ash soil, low sodium values (less than 100 p.p.m. Na) are associated with about 1,900 p.p.m. Cl at both 400 yards and two miles from the sea. In New Ireland, samples from near the shore and half a mile inland differ very little in chloride content (2,177 to 1,952 p.p.m. Cl), although the sodium level varies considerably (see Table IV).

Phosphorus: As shown in Table IV, the poorer palms further inland have a relatively higher level of phosphorus in the nut water. These levels (120-140 p.p.m. P) are higher than those found in productive palms on other soil types.

At Site 7, where the level falls to 84 p.p.m. P, the coral is exposed in many parts with only pockets of soil occurring in the crevasses.

Areas such as this give relatively good, but often still less than optimum production. The adequacy of phosphorus in these areas is under investigation.

(b) FROND ANALYSIS.

Potassium: The figures in Table I show that the potassium content of the fronds ranges from 2.1 per cent. K in good palms to as low as 0.10-0.28 per cent. K in the poorest palms. As with the nut water values, there is a close relationship between productivity and potassium content. The average values in each of the groups are as follows:—

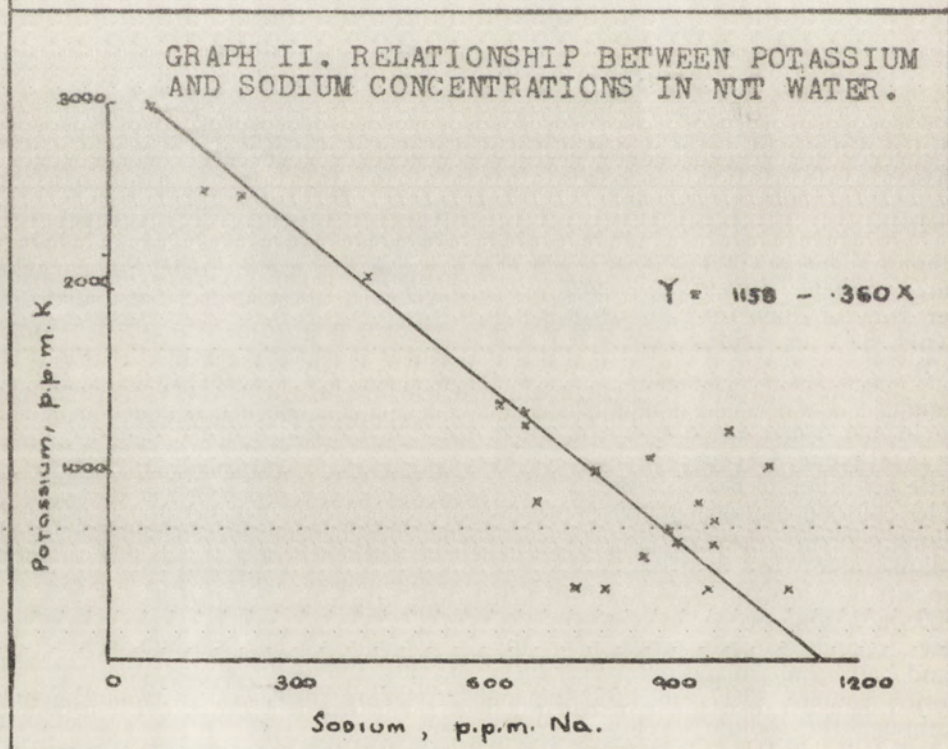
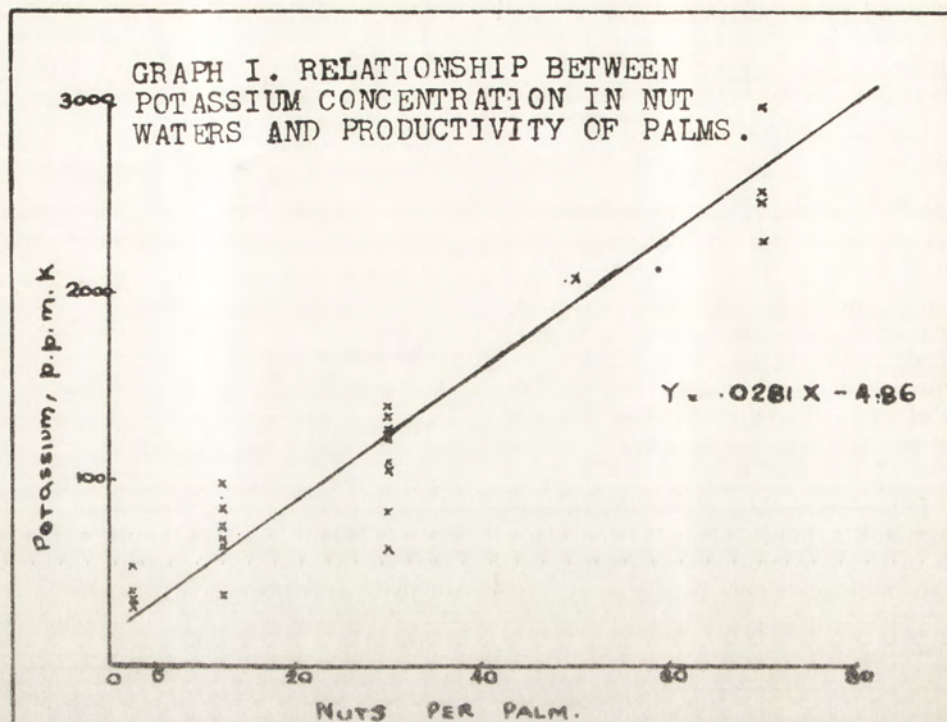
	Productivity	K per cent. (dry basis)
1	High	2.1
2	Fairly high	—
3	Medium	.77
4	Low	.49
5	Very low ...	.22

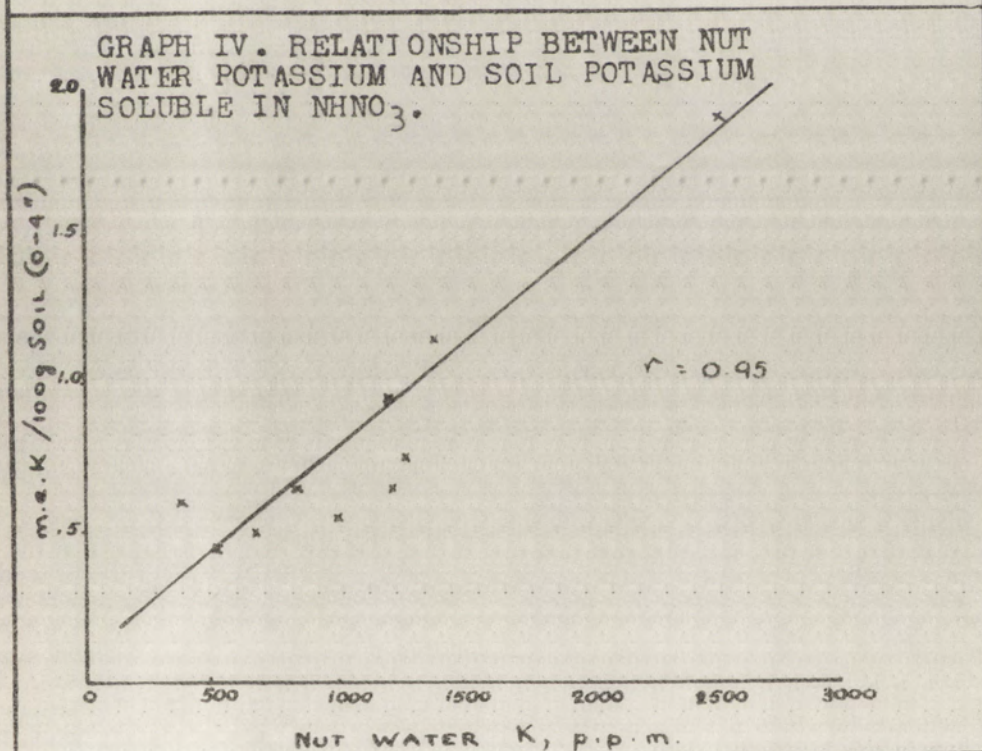
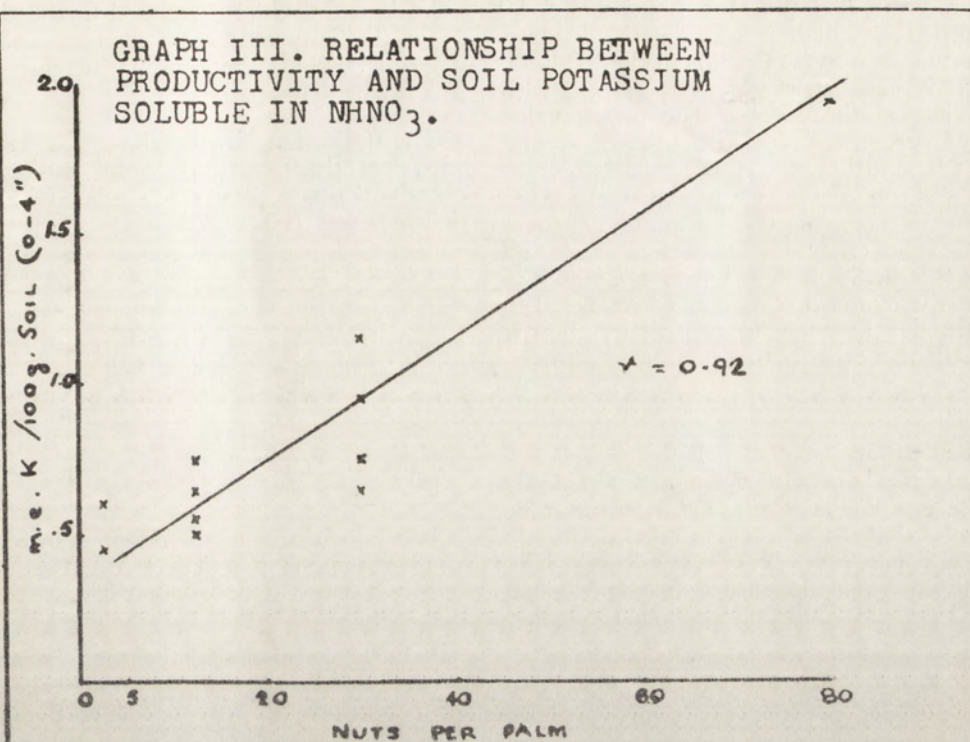
From the analysis and field notes it appears that symptoms of chlorosis sometimes occur when the level of potassium is below 0.8 per cent. K, and are invariably present when the level falls below 0.5 per cent. K.

Prevot and Ollagnier (1957) place the critical level of potassium in fronds at 0.45 per cent. K.

Sodium: The uptake of sodium is considerable in the medium, low and very low productivity groups. Such a high content would be considered toxic in many plants, but in the case of the coconut palm it appears that sodium is only absorbed in quantity as a compensatory action when there is a potassium deficiency.

Calcium: The calcium content of the fronds shows little variation that can be related to the productivity of the palms or the amount of exchangeable calcium in the soil.





Nitrogen : A level of approximately 2.0 per cent. N, which is considered adequate, was found in fronds of palms in the medium, low and very low productivity groups, with exceptions at three sites. The lowest value of 1.67 per cent. occurred at Site 6, a coral sand where little organic matter had accumulated and conditions were too alkaline for the establishment of the usual leguminous cover crops. The other low values of 1.74 and 1.71 per cent. N occurred at Sites 24 and 25 where the *Pueraria* cover was so restricted in growth, due to potassium deficiency, that it probably was contributing very little nitrogen to the soil.

The nitrogen levels of palms in the areas investigated are generally high, giving evidence of the beneficial effects of maintaining a good leguminous cover. Palms on volcanic ash soil with no cover crop contain only about 1.7 per cent. N in the fronds. The critical level for nitrogen in fronds is given as 1.70 per cent. N by Prevot and Ollagnier.

Phosphorus : The average phosphorus content of fronds of palms in the medium, low and very low productivity groups is 0.15, 0.17, 0.13 per cent. P respectively. It is difficult to assess how marked an effect a severe deficiency of potassium has on the phosphate level, but, as far as can be judged, the contents found would not indicate a deficiency. Prevot and Ollagnier give the critical level as 0.10 per cent. P.

Manganese : There is a tendency towards higher contents of manganese in the fronds of palms from the poorer areas on the more acid soils. This is shown in Table IV.

It has been found that sun drying of soils preparatory to analysis releases a considerable amount of exchangeable manganese (up to 250 p.p.m. Mn^{++}) from the acid coral-derived soils. The same soils release less than 2 p.p.m. Mn^{++} if not sun dried.

The analysis of fronds and leaves of indicator plants gives no evidence of manganese toxicity under normal rainfall conditions, but the possibility of damage from excess manganese during exceptionally dry periods is still being investigated.

(c) HUSK ANALYSIS.

Potassium and Sodium : The percentage of potassium in the husk ash shows a consider-

able decrease which is related to the decline in productivity of the palms (see Table I). There is also a corresponding increase in the sodium content.

The following figures show the extreme variation that can occur in husks from potash-adequate volcanic soil (A) and deficient soil (B).

	A	B
Weight of dry husk (gm.)	414.0	270.0
Ash per cent.	4.21	3.78
K per cent. in ash	35.7	3.79
Na per cent. in ash	0.66	28.1
Total K content per husk (gm.)	6.2	0.39

The significance of these figures in relation to management practices is discussed later.

(d) SOIL ANALYSIS.

A fairly complete analysis of soil samples from 11 of the 23 sites was undertaken and the results are shown on Tables II and III. While most attention was paid to the potassium status of the soil, factors influencing this status, e.g., exchange capacity and mechanical composition, also were examined.

The pH of the soils varies from slightly alkaline on some of the red-brown loams over raised coral to markedly acid on the deep brown-yellow clays further inland. The pH correlates well with the percentage base saturation which varies from 62 to 100 per cent. The total exchange capacity of the coral-derived soil is fairly constant, and relatively high, probably due to the high organic matter content of the topsoil. The total nitrogen content of the soils, most of which are under heavy legume cover, is high; and leaf analysis confirms the view that no serious nitrogen deficiency exists throughout the plantations.

The phosphorus status of most of the soils is fairly low by the two methods used for determining available phosphorus. However, coconuts have a low requirement for phosphorus and the analysis of plant samples shows that phosphorus is not likely to be a seriously limiting nutrient. Further investigations are being carried out to define more clearly the P status of these soils.

As expected, calcium is the dominant cation in the exchange complex and exchangeable magnesium is also present in normal quantities. The exchangeable potassium content is not high in any of the soils and examination of Table III shows that it can roughly be correlated with the degree of productivity of the palms on coral-derived soils. Further differentiation of the potassium content of the soil was made by boiling with (a) N HNO_3 and (b) conc. HCl . The former was used to extract the less available potassium as well as exchangeable potassium, while the latter should give results approximating the total potassium content of soils derived from limestone.

A good relationship was found to exist between the productivity and condition of palms and nitric acid-extractable potassium (Graph III). On some of the poorer soils this potassium is estimated to be less than 200 lb. per acre foot of soil and as an acre of healthy coconuts may remove annually up to 100 lb. of potassium, it is not surprising that many palms are showing gross deficiency symptoms. The total reserves of potassium on many of the better soils are less than 1,000 lb. per acre foot of soil and continued healthy growth does not appear possible as, under normal plantation practices, little potassium is returned to the soil.

There is good correlation between the potassium contents of the soil, particularly the nitric acid-extractable potassium, and the potassium content of the coconut water (Graph IV). No significant relationships are apparent between the decline in productivity in palms and $\text{Ca}:\text{K}$ ratio or potassium percentage of the exchange complex. Nor is there evidence in soil analyses of any marked accumulation of sodium, either in the soluble or exchangeable form, to account for the large amounts absorbed by the palms.

It can be concluded from soil analyses and their relationship to palm production that:—

(a) The available potassium status of the coral-derived soils is low, especially on the areas of most decline and chlorosis;

(b) Coral-derived red and yellow clay soils containing less than 0.6 m.e. per cent. of exchangeable K and less than 1.0 m.e.

per cent. of K soluble in normal nitric acid can be regarded as unlikely to produce optimum yields of coconuts; and

(c) The potassium reserves of most of the soils are inadequate for the continued healthy growth of coconuts without further additions of potassium.

(e) PUERARIA SYMPTOMS.

In the field there is ample evidence of close association between the occurrence of symptoms in *Pueraria* and the vigour of coconut palms in the same area. To assess the value of *Pueraria* as an indicator plant, leaves from several sites were analyzed. Pot tests and field applications of fertilizer were also made.

Leaf Analysis: From the descriptions and figures in Table IV it will be seen that, on a traverse in from the shore, the potassium status of *Pueraria* parallels that of the palms and falls progressively from 1.64 to 0.44 per cent. K. No marked change occurs in the sodium, calcium or phosphorus levels.

Samples collected from Sites 16, 19, 22, 23, 25, where palms were poor and symptoms occurred in the *Pueraria*, had potassium contents ranging from 0.44 to 0.60 per cent. K. Samples from 7 and 11, where there were no symptoms, contained 1.64 and 2.70 per cent. K.

Pot Tests: Treatments of no fertilizer, N, N+P, N+P+K, and N+P+K+ trace elements showed that the symptoms developed only in pots without the potassium application. (See Plate 7.)

Fertilizer Application in the Field: Application of KCl in the field gave complete removal of the chlorosis as well as a substantial increase in vigour of the *Pueraria* after a few months.

It is evident from these investigations that the symptom illustrated in Plates 5 to 7 is due to potassium deficiency and that *Pueraria* can be considered a useful indicator plant for detecting a deficiency of potash in soils.

(f) LEUCAENA SYMPTOMS.

Leaf samples from four locations where there was leaf tip scorch on *Leucaena* seedlings had potassium contents of 0.51-0.75 per cent. K. Samples from seedlings with no scorch contained more than 1.0 per cent. K.

Applications of potash in the field removed the symptoms and improved growth, substantiating the conclusions from leaf analysis that the symptom was an indication of potassium deficiency.

(g) CACAO SYMPTOMS.

Marginal leaf scorch occurs frequently in *cacao* near the sea, but seldom further inland. Leaf samples from eight sites with scorch showed that a negligible amount of sodium was present in the young leaves (0.02 per cent. Na), and the potassium content ranged from 0.38-1.06 per cent. K. Samples from six sites with no scorch also were low in sodium and contained 0.96-1.86 per cent. K. Although the possibility of excessive amounts of salt in the older leaves which show the symptom is not excluded, it is evident that the potassium status of the trees at all sites is low. The average content in 30 samples from thrifty trees on volcanic ash soil was found to be 2.55 per cent. K. A level of 2.12 per cent. K is given for "good standard plots" in Trinidad (McDonald 1934).

Reduced uptake of potassium by trees nearer the shore, because of the lower K/Ca ratio in these soils and increased sensitivity to salt due to the low potassium status of the trees, are factors still under investigation in relation to the cause of the marginal scorch symptom.

The phosphorus contents of samples from the 14 sites gave an average value of 0.18 per cent. P (range 0.14-0.22 per cent. P) which is slightly below 0.219 per cent. P recorded for "good standard plots" in Trinidad, and 0.21 per cent. P from 30 samples from healthy *cacao* on volcanic ash soil.

Discussion and Conclusions.

It has been shown that the considerable range of productivity (from less than five to more than 60 nuts per palm) occurring among palms on coral-derived soil is closely related to the potassium levels found in nut waters, husks, fronds and soils. The intensity of symptoms such as chlorosis, smallness and sparseness of fronds is similarly related to the potassium level.

The general pattern of distribution of healthy and poor palms on the east coast of New Ireland can be explained in terms of

the potassium status of the palms and the change in soil characteristics. The better palms with a higher potassium status occur on a narrow coastal strip of shallow, neutral to slightly acid, red-brown clay-loams, and poorer palms with a low potassium status are located on a much deeper, acid, yellow-brown clay that is present on the inland side of this strip. There is a graduation in soil characteristics (depth, pH, potassium content) and in the potassium status of the palms between these extremes which coincides with a change in productivity.

The analysis of nut water, first used by Salgado (1946), has been shown to be a useful diagnostic method which appears to be capable of indicating not only the presence but, to some extent, the degree of potassium deficiency in coconut palms. From the data in this report, a tentative scale has been drawn up which may prove useful as a guide to the potassium status of palms on other soil types. Preliminary studies have not indicated that there is any marked change in nut water potassium with season, this being due probably to the continuous-bearing nature of the coconut palm and the absence of extreme seasonal variations in the areas investigated. Nut water analysis has a considerable advantage over frond analysis as a diagnostic method for potassium deficiency because of the difficulties of large-scale sampling of fronds.

From frond and nut water analysis there is no indication that phosphorus is connected with the decline of palms.

The nitrogen level in both soil and fronds has been found to be high where good cover crops are established. Most plantations carry adequate cover.

Damage from excessive manganese during exceptionally dry periods might appear to be a possibility, from the evidence that sun-drying of soil samples before analysis releases large amounts of exchangeable manganese from the more acid soils where palms are poorest. Leaf analyses of coconuts, cover crop and *cacao* have given no evidence of excessive manganese uptake during a season of normal rainfall. It is possible that a critical soil moisture level must be reached before manganese is released and that such a level rarely, if ever, occurs in the field. A similar effect of manganese release by air-

drying of red clayey "Lunyu" soils in Uganda has been recorded by Chenery (1954).

The commonly-held opinion that palms perform better near the sea because of the influence of salt either in spray or ground water is not supported by this investigation. The nut water and frond analyses show that the uptake of sodium is greater in those palms which are poorer and further from the sea and is closely and inversely related to the uptake of potassium. The chloride content of nut water appears to be fairly constant (2,000 p.p.m. Cl), irrespective of the potassium or sodium levels or proximity of the sea.

The amount of potassium in husks is of some interest, since the practice of returning husks to the soil is not always adopted. It is worth noting that 6,000 husks from healthy palms contain nearly 100 lb. of potash (K_2O), so that a plantation producing 100 tons of copra annually removes about 10,000 lb. of potash from the soil by way of the husks alone. The potash removal over 30 to 40 years would be considerable and an important depleting factor.

In seed selection for replanting, it is important to consider the food reserves of the nut, since for several months the developing plant relies almost entirely on the nutrients within the nut, and even after root establishment in the soil some roots continue to draw on reserves within the husk. There is 17 times as much potassium in nuts from healthy palms (6.8 gm. K in husk and water) than in nuts from deficient palms (0.40 gm.

K), and for this reason alone the collection of seed nuts from deficient areas should be avoided.

Cacao is an important secondary crop being developed on many of the plantations which were investigated, and leaf analysis indicates the potash status is generally low. It must be considered a distinct possibility that, in this crop also, potassium deficiency may in time reveal itself by way of loss in productivity.

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