# THE DISTRIBUTION OF TRACE ELEMENTS IN THE LEAVES OF THE COCONUT PALM, AND THE EFFECT OF TRACE ELEMENT INJECTIONS

P. J. SOUTHERN AND KAY DICK


## ABSTRACT

*A study was made on the distribution of manganese, iron, copper, zinc and boron in the leaves of coconut palms from different areas. There were large variations in leaf composition according to age of leaves and within the sampled leaflets.*

*Results showed increased uptake of manganese, iron, zinc and boron following solid injections of trace elements into coconut stems. Trace element contents of coconut leaves in all parts of Papua and New Guinea are tabulated and compared with figures obtained elsewhere.*


## INTRODUCTION

During the past few years, research on the trace element requirements of coconut palms has received an increasing amount of attention. A number of references (Fremond (1958, 1961), Pomier (1964), Meadows (1964), Bachy and Hoestra (1958)), quote chemical analyses for trace elements and give details of fertilizer and injection experiments with the trace elements, particularly iron and manganese.

A considerable number of trace element analyses has been made in Papua and New Guinea in conjunction with major nutrient analysis and investigations of nutritional problems in coconut areas. The tentative critical levels proposed by Fremond (1961) have been used as a guide to the trace element status of various areas and plantations.

This paper describes investigations carried out to determine the distribution of these trace elements in the leaves of untreated palms and the effect of solid injections on the trace element contents of the leaves. It also summarises other trace element results so far obtained in Papua and New Guinea.

## DESCRIPTION OF SITES

Three areas were selected for this initial investigation. All were believed to have a low, but not necessarily deficient, trace element status as they were situated on soils with a high base status and tending towards alkalinity. The main investigations took place at Finschhafen, New Guinea (Site 1), where soils were derived from coral limestone. At this site deficiency symptoms, particularly those caused by manganese and iron, were prevalent in coffee, cocoa, legumes and ornamentals.

There were symptoms of chlorosis and necrosis in some coconuts and it had been thought that they could have been due to a trace element deficiency, but events subsequently showed that they were more likely to have been caused by leaf hopper insects.

Site 2 was situated at Hisiu, Papua, on an alluvial area known to have a marginal sulphur status. The palms were healthy and showed no abnormalities. Palms at Site 3, Kapogere, Papua, were also in healthy condition, although zinc deficiency had occurred in a nearby rubber nursery.

All the palms selected were immature and under 5 years old. There were no more than 12 leaves on each so that the ten leaf positions selected covered the range from young to old leaves.

## SAMPLING METHODS

Leaf samples were collected from consecutive fronds, the first partly opened frond being counted as No. 1. Six leaflets from the medial part of the fronds were selected and the middle thirds, minus midrib, used for the sample. In each case, the leaves from no less than five palms were composited to form the final sample. In the case of Sites 1 and 3, additional samples consisting of the basal and tip parts of the leaflets were also sampled and in the latter case, the leaflet midribs were also kept for analysis.

## INJECTION METHODS

Injections were carried out at Site 1 where palms were a little older and had developed a short trunk. Six holes were bored at equidistant positions around the bases of five palms, using a brace and ¾in. bit. Holes were about four inches deep. The solid salts were forced into the holes using a plastic syringe and the holes were sealed with cotton wool and a sealing compound. The types of salts and amounts of each were as follows:-

| | |
|---|---|
| Manganese sulphate | 5 cc |
| Ferrous sulphate | 5 cc |
| Copper sulphate | 5 cc |
| Zinc sulphate | 5 cc |
| Borax | 5 cc |
| Sodium molybdate | 5 cc |

Samples of leaves were collected ten weeks after the injections had been carried out. At the same time control samples were collected from a group of untreated palms immediately adjacent. The injections produced no visible effects on the palms at the time of sampling or later.

## RESULTS AND DISCUSSION

The results of all analyses of the trace elements manganese, iron, copper, zinc and boron are given in *Tables* 1 to 5. Molybdenum was not determined. The analytical methods used were those given by Southern and Hart (1968).

The trends according to leaf age and sampling position are depicted graphically in *Figures* 1 to 5. (Note that the contents in parts per million are now always represented by the same scale).

From examination of the analytical results and graphs the main conclusions of the investigations were as follows:-

### Manganese Contents.

*Variation within leaflets*. There were no consistent differences between analyses for the basal, central or tip positions of the leaflets (*Fig*. 1a). However, the manganese contents of the midribs on the site investigated were much less than the contents of the leaves for every leaf position.

*Variation with age of leaves*. As is the case with other plants, manganese tended to accumulate in the older leaves. For the three sites the increase in manganese content with age of leaves was well demonstrated (*Fig*. 1b). Although the leaf values for the young leaves were fairly similar, differences in manganese contents for the older leaves were very large. Thus it is apparent that sampling of the older leaves is preferable when comparing manganese uptake (and availability) in different coconut areas.

*Effect of injections*. Solid manganese salt injections were clearly effective in increasing the content of the leaves. Large increases in manganese content following trunk injections have also been reported by Fremond (1961), Pomier (1964) and Meadows (1964), working on palms in coral soils where soil amendments are ineffective. They also noted some foliage colour improvement due to the injections although iron effects were greater. Two and a half months after injection at Site 1 in these experiments, manganese contents had risen markedly but translocation in the palms was very uneven. In general, the effects were greater for the younger leaves and there was evidence that manganese was still being absorbed at the time of sampling.

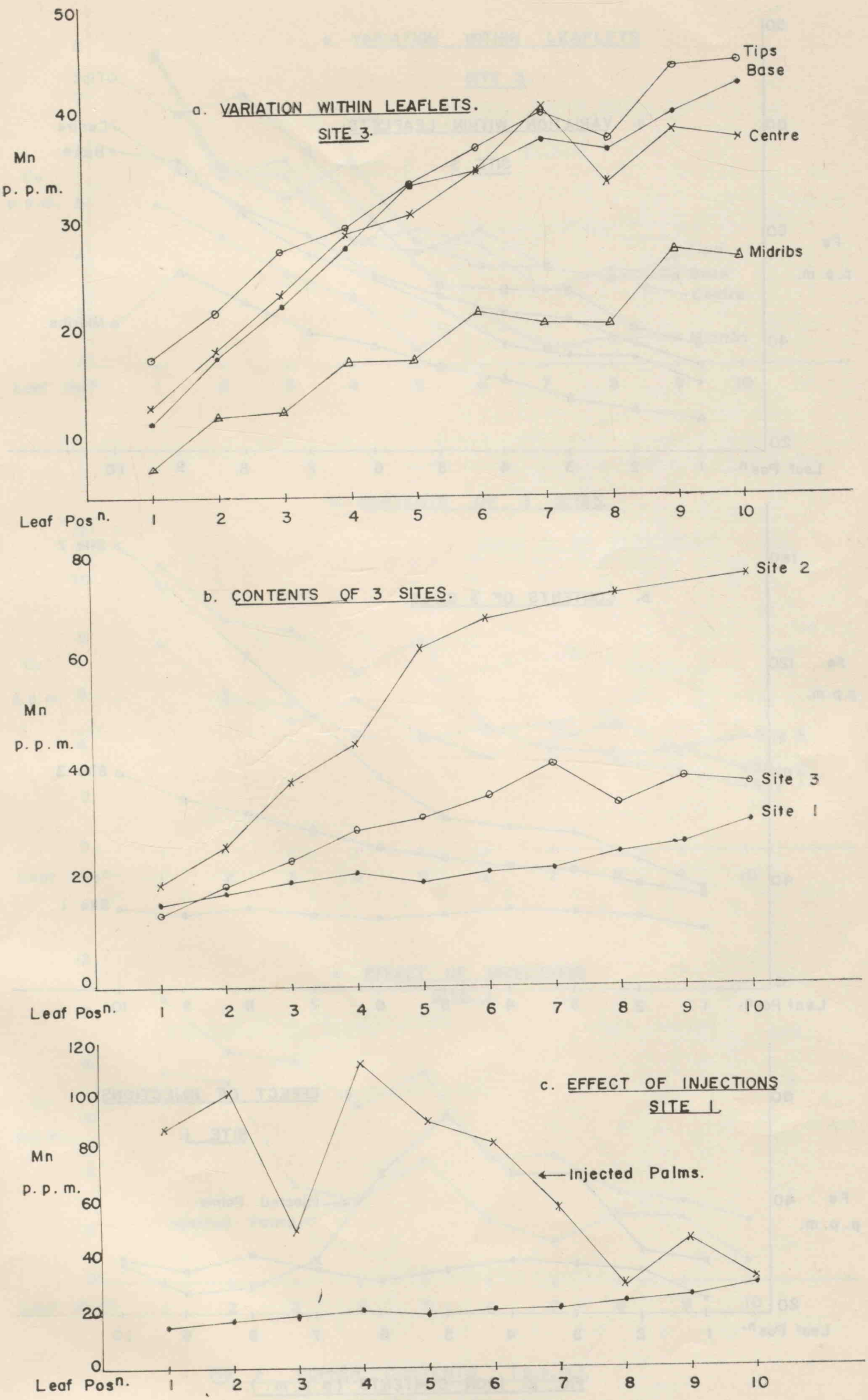


FIG. 1. MANGANESE CONTENTS (p. p. m.).

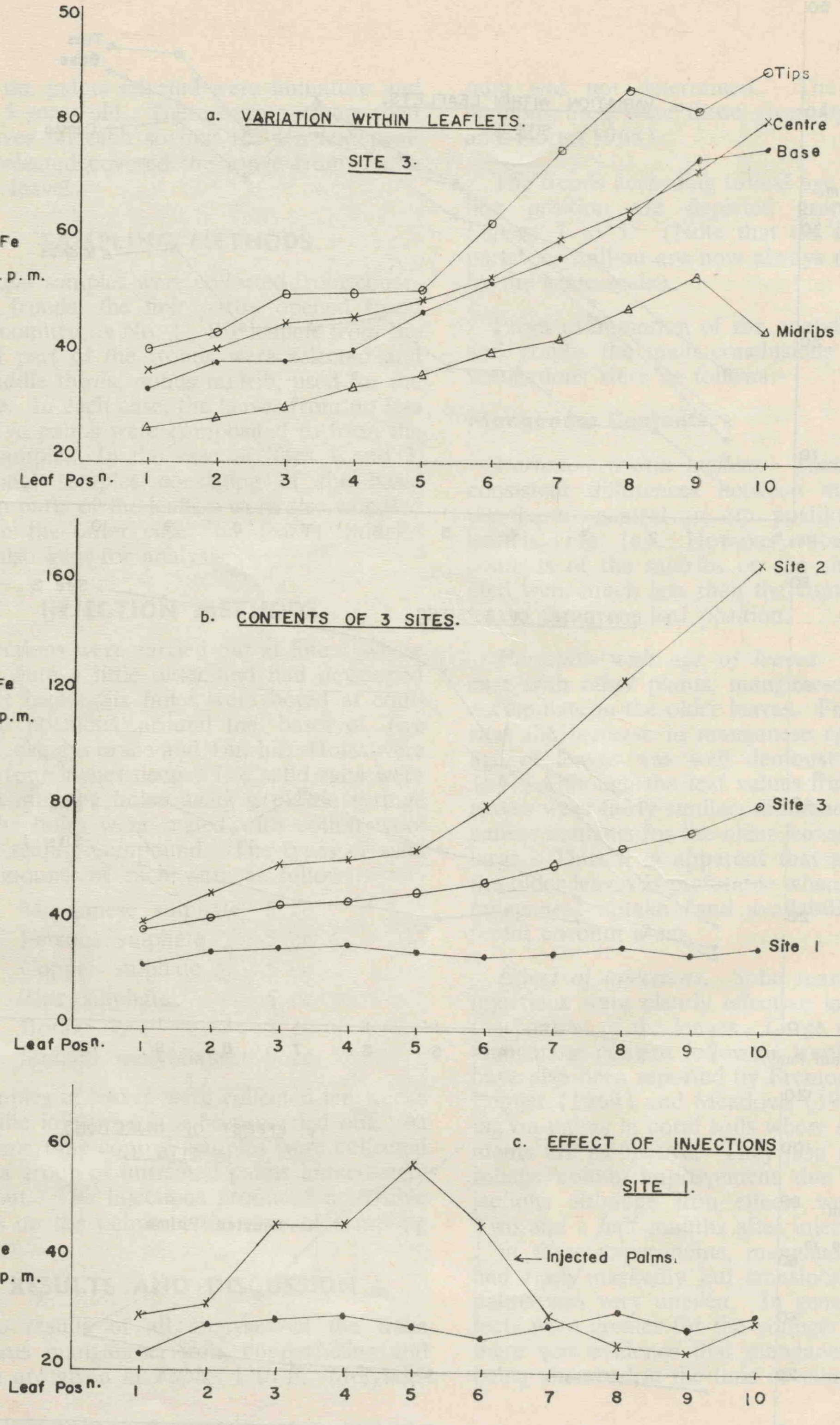


FIG. 2. IRON CONTENTS (p.p.m.).

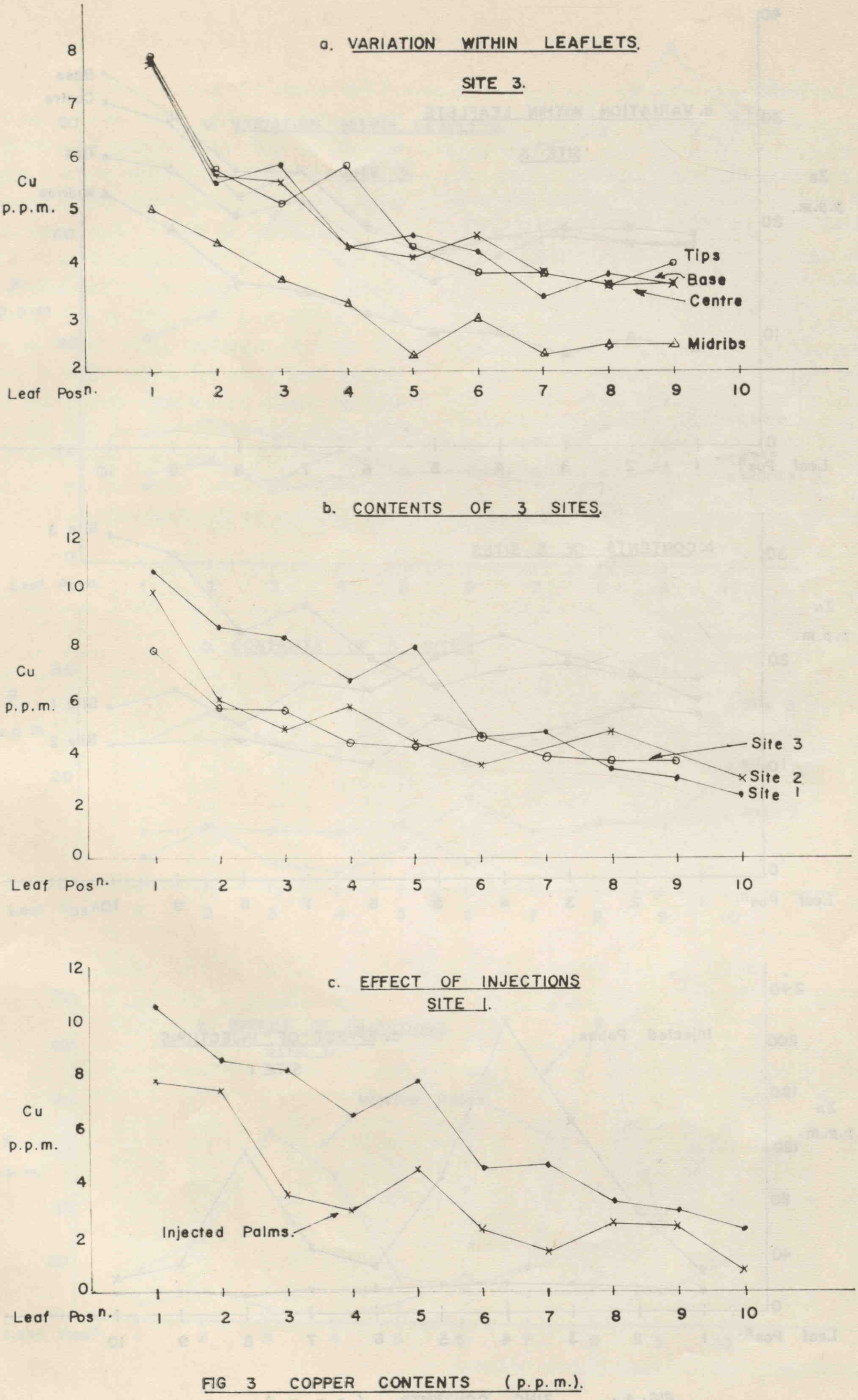


FIG 3 COPPER CONTENTS (p.p.m.).

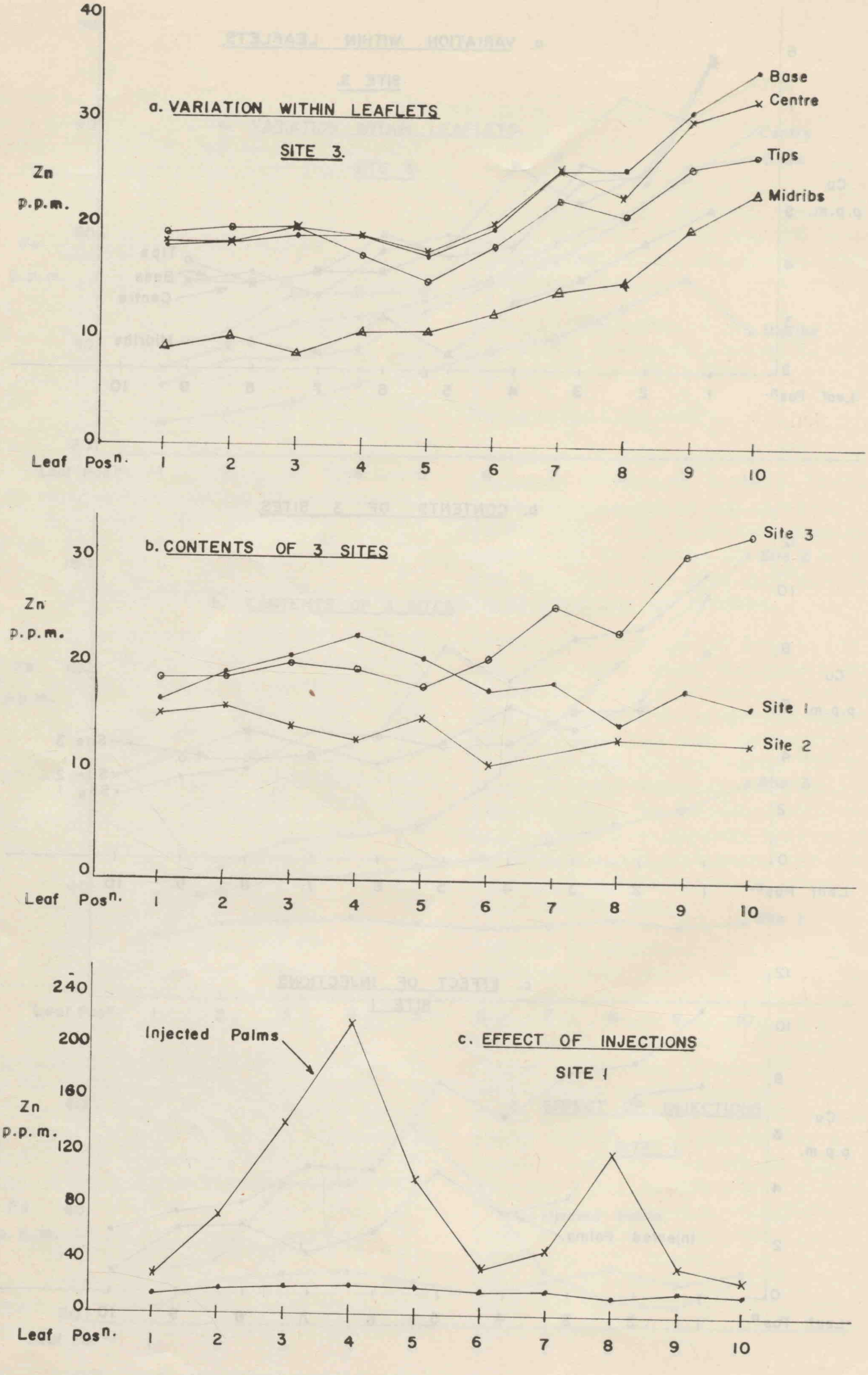


FIG. 4. ZINC CONTENTS (p.p.m.)

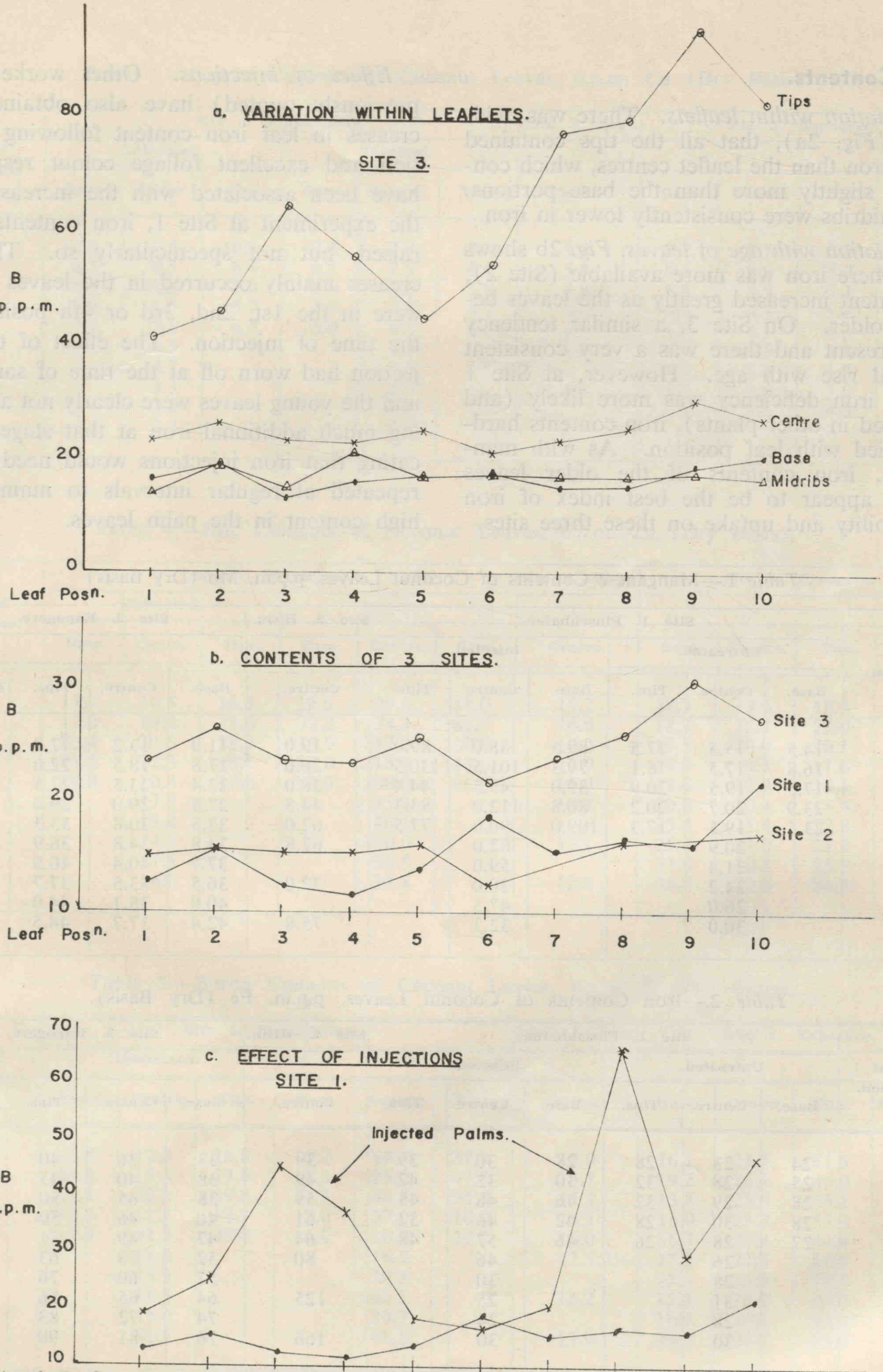


FIG. 5. BORON CONTENTS (p.p.m.).

**Iron Contents.**

*Variation within leaflets.* There was evidence (*Fig.* 2a), that all the tips contained more iron than the leaflet centres, which contained slightly more than the base portions. The midribs were consistently lower in iron.

*Variation with age of leaves. Fig.* 2b shows that where iron was more available (Site 2), its content increased greatly as the leaves became older. On Site 3, a similar tendency was present and there was a very consistent gradual rise with age. However, at Site 1 where iron deficiency was more likely (and occurred in other plants), iron contents hardly varied with leaf position. As with manganese, iron contents of the older leaves would appear to be the best index of iron availability and uptake on these three sites.

*Effect of injections.* Other workers (as previously quoted) have also obtained increases in leaf iron content following injection and excellent foliage colour responses have been associated with the increase. In the experiment at Site 1, iron contents were raised, but not spectacularly so. The increases mainly occurred in the leaves which were in the 1st, 2nd, 3rd or 4th position at the time of injection. The effect of the injection had worn off at the time of sampling and the young leaves were clearly not absorbing much additional iron at that stage, indicating that iron injections would need to be repeated at regular intervals to maintain a high content in the palm leaves.

*Table* 1.—Manganese Contents of Coconut Leaves, p.p.m. Mn (Dry Basis)

| Leaf Position. | Site 1. Finschhafen. | | | | | | Site 2. Hisiu. | Site 3. Kapogere. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Untreated. | | | Injected. | | | | | | | |
| | Base. | Centre. | Tips. | Base. | Centre. | Tips. | Centre. | Base. | Centre. | Tips. | Midribs. |
| 1 | 14.5 | 15.5 | 17.5 | 89.5 | 88.0 | 89.0 | 19.0 | 11.9 | 13.2 | 17.8 | 7.8 |
| 2 | 16.8 | 17.5 | 18.1 | 79.3 | 101.5 | 130.5 | 26.0 | 17.8 | 18.5 | 22.0 | 12.4 |
| 3 | 17.5 | 19.5 | 20.9 | 39.0 | 49.5 | 44.4 | 38.0 | 22.4 | 23.5 | 27.5 | 12.8 |
| 4 | 23.9 | 20.7 | 20.2 | 86.8 | 112.0 | 83.3 | 44.5 | 27.8 | 29.0 | 29.4 | 17.4 |
| 5 | 23.5 | 19.5 | 17.3 | 109.0 | 90.0 | 77.5 | 62.0 | 33.5 | 30.8 | 33.5 | 17.4 |
| 6 | | 20.9 | | | 82.0 | | 67.8 | 34.8 | 34.8 | 36.9 | 22.0 |
| 7 | | 21.4 | | | 59.0 | | | 37.7 | 40.4 | 40.0 | 20.9 |
| 8 | | 24.2 | | | 30.0 | | 72.0 | 36.5 | 33.5 | 37.7 | 20.6 |
| 9 | | 26.0 | | | 47.5 | | | 40.0 | 38.1 | 44.0 | 27.4 |
| 10 | | 30.0 | | | 32.3 | | 75.8 | 42.4 | 37.7 | 44.5 | 26.8 |

*Table* 2.—Iron Contents of Coconut Leaves, p.p.m. Fe (Dry Basis).

| Leaf Position. | Site 1. Finschhafen. | | | | | | Site 2. Hisiu. | Site 3. Kapogere. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Untreated. | | | Injected. | | | | | | | |
| | Base. | Centre. | Tips. | Base. | Centre | Tips. | Centre. | Base. | Centre. | Tips. | Midribs. |
| 1 | 24 | 23 | 28 | 28 | 30 | 39 | 39 | 33 | 36 | 40 | 26 |
| 2 | 25 | 28 | 32 | 30 | 32 | 42 | 49 | 38 | 40 | 43 | 28 |
| 3 | 28 | 29 | 32 | 46 | 46 | 43 | 59 | 38 | 45 | 50 | 30 |
| 4 | 28 | 30 | 28 | 42 | 46 | 52 | 61 | 40 | 46 | 50 | 34 |
| 5 | 27 | 28 | 26 | 46 | 57 | 48 | 64 | 47 | 49 | 51 | 36 |
| 6 | | 26 | | | 46 | | 80 | 52 | 53 | 63 | 40 |
| 7 | | 28 | | | 30 | | | 57 | 60 | 76 | 42 |
| 8 | | 31 | | | 25 | | 125 | 64 | 65 | 86 | 48 |
| 9 | | 28 | | | 24 | | | 74 | 72 | 83 | 54 |
| 10 | | 30 | | | 30 | | 166 | 76 | 81 | 90 | 44 |

*Table* 3.—Copper Contents of Coconut Leaves, p.p.m. Cu (Dry Basis).

| Leaf Position. | Site 1. Finschhafen. | | | | | | Site 2. Hisiu | Site 3. Kapogere. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Untreated. | | | Injected. | | | | | | | |
| | Base. | Centre. | Tips. | Base. | Centre. | Tips. | Centre. | Base. | Centre. | Tips. | Midribs. |
| 1 | 11.0 | 10.5 | 10.3 | 7.0 | 7.8 | 7.8 | 9.8 | 7.7 | 7.7 | 7.8 | 5.0 |
| 2 | 8.5 | 8.5 | 8.4 | 8.5 | 7.5 | 6.0 | 5.9 | 5.5 | 5.6 | 5.7 | 4.4 |
| 3 | 8.5 | 8.2 | 7.0 | 5.0 | 3.6 | 5.8 | 4.8 | 5.8 | 5.5 | 5.1 | 3.7 |
| 4 | 6.9 | 6.5 | 5.7 | 5.3 | 3.0 | 4.7 | 5.6 | 4.3 | 4.3 | 5.8 | 3.3 |
| 5 | 7.0 | 7.8 | 6.2 | 6.0 | 4.5 | 3.6 | 4.3 | 4.5 | 4.1 | 4.3 | 2.3 |
| 6 | | 4.5 | | | 2.3 | | 3.5 | 4.2 | 4.5 | 3.8 | 3.0 |
| 7 | | 4.7 | | | 1.5 | | | 3.4 | 3.8 | 3.8 | 2.3 |
| 8 | | 3.3 | | | 2.5 | | 4.7 | 3.8 | 3.6 | 3.6 | 2.5 |
| 9 | | 3.0 | | | 2.4 | | | 3.6 | 3.6 | 4.0 | 2.5 |
| 10 | | 2.3 | | | 0.8 | | 2.9 | | | | |

*Table* 4.—Zinc Contents of Coconut Leaves, p.p.m. Zn (Dry Basis).

| Leaf Position. | Site 1. Finschhafen. | | | | | | Site 2. Hisiu. | Site 3. Kapogere. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Untreated. | | | Injected. | | | | | | | |
| | Base. | Centre. | Tips. | Base. | Centre. | Tips. | Centre. | Base. | Centre. | Tips. | Midribs. |
| 1 | 17.7 | 16.5 | 16.5 | 29.6 | 29.6 | 31.0 | 15.2 | 18.3 | 18.6 | 19.5 | 9.1 |
| 2 | 17.0 | 19.0 | 18.0 | 72.2 | 74.3 | 63.7 | 16.0 | 18.7 | 18.7 | 20.0 | 10.0 |
| 3 | 20.4 | 20.6 | 18.7 | 115.0 | 142.0 | 100.0 | 14.2 | 19.5 | 20.0 | 20.1 | 8.5 |
| 4 | 21.1 | 22.3 | 18.4 | 185.0 | 216.0 | 133.0 | 13.0 | 19.5 | 19.5 | 17.6 | 10.4 |
| 5 | 21.5 | 20.4 | 17.0 | 98.0 | 100.0 | 96.0 | 15.0 | 17.6 | 17.9 | 15.1 | 10.6 |
| 6 | | 17.5 | | | 35.8 | | 10.8 | 20.0 | 20.4 | 18.4 | 12.3 |
| 7 | | 18.2 | | | 48.1 | | | 25.4 | 25.4 | 22.8 | 14.4 |
| 8 | | 14.3 | | | 120.0 | | 13.1 | 25.4 | 23.0 | 21.1 | 15.1 |
| 9 | | 17.5 | | | 36.5 | | | 31.0 | 30.1 | 25.8 | 20.1 |
| 10 | | 16.0 | | | 27.8 | | 12.8 | 34.8 | 32.0 | 26.9 | 23.4 |

*Table* 5.—Boron Contents of Coconut Leaves, p.p.m. B (Dry Basis).

| Leaf Position. | Site 1. Finschhafen. | | | | | | Site 2. Hisiu. | Site 3. Kapogere. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Untreated. | | | Injected. | | | | | | | |
| | Base. | Centre. | Tips. | Base. | Centre. | Tips. | Centre. | Base. | Centre. | Tips. | Midribs. |
| 1 | 12.8 | 12.8 | 18.8 | 18.2 | 19.4 | 37.3 | 15.0 | 16.1 | 23.5 | 41.5 | 14.0 |
| 2 | 14.2 | 15.6 | 17.0 | 18.3 | 25.0 | 47.8 | 15.7 | 19.2 | 26.3 | 46.0 | 19.5 |
| 3 | 11.8 | 12.2 | 19.8 | 21.3 | 44.8 | 95.5 | 15.3 | 13.8 | 23.6 | 65.1 | 15.0 |
| 4 | 10.8 | 11.5 | 19.3 | 32.0 | 37.0 | 110.0 | 15.3 | 16.0 | 23.2 | 55.9 | 21.4 |
| 5 | 11.0 | 13.9 | 19.8 | 16.0 | 18.2 | 29.2 | 16.0 | 16.7 | 25.4 | 44.9 | 16.8 |
| 6 | | 18.6 | | | 16.5 | | 12.5 | 17.2 | 21.5 | 54.5 | 17.5 |
| 7 | | 15.3 | | | 20.5 | | | 15.3 | 23.8 | 78.0 | 16.8 |
| 8 | | 16.5 | | | 66.5 | | 16.2 | 15.5 | 25.9 | 80.0 | 17.1 |
| 9 | | 16.0 | | | 29.3 | | | 18.6 | 30.5 | 96.0 | 17.8 |
| 10 | | 21.5 | | | 46.5 | | 17.0 | 20.3 | 27.2 | 83.0 | 16.6 |

## Copper Contents.

*Variations within leaflets.* There were no consistent or large differences between the various parts of leaf tissue, but midribs contained less copper than the laminae.

*Variation with age of leaves.* The copper contents of the first leaves were the highest at all three locations and the values decreased with age so that the oldest leaves contained about one third of the young leaf content. Differences in copper contents between the three sites were not consistent and it was not clear which sampling position would best show differences in uptake. It is possible that copper availability at the three sites was similar; certainly leaf analysis could not differentiate between them satisfactorily.

*Effect of injections.* Copper contents of injected palms were considerably lower than those of untreated palms and thus the injections were not successful. This was a surprising result and is considered in the general discussion.

## Zinc Contents.

*Variation within leaflets.* The differences between the three portions of leaflets were not great but there was a definite tendency for the tips to contain less zinc, particularly in the older leaves. This tendency was also shown at Site 1. The midribs again contained much less of the trace element.

*Variation with age of leaves.* For Site 3 where zinc uptake was generally higher, there was a tendency for zinc to accumulate in the older leaves. For the other two sites there were no general trends. Older leaves would appear to give a better indication of zinc uptake and status than the young leaves, where zinc contents did not vary greatly between areas.

*Effect of injections.* The results and *Fig.* 4c show that zinc salt injections were extremely effective in increasing zinc contents, with the fourth leaves increasing in content by nearly 200 p.p.m. Increases were irregularly distributed, with a tendency for higher contents at the fourth and eighth leaf positions.

## Boron Contents.

*Variation within leaflets.* These results were interesting. The tips contained very high concentrations of boron, the centres much less, with the base portions and midribs less again and only one third to one fifth the content of the tips. Similar results were obtained at Site 1, but the tip content of untreated palms was not nearly as high by comparison. However, after injecting with boron the increased concentration at the tips became obvious (*Table* 5). It is clear that sampling must be carried out very carefully if an adequate result for the boron content of leaves is to be obtained.

*Variation with leaf position.* Results were variable and no consistent trends were noted for the three sites. All leaf positions for Site 3 gave higher boron contents than for the other two sites, thus no particular sampling position could be recommended from the results.

*Effect of injections.* There were large increases in boron content following injection of borax but there was evidence that boron was only translocated to certain leaf positions (*Fig.* 5c). Peak absorption occurred in leaves 3-4 and 8-10. The reasons are not clear but it has already been noted that such irregular distribution of injected nutrient also occurred with zinc and manganese.

## DISCUSSION OF RESULTS

The injection of a variety of inorganic salts into the transpiration stream of plants could well produce a number of possible changes in ionic equilibria affecting absorption and translocation. The ability of particular elements to reach the growing point and be translocated to the leaves would depend on a number of factors, e.g. their compatibility with other ions (i.e. their position in the electrochemical series). Thus, in the injection experiments conducted, irregular distribution or no uptake at all (in the case of copper) could be due to the effect of other ions injected. Possibly copper could be injected by itself with better results. (It should be noted that Bachy and Hoestra (1958) achieved some uptake following injections with copper). This points to a possible side effect of injecting high concentrations of single salts in that they may disturb the normal distribution and functions of other elements, particularly where known ionic relationships exist (e.g. Fe-Mn).

The experiments were conducted on young palms but the results should still be applicable to mature palms as a good range of young to old leaves was taken. Other samples collected from widely separated areas in Papua and New Guinea and using various leaf positions confirmed the main trends, namely that iron and manganese tend to accumulate in older leaves, leaf copper contents are higher in the young leaves, while boron and zinc contents may vary.

It is perhaps possible to determine whether iron or manganese are being supplied in sufficient quantity by examining the trend with leaf position in a certain area. If the elements are being accumulated in the older leaves, there is probably a sufficient supply (e.g. Site 2, *Figs.* 1b and 2b). Where no accumulation is occurring (Site 1), the supply of iron and manganese may be only just meeting the plant's requirements or may even be deficient. It is interesting to note that consistent trends were obtained for these relatively immobile nutrients, even though palms at Sites 2 and 3 were subject to severe long dry periods. The uptake as reflected by nutrient content for the various leaf positions thus does not appear to fluctuate much during a year's growth.

*Table* 6.—Range of Trace Element Contents for Various Districts of Papua and New Guinea (p.p.m. on dry basis).

| | Mn | Fe | Cu | Zn | B |
|---|---|---|---|---|---|
| 1st LEAVES | | | | | |
| Central | 13 - 40 | 22 - 100 | 3.3 - 9.8 | 10-22 | 11-24 |
| Morobe | 11 - 27 | 22 - 68 | 2.8 - 10.5 | 12-22 | 10-19 |
| New Britain | 13 - 54 | 35 - 57 | 3.5 - 6.8 | 10-24 | 9-25 |
| Papua and New Guinea | 11 - 54 | 22 - 100 | 2.8 - 10.5 | 10-24 | 9-25 |
| 4th LEAVES | | | | | |
| Bougainville | 30 - 75 | 40 - 62 | 4.8 - 9.5 | 19-39 | 10-15 |
| Central | 24 - 87 | 38 - 284 | 2.3 - 5.6 | 10-22 | 11-27 |
| Gulf | 15 - 126 | 60 - 228 | 2.8 - 5.8 | 11-34 | 14-20 |
| Milne Bay | 30 - 37 | 64 - 100 | 4.5 - 5.3 | 21-22 | 18-20 |
| Morobe | 10 - 52 | 18 - 133 | 1.9 - 8.3 | 12-24 | 11-29 |
| New Britain | 24 - 105 | 70 - 146 | 2.4 - 4.4 | 11-19 | 12-22 |
| New Ireland | 8 - 18 | 32 - 41 | 2.9 - 5.0 | 12-23 | 14-20 |
| Sepik | 35 - 51 | 46 - 56 | 4.3 - 6.5 | 13-16 | 10-11 |
| Papua and New Guinea | 8 - 126 | 18 - 284 | 1.9 - 9.5 | 10-39 | 10-29 |
| 9th LEAVES | | | | | |
| Bougainville | 46 - 60 | 52 - 80 | 4.5 - 7.0 | 15-55 | 10-13 |
| Central | 14 - 72 | 32 - 322 | 2.5 - 8.9 | 12-30 | 12-35 |
| Madang | 18 - 59 | 39 - 75 | 3.2 - 5.3 | 13-20 | 13-20 |
| Milne Bay | 4 - 30 | 48 - 60 | 1.4 - 4.5 | 7-36 | 16-24 |
| Morobe | 14 - 57 | 18 - 190 | 1.6 - 4.5 | 13-31 | 12-24 |
| New Ireland | 8 - 140 | 30 - 138 | 2.9 - 6.4 | 12-65 | 9-34 |
| Sepik | 39 - 74 | 49 - 52 | 3.3 - 3.5 | 14-20 | 10-14 |
| Papua and New Guinea | 4 - 140 | 18 - 190 | 1.4 - 8.9 | 7-65 | 9-35 |
| 14th LEAVES | | | | | |
| Bougainville | 26 - 178 | 44 - 196 | 2.3 - 9.3 | 11-144 | 13-22 |
| Central | 15 - 84 | 40 - 315 | 3.0 - 7.9 | 13-39 | 12-23 |
| Madang | 20 - 69 | 44 - 74 | 2.6 - 3.8 | 12-20 | 17-22 |
| Morobe | 14 - 60 | 28 - 238 | 1.7 - 3.0 | 20-48 | 13-39 |
| New Britain | 21 - 144 | 44 - 196 | 3.2 - 6.6 | 11-40 | 13-21 |
| New Ireland | 5 - 200 | 35 - 150 | 1.4 - 6.4 | 6-53 | 9-31 |
| Northern | 48 | 57 | 3.0 | 24 | 20 |
| Papua and New Guinea | 5 - 200 | 28 - 315 | 1.4 - 9.3 | 6-144 | 9-39 |

*Table* 7.—Comparison of Papua and New Guinea values with those in other countries

| | Mn | Fe | Cu | Zn | B |
|---|---|---|---|---|---|
| 4th LEAVES | | | | | |
| Average, Papua and New Guinea | 8 - 126 | 18 - 284 | 1.9 - 9.5 | 19-39 | 10-29 |
| British Solomon Islands | 51 | 42 | 2.9 | 23 | 15 |
| Western Samoa | 147 - 343 | 58 - 154 | 3.9 - 4.9 | 10-19 | 13-15 |
| Tonga | 18 - 75 | 48 - 164 | 3.1 - 8.0 | 11-21 | 10-21 |
| French Polynesia (coral) | 18 - 28 | 25 - 35 | 1.0 - 1.4 | 13-16 | 24-30 |
| 9th LEAVES | | | | | |
| Average, Papua and New Guinea | 4 - 140 | 18 - 190 | 1.4 - 8.9 | 7-65 | 10-35 |
| Tonga | 27 - 96 | 62 - 254 | 4.9 - 7.5 | 11-21 | 14-21 |
| Cocos Island (coral) | 9 - 27 | 24 - 130 | 2.5 - 4.5 | 9-21 | 11-39 |
| 14th LEAVES | | | | | |
| Average, Papua and New Guinea | 5 - 200 | 28 - 315 | 1.4 - 9.3 | 6-144 | 9-39 |
| British Solomon Islands | 51 - 61 | 46 - 49 | 6.4 - 7.3 | 17-22 | 17-21 |
| Cocos Island (coral) | 7 - 34 | 36 - 102 | 2.0 - 4.8 | 8-21 | 12-38 |
| French Atolls (coral) | 4 - 25 | 30 - 56 | 1.8 - 6.7 | — | 18-33 |
| Other French Territories | 40 - 656 | 98 - 151 | 3.6 - 8.4 | 13-78 | 6-18 |
| I.R.H.O. Critical Levels | 120 | 100 | 5 | — | 10 |

The results presented should give basic information to agronomists or chemists experimenting with trace element injections and using foliar analyses as a guide to trace element status. Many other analyses have been made in Papua and New Guinea of coconut foliar material from various leaf positions and these are summarized in *Table* 6. They show a very wide range of contents. In addition, samples from other South Pacific countries and from Cocos Island (a typical coral atoll) have been examined and these results are given in *Table* 7, together with the I.R.H.O. critical levels and results from French atolls and other French territories (Fremond, 1961).

Most values for iron and manganese found in the 14th leaves in this country have been much lower than Fremond's provisional critical levels. Only one case of probable iron or manganese deficiency symptoms was reported, on an atoll in the Milne Bay district. There the 9th leaves had low manganese (4-30 p.p.m.), fairly low iron contents (48-60 p.p.m.), low copper contents (1.4-4.5 p.p.m.), some low zinc contents (7-36 p.p.m.) and satisfactory boron contents (16-24 p.p.m.).

It would appear that Fremond's critical levels are too high for iron and manganese. Values of about half his proposed levels for these nutrients are suggested from the results obtained in Papua and New Guinea, where obviously healthy palms have been sampled. Copper levels in this country are usually between 2 and 5 p.p.m., zinc levels between 10 and 50 p.p.m., while boron contents are in the range 10-40 p.p.m. All these levels are associated with coconuts growing in areas where trace element deficiencies are not suspected, but unfortunately there is no agronomic information available and it is not known whether yields have always been optimal.

## SUMMARY

Investigations carried out in Papua and New Guinea showed the distribution within leaflets and for various leaf positions of the trace elements iron, manganese, copper, zinc and boron. The main findings were:-

(a) Iron and manganese contents were greater in the older leaves, copper contents were greater in younger leaves, zinc and boron had irregular distribution.

(b) Boron contents increased markedly from the basal to the tip portions of leaflets. The same tendencies were found for iron and zinc, but they were not so strong. The midribs had low contents of all trace elements.

(c) Generally the sampling of older leaves appeared to give the best definition of trace element status.

(d) Injections of six trace element salts into the same palm gave greatly increased contents of manganese, zinc and boron in leaf tissues, smaller increases of iron and no increase of copper.

The range of values obtained in Papua and New Guinea for trace element contents of coconut leaves are summarized. Comparisons are made with results obtained elsewhere and with suggested critical levels.

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## AUTHORS' NOTE

This paper was a contribution to the South Pacific Commission Technical Meeting on Coconut Production, Rangiroa, French Polynesia, in August, 1967. It should be noted that the iron contents as reported in the original paper differ from those reported in this paper. The latter are the correct values. In addition, considerable changes have been made in the script.