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METRIC CONVERSION FACTORS

A	B	To convert A to B multiply by	To convert B to A multiply by
inches (in)	centimetres (cm)	2.54	0.394
feet (ft)	metres (m)	0.305	3.28
yards (yd)	metres	0.914	1.09
chains	metres	20.1	*
chains	kilometres (km)	0.0201	49.8
miles	kilometres	1.609	0.621

A	B	To convert A to B multiply by	To convert B to A multiply by
ounces (oz)	grams (g)	28.35	0.035
pounds (lb)	grams	454	*
pounds	kilograms (kg)	0.454	2.205
hundred-weights (cwt)	kilograms	50.8	*
tons	kilograms	1016	*
tons	metric tons (tonnes) (mt)	1.016	0.984

A	B	To convert A to B multiply by	To convert B to A multiply by
square in (sq in)	square cm (cm^2)	6.45	0.155
square ft (sq ft)	square metres (m^2)	0.0929	10.8
square yd (sq yd)	square metres	0.836	1.196
square chains	square metres	405	*
square chains	hectares (ha)	0.0405	24.7
acres (ac)	hectares	0.405	2.47
square miles	hectares	259	*
square miles	square km (km^2)	2.59	0.386

A	B	To convert A to B multiply by	To convert B to A multiply by
fluid ounces	millilitres (ml) †	28.4	*
pints	litres (1)	0.568	1.76
gallons	litres	4.55	0.22
cubic feet	cubic metres (m^3)	0.0283	35.3
cubic yards	cubic metres	0.765	1.31

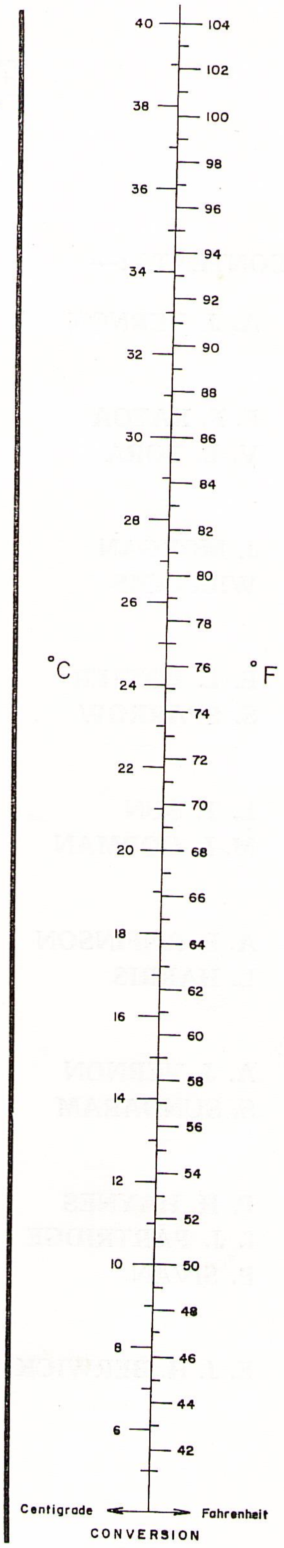
A	B	To convert A to B multiply by	To convert B to A multiply by
lb/ac	kg/ha	1.12	0.89
cwt/ac	kg/ha	125.5	*
ton/ac	mt/ha	2.51	0.398
pint/ac	1/ha	1.40	0.712
gall/ac	1/ha	11.2	0.089

$$°C = 5\,(°F - 32)/9$$

$$°F = [9\,(°C)/5] + 32$$

* These factors will seldom be needed.

† For practical purposes 1 ml = 1 cubic centimetre.



Fiji agric J. (1973), **35**, 1-10

THE FIRST FIVE YEAR'S RESULTS OF THE COCOA PRUNING EXPERIMENT AT WAIMARO

by

A. J. VERNON

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SUMMARY

A cocoa pruning trial was begun in Fiji in 1968 by allowing, on hitherto strictly pruned, ten-year-old, Amelonado cocoa (a) continued vertical growth from the first jorquette, (b) some chupon growth on leaning or sickly trees and (c) complete freedom of chupon growth. A fourth treatment was continuation of strict chupon removal. During the next five years annual yields rose, with deshading, to the exceptionally high average of 2.8 mt/ha (potential: 25% of this was lost to black-pod). Apart from a depression in yield of the completely unpruned cocoa in 1969, there was never any significant difference between treatment yields; but by October 1972 the strictly pruned was the lowest yielding and the completely unpruned was appearing to be the best treatment. A hurricane then practically destroyed the trial.

INTRODUCTION

The trial now described was the first large scale cocoa field experiment in Fiji. In 1958 Amelonado seed was imported (from Malaya; where it had been grown from seed imported from West Africa) and used to plant a 1.7 hectare (4-acre) block at Waimaro. Of this area, about 0.2 ha is on the river plain, (at 8' x 8' spacing), about 0.15 ha (at irregular spacing) on a slope up from the plain to a small plateau, and the rest is at 10' x 10' spacing on the plateau top, about 8 m above the level of the plain (Fig. 1). On the plain there is a gley soil: on the plateau there are two phases of Koronivia Sandy Loam, one free draining and the other with impeded drainage (8).

By early 1968 the cocoa on the plain, and the free draining plateau soils was well grown; but on the soils of impeded drainage none of the plants appeared more than 4-5 years old and there were many gaps and seedling replacements. The well-grown cocoa was generally well-shaded by large trees of various species, the less-well grown relatively unshaded. According to hearsay (there was no written history) the cocoa had suffered hurricane damage in 1964-65, chiefly from falling shade trees.

These irregularities of spacing, shade, and growth of cocoa made the site far from ideal for field experimentation. But there was then little line-planted, well established, cocoa in Fiji available for research, so it was necessary to make some use of this Waimaro block.

Hitherto most cocoa in Fiji (including this block) had been strictly pruned according to the orthodox plantation system. The introduction of Amelonado cocoa, however, suggested that a less strict pruning system, such as practised by the peasant farmers of West Africa, might be better; and it was decided to use Waimaro for a comparison of strict pruning with various relaxed systems.

In October 1972 a hurricane blew down most of the trees. Had the area been non-experimental, or in almost any other type of experiment, it would have been best to have coppiced the fallen trees; but this would have destroyed the treatment comparisons of habit, built up over five years. An attempt was made, therefore, to preserve something of the treatment comparison by propping up the fallen trees and by March 1973 most of these were recovering. But further irregularity has been introduced into a trial that already had a somewhat unsatisfactory experimental error. Its future value as an experiment, therefore, is now doubtful.

REVIEW OF COCOA PRUNING

Plantation practice

Until recently, accounts of cultivation methods in cocoa textbooks have been based not on research but on the standard practices evolved on plantations in the West Indies, Central, and S. America during 1600-1900, and later copied on plantations in Ceylon, Indonesia, etc. The practices of the W. African peasant farmers, who have, since about 1920, produced 60-80% of the world's cocoa, have been largely ignored (or condemned) by the textbook authors.

These writers invariably recommend keeping cocoa to a single-stemmed, low-branched habit by strict chupon* pruning. Most agree that if the first jorquette is very low (say under 1.5m) a single chupon should be allowed to grow from beneath it, and carry on vertical growth to give an upper storey of fan branches. Others do not mention this practice, and Van Hall (18), who calls it the 'Java system', condemns it. Most writers agree that if the original trunk and branch structure becomes senescent, or badly diseased or damaged, one (or possibly two) basal chupons should be allowed to grow and 'regenerate' or 'rejuvenate' the tree, but they differ greatly in the emphasis they place on this. Wright (26) and Jones (7) stress the need for such regeneration, particularly of canker-diseased trees. Van Hall (18) gives it less emphasis, while Hart (5) and Urquhart (17) mention only rejuvenation of aging trees.

These textbook recommendations have been copied by writers of advisory papers in other parts of the world, including the Pacific area generally (12) and specifically New Guinea (2, 4), Samoa, (3), the Caroline Islands (10) and Fiji (6). Unfortunately, these writers have generally neglected to mention the need to allow regenerative chupon growth on badly diseased trees. In the Pacific area in general, and in Fiji in particular, this neglect has been particularly unfortunate, because until recently most cocoa cultivation here has been of canker-susceptible varieties (20).

The foregoing notes refer only to *chupon* pruning. Many of the writers cited pay more attention to fan-branch pruning, stressing the desirability of shaping the trees in particular ways, and dismiss chupon pruning briefly as self-evidently essential (with the two possible provisos noted). Knapp (9) is exceptional in suggesting that 'pruning' and 'shaping' is 'largely governed by taste'.

Experimental evidence and W. African practice

Most of the writers cited above advance little argument and no evidence in support of their statements of 'correct' practice. Urquhart, in his second edition (17), mentions an example of strictly pruned cocoa giving an exceptionally high yield; and says that "the skilful use of the pruning-knife to regulate vegetative growth will induce greater crop yield: but this claim is unusual.

On the contrary, several pre-1939 writers mention, without details, evidence that relaxation of pruning increases yield. A review of the cocoa industry of Trinidad in 1937 (14) says that "many planters encourage the growth of one or more suckers on a tree which is giving a satisfactory yield" and that "a detailed analysis of the records of multi-stemmed trees shows that they have higher average yields". But the writer argues that these trees are "mishapen", "the excessive height renders reaping difficult and expensive", and concludes "suckering should be discouraged". Van Hall (18) concedes that unpruned cocoa, in Ecuador, may outyield strictly pruned; but he attributes this to overwide spacing. Wright (26) gives some yield figures to support his contention that regeneration of canker-damaged trees should be allowed.

Many writers, eg. Shepherd (14) quoted above, argue the case for keeping the branches low, saying that such cocoa is easier to harvest. But this is not supported by the experience of W. African

* See Appendix 1 for definitions of terms.

farmers, who allow their cocoa to grow almost completely unpruned and who seem to find no difficulty in harvesting, using blades set on long poles. Indeed, as almost all the pods carried by very tall trees are borne on the main trunk, whereas on short trees they are mainly on the fan branches, harvesting may actually be easier in tall cocoa than short.

Formal experimental evidence is extremely slight and quite inconclusive. The only reports I have traced are of the Ghana experiments reviewed and reported by Bonaparte (1) and of a trial in New Guinea (13). The former had a limited range of treatments, between which there were no significant differences in yield except that relaxation of pruning temporarily depressed yield. In the latter, 'unpruned' cocoa outyielded 'pruned', the exact treatments not being well defined. There has also been another report from New Guinea (11) that, in informal pruning trials, without exception severe pruning has resulted in loss of yield, the extent of the loss being related directly to the severity of the pruning.

EXPERIMENTAL DESIGN

Material limitation

Including bad patches, the site comprised only about 1800 trees, some of which could not be fitted into experimental plots because of the irregular shape of the site, and nearly half of the remainder of which were necessarily in guard rows (Edge effects are to be expected between treatments of different growth habit). Thus with four treatments there could be only about 200 trees per treatment. This amount of replication was expected to give a coefficient of variation of about 25%, reducing to 15% with calibration and covariance analysis*. Any more treatments would have meant fewer plants per treatments, and greater error, which was considered unacceptable.

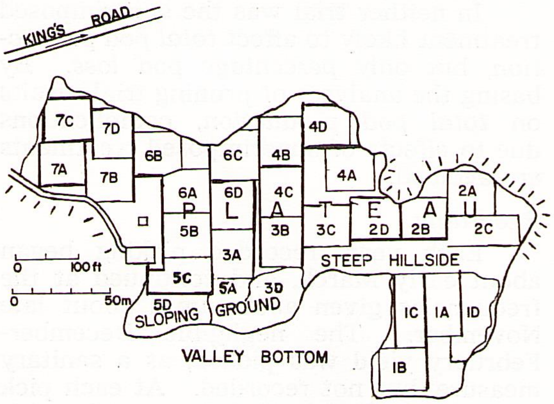

Figure 1.

Treatments

A thorough study of this subject would need about eight treatments including some variation of fan-branch pruning. With a limit of four treatments no fan-branch pruning was practised (except of low-hanging branches) and the following chupon-pruning regimes compared.

	Code name	Code letter
1. Strict pruning of all chupons	Strict pruning	A
2. All chupons pruned except one from first jorquette, which was to be allowed to grow up, jorquette, and produce a second storey of fan branches.	Vertical growth	B
3. All chupons to be pruned on each tree as long as its original main trunk remaining upright and healthy, and its original set of fan branches remaining intact and healthy. If not, then some regenerative chupon growth to be allowed.	Discretionary	C
4. Absolutely no pruning	Unpruned	D

Design

One "blocking" feature was demanded by the site; ie. that the low-lying area should be a single block. A plot-size of 30 trees net was fixed as the largest that allowed four plots to fit into this area. (The larger the plot size, the less the percentage wastage on guard-rows). Seven such blocks, were eventually secured (Fig 1).

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* An expectation that was exactly fulfilled: see "Results".

FIELD WORK

Plot marking (1968)

In early 1968, twenty plots were marked out as shown in Fig 1 as blocks 1 to 4, plus plots 5B, 5C, 6C and 6D (See appendix 2 for original notation and other details). The boundaries of blocks 1 and 2 were dictated by site outline, but elsewhere the vegetative condition of the cocoa was taken into account. Block 4 was a poorly-grown area. Treatments were assigned at random to plots in blocks, except that 'Unpruned' was deliberately assigned to the worst-grown plot in Block 2, that was about half-occupied by an exceptionally badly-grown, uncanopied patch of stunted trees.

Re-marking in 1969

In early 1969 the cocoa at the southern end, which had in 1968 seemed in a precarious state (see introduction) had improved substantially so a further eight plots were marked out, and the trial then became as shown in Fig 1.

To preserve compact blocks it was necessary to change the block allocation of some of the existing plots (See Appendix 2) and to change the treatment of one plot from 'strict' to 'discretionary' pruning. As 'discretion' had up till then been little exercised this change would have been immaterial in the long run; but it complicates analysis of the opening years (Appendix 3).

Calibration

The circumferences of all net-plot trees were measured at the time of plot-marking. This was done to provide a basis for subsequent adjustment of yield and reduction of experimental error by covariance analysis, which makes allowance for original plot-to-plot variation. The first year's yields could also be used for this purpose because most of the year's yield had been harvested, and almost all the rest "set" before any appreciable chupon growth started, hence before there could be any variation in yield due to treatment (see [24] for a review of this topic).

Treatment application

Any chupon in an (A) plot, or any except the permitted one in a (B) plot was removed as soon as noticed. Discretion was excercised in the (C) plots; but during 1968-1971 pruning was conservative and by the end of 1972 only a few of the 30 trees had developed an extra, bearing, stem. The (B) plots also were not strikingly different to the (A) because, on many trees no further chupon growth came from this point. Thus although, in most (B) plots, several trees had developed an upper storey by 1972, the striking contrast in the trial was between the 'strictly pruned' and the 'unpruned'. On many of the latter 6-10 good, strong, pod bearing, new trunks had formed by 1972.

Superimposed trials: picking frequency

Black-pod-control trials were superimposed in 1969 and 1970 (21, 22). The latter involved picking frequency, which in that trial and throughout the other years, was:

1968 and 1969	— Fortnightly	
1970	— Treatment	(a) Twice weekly
		(b) Weekly
		(c) Fortnightly
		(d) 4-weekly
1971 and 1972	— Weekly	

In both these trials, each superimposed treatment occurred once in each block, with a systematic change-round of superimposed and pruning treatments so that the effect of the one was as well balanced as possible on the other.

In neither trial was the superimposed treatment likely to affect *total pod production*, but only *percentage pod loss*. By basing the analyses of pruning trial results on *total pod production*, complications due to effects of superimposed treatments are avoided.

Recording

Each year, recorded picking began about early March, and continued at the frequencies given above until about late November. The negligible December-February yield was picked, as a sanitary measure, but not recorded. At each pick every 'pod-sized' fruit that was either (a) ripe or (x) irrecoverably diseased or damaged was picked. Those in category (x) were subdivided into (b) black, (c) rat-damaged, and (d) otherwise unusable and the (a), (b), (c) and (d) counts recorded for each plot. 'Pod-size' is an arbitrary criterion, based on eye-judgment rather than measurement, copied from field experiment practice in West Africa. It corresponds to a length of about 75 mm, but the eye responds to 'filling-out', as much as to length: a young fruit is considered as a pod if it is noticeably 'filled-out' but as a 'cherelle' if it is not.

Management

Shade was progressively thinned over the better-grown areas during the five years. In the other areas, a continuing effort was made to supply gaps and to increase the shade; but progress was very slow. In these areas of poor establishment, more good was done by regular paraquat spraying. Urea was applied generously each year, with less potassic and little phosphatic fertilizer (15). Rodents, which were causing 20% pod loss in early 1969 were controlled later that year, and again in 1972, by poison baits. During 1970 and 1971 they were left uncontrolled, and a 10% pod loss incurred to facilitate the rodent behaviour studies of Williams (25). During 1971 and 1972 copper fungicide was sprayed frequently throughout the main cropping periods in an attempt to control black-pod.

EXPERIMENTAL RESULTS

Yield levels

By 1969 the area was yielding at what was then considered a most satisfactory rate of 37,000 pods per hectare (15,000 pods/ac) i.e. a *potential* yield of 1.6 mt/ha (1,400lb/ac) had all the pods been usable, at the rate of 44 gm/pod. By 1972, thanks to de-shading, and chemical weed control this potential yield rate had risen to 2.8 mt/ha (2,460 lb/ac), an extraordinarily high figure by world standards for a somewhat unsuitable site. It is, however, seriously discounted by the crop loss, in 1972, of about 25% to black-pod, despite frequent spraying, weekly picking, and good sanitation. The practical implications of the high potential yield coupled with high black-pod loss, will be discussed in a later paper (15), which will also consider the relation of yield to soil-type at this site. On the better soils the 1972 potential yield exceeded 3.2 mt/ha.

Analysis and results

The results previously published (21, 23) have been as analysed each year, ignoring the fact that two of the seven replications are a year behind-hand in start of treatments. The results now presented have been calculated on a "years-from-start" basis: i.e. the 'year 1' yield has been taken as that of 1968 for the first 20 plots but as that of 1969 for the other 8, similarly for the yields of years 2, 3, and 4. For year 5 there are only 20 figures (see appendix 3 for further details).

Both 'initial girth' and 'year 1 yield' were considered as calibratory variables for co-variance analysis of the yields of

TABLE 1

YIELD IN METRIC TONNES PER HECTARE

adjusted to a common Year 1 basis by covariance.

	Year 1	Yr. 2	Yr. 3	Yr. 4	Yr. 5
Strictly pruned	1.66	1.81	1.89	2.39	2.68
Vertical growth allowed		1.82	2.06	2.71	3.11
Discretionary regime		1.79	2.02	2.49	3.01
Unpruned		1.55	1.85	2.37	3.08
		±0.070	±0.093	±0.180	±0.165

years 2 to 5. The year 1 yield was found to give greater reduction of error, and the Table 1 figures are as analysed and adjusted by co-variance on the year 1 yield. The yield shown for year 1 is the mean of all treatments, which is appropriate for comparison with yields of later years, as the covariance analysis has adjusted these to the basis of equal initial yield.

As was to be expected the error reduction due to covariance was greater in the early years than the later; but as the fifth year yield were based only on the more carefully selected, original, 20 plots its error was satisfactorily low. The coefficients of variations were:

	Without covariance	After reduction by covariance on Yr 1 yield
Of year 2 yield	22.2%	10.7%
" " 3 "	28.0	12.5
" " 4 "	24.0	19.2
" " 5 "	15.1	12.7

DISCUSSION

Yield comparison of treatments

The depression of yield of the 'unpruned' treatment, compared with the other three treatments, in year 2, is highly significant. Otherwise little statistical significance attaches to the treatment differences in any one year. In year 5, however, the mean yield of the three 'relaxed' pruning treatments is significantly greater than the 'strictly pruned' at about 5% probability.

Field observation suggested that the "completely unpruned" was actually much the highest-yielding treatment, but did not appear so in the results for the following reasons. First, not only had this treatment been deliberately assigned to much the worst plot in Block 2 (see "Field Work"), but by chance it was also assigned to much the worst plot in block 1. The covariance analysis makes some allowance for this, but by no means a full allowance. Secondly, in 1970 there was an accidental fire in one plot in block 4, again the unpruned treatment being by unfortunate coincidence the one affected. Two trees were killed outright, a third has rejuvenated only from one basal chupon, and several others were severely damaged. This was allowed for in analysis by scaling the actual yields of 1970, 1971, and 1972 up by 30/25, 30/26, and 30/27 respectively, which certainly underestimates the loss.

The relaxation of pruning seems to have been most beneficial in areas where the trees were relatively poorly grown, as can be seen by considering 5th year yields expressed as percentages of 1st year yields. In the poorly-grown Block 4 this figure was 190 in the 'strictly pruned' and 244 in the unpruned, despite the only-partial allowance for fire-damage in this plot (see above). In block 2 the figure for the originally well-grown, strictly-pruned plot was 103, and for the originally poorly-grown, unpruned it was 133. In Block 3 which was initially well-grown, but overshaded, both strictly pruned and unpruned had a big increase in yield following de-shading but with relatively little difference between these treatments, their respective figures being 175 and 206.

Other considerations

In the poorly-grown areas the 'unpruned' treatment has another advantage over the 'strictly pruned', besides yield, namely that it tends to canopy better, and hence suppress weeds better.

In other respects the 'unpruned' is arguably much inferior to the strictly pruned cocoa. It certainly looks untidy. It is much taller, some of the basal chupons growing to 3.5 m before jorquetting. Although, as explained earlier, single-stemmed tall cocoa is not necessarily more difficult to harvest than short, these tall multi-stemmed trees gave difficulties. Some pods developed between stems and became jammed, and the labourers found the height troublesome, although this was largely because of their inexperience. More seriously, there were suspicions of greater black-pod loss, and of worse hurricane damage, in the unpruned cocoa.

As to the former, most advocates of Fan-Branch pruning claim that by "opening up the canopy" and hence improving air circulation black-pod incidence is reduced. I know of no previous evidence to support this; and as most modern authorities agree that cocoa should be grown under little or no top-shade, in which condition it is essential for weed control to maintain a closed canopy, the arguments in favour of such 'opening up' are dubious. Such little evidence as there is (eg. 11) suggests that fan-branch pruning may severely reduce yield. But allowinging a proliferation of trunks and an upper canopy to form may be thought more likely to affect black-pod than merely maintaining a low, closed, canopy. Black-pod incidence in the pruning trial in 1972 was:

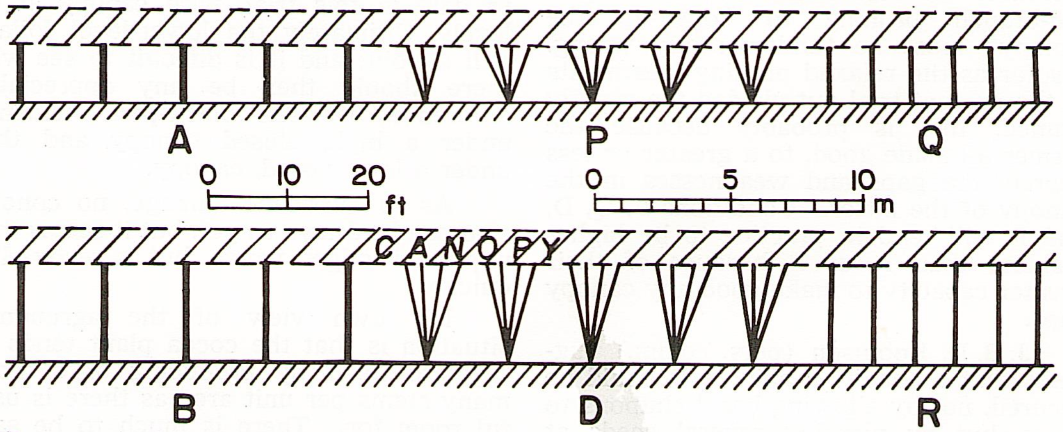
	% black-pod loss
Strictly pruned (A)	26.0
Vertical growth allowed (B)	22.6
Discretionary (C)	23.2
Unpruned (D)	31.2
S.E.	± 1.93

By an F-test the treatment variance is significant at about 3% probability; but the pattern of treatment variation makes little sense. One would expect the sequence to be in accord with the amount of top growth, ie. from least loss to worst, A - C - B - D. In fact the most significant difference is between B and D. The suggestion of the D figure, that relaxation of pruning increases black-pod loss, is therefore inconclusive. It seems likely that there is some real effect, but its magnitude is uncertain.

The possibility that unpruned cocoa was more susceptible to hurricane damage than strictly pruned was suggested by J. Deering (pers. comm.) and the appearance of Waimaro after hurricane 'Bebe' seemed to confirm it. The farm was struck by a particularly severe gust, which flattened most of the trees on the plateau. In the confusion of lodged trees it was difficult to make any exact assessment; but it did seem that the unpruned trees had tended to suffer worse than the strictly pruned — not suprisingly, considering their very much greater total stem and branch growth, hence resistance to wind. But since then the unpruned trees seem to be making a better recovery. It is possible that the growth of new trunk was accompanied by considerable new root growth, much of which has survived in connection with the stem-structure to allow the latter quickly to regenerate foliage. By contrast, the root structure of the strictly pruned trees seems to have been so shaken that (by 1st March) many were making little leaf growth, and some had died.

PRUNING IN RELATION TO SPACING

Fig 2 shows diagrammatically several distinct conditions that well-canopied cocoa may be in, as a result of various spacing and pruning regimes. Of these, 'P' is hypothetical as it seems (from experience of the trial now reported) that if basal-chupons are allowed to grow they grow to such a height as to develop condition 'D' rather than 'P'.



A,B,D: as secured by treatments **A,B,** and **D** of trial.
P: hypothetical
Q,R: as could be secured by closer spacing
FIG 2. DIAGRAM OF COCOA GROWTH HABITS.

Neither in the present trial, nor in any previously reported spacing or pruning trial, has there appeared any conclusive evidence of any significant difference in yield between any of these conditions. Nor does there seem to be any fundamental reason why there should be, as yield is primarily determined by the photosynthetic performance of the canopy, which is in turn determined by the sunlight reaching the canopy, the supply of water and nutrients coming up from the soil, and other factors (eg temperature) affecting rate of photosynthesis.

Q and R are intended to represent 1.5 m (4.5 ft) square spacing. At closer spacings, or if the basal chupons of cocoa at these spacings are allowed to grow, there will be more trunks per unit area than shown in P, Q, D, or R; but there is no fundamental reason why this should depress yield. A, P, B and D are drawn at 3m (10 ft) square spacing. Such little evidence as there is from cocoa spacing experiments suggests that this will give as good a yield as any closer spacing, provided the canopy remains healthy and intact.

But any breaks in the canopy cause loss of yield; as seen in the spacing trial at Tafo, Ghana, where thrips and capsids broke the canopy at 10 ft square spacing, which then yielded much less than the closer spacings (19). Canopy gaps waste sunlight, hence cause a direct loss of yield potential; and allow weed growth, which increases the cost of maintenance. Thus fan-branch pruning to "open-up the canopy" must be fundamentally wrong. Insofar as the relaxed pruning treatments in the present trial out-yielded the strictly pruned, this is probably because the former all made good, to a greater or less degree, the gaps and weaknesses in the canopy of the latter. Conditions P, Q, D, and R will tend in practice to be higher yielding than A or B because of their greater capacity to make good any canopy gaps.

J. B. D. Robinson (pers. comm.) suggests that a condition akin to D could be secured, not by allowing basal chupons to grow, but by planting several seeds at each "stake" (the usual practice in direct seeding) and allowing all to grow (instead of thinning to one). A somewhat closer spacing than that pictured in D could well be used. He points out that this practice has proved successful with coffee in Brazil and Tanzania. It has the merit of having several separate root systems functioning at each point, so that if one is damaged others may provide for all the top-growth needed at that point. This is certainly worth trying.

CONCLUSION

It seems certain that relaxation of pruning will not, in the long run, depress yield, although complete relaxation does depress yield for a year or two; and it seems highly likely (more from old textbook discussions of the subject than from the results to date of this trial, although the latter were tending in this direction) that some relaxation of strict pruning is necessary, in the long run, to maintain yield, as the original stem and branch structure becomes diseased or senescent.

Whether or not the extra height of unpruned cocoa is regarded as a practical disadvantage seems to depend largely on personal preference. Many workers with experience of tall cocoa like the ease of movement, with knapsack sprayers etc., that the extra head-room provides, and find little difficulty in using long poles for harvesting. Others think the height a serious disadvantage.

The results of this trial suggest that there is greater black-pod loss in unpruned cocoa. This may have been due to the only partially developed "unpruned" condition to date in this trial, with canopy at all levels. Ultimately the lower-level foliage will die-out; and it is difficult to see why there should then be any appreciable difference between black-pod incidence under a high, closed canopy and that under a low, closed, canopy.

As to hurricane damage, no conclusion can be drawn as yet; but it seems that unpruned lodged worse, but is recovering quicker.

My own view of the agronomic situation is that the cocoa plant tends to regulate itself by producing only those many stems per unit area as there is useful room for. There is much to be said for allowing cultivated cocoa to thus regulate itself, rather than imposing any contrary regulation on it.

ACKNOWLEDGEMENTS

During these five years the field work has been supervised by Mr. M. Hassan. For part of the time Mr. S. Sundaram assisted in the direction of the trial; and, with access to the library at the College of Tropical Agriculture, Trinidad, he has since given great bibliographical help with the "Review" section.

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Appendix 1. PRUNING TERMINOLOGY

A young cocoa tree has a single stem (trunk) terminating about 1-2 m above ground at a branching point *(jorquette)* from which 3-5 *main fan branches* grow more or less laterally, and themselves bear *secondary,* and these in turn *tertiary* fan branches. Adventitious, shoots *(chupons, or water shoots)* then arise, chiefly at the base of the stem and just below the jorquette. In plantation cultivation these are usually *pruned* (cut off close to the trunk) as soon as they are noticed. If not pruned, they grow vertically, for 1-3 m before themselves jorquetting. Scores of chupons may arise within a few years. If none are pruned, some will grow more strongly than others, and many of the latter will wither away, but within a few years the tree will have a *multi-trunked* habit, and some trunks will eventually have three or more tiers *(storeys)* of fan branches, vertical growth having being continued by a succession of sub-jorquette chupons.

In plantation cultivation, not only chupons but also fan branches, particularly secondaries near to the trunk, are sometimes pruned. This paper is concerned primarily with chupon pruning.

Appendix 2. FURTHER DETAILS OF PLOTS

Typically these were 8 rows of 7 trees gross, 6 rows of 5 trees net. As shown in Fig. 1, some were otherwise shaped, including three plots on the irregularly planted area, which consisted of 30 trees each, with a boundary (hence area) determined by surveying. Plot 1a, with 8 rows of 4 trees net was the only one with other than 30 trees.

The nominal spacing of 10 ft. x 10 ft. should give a standard plot area of 3000 sq. ft. (279 sq. m.). Exact measurement in 1972 showed that the areas of 19 of the plots ranged between 280 and 288 sq. m. For simplicity, the size of these plots was taken as 284 sq. m. in calculating yield per acre. The sizes of the other nine plots, in sq. m., were:

1 A — 221	1 D — 207	5 D — 272
1 B — 194	3 D — 243	7 C — 291
1 C — 187	5 C — 295	7 D — 301

Plot renumbering

In early 1970 the block allocations of what were then plots 4c. and 6c. were reversed, in an attempt to get more homogenous blocks. Back-reversal of these plots, as shown in Fig 1, therefore give the situation as it was in early 1969. This situation was unchanged since the start of the trial as regards all the plots of blocks 1, 2, and 4, and plots 3 B, 3 D, 5 B, and 5 C. The following plots had changed in January 1969.

3 A in 1968 became 3 C in 1969
5 A in 1968 became 3 A in 1969
5 D in 1968 became 6 D in 1969
3 C in 1968 became 6 C in 1969

Plots 5 A, 5 D, 6 A, 6 B, and all block 7 were first marked in early 1969.

Appendix 3. COMPLICATIONS OF ANALYSIS

Because of the re-arrangement of block boundaries in 1969 two of the seven blocks now recognized each have two plots starting in 1968 and two in 1969. An adjustment for years was, therefore, made to obviate the within-block error that would otherwise arise from this. The amount by which the mean plot yield of year (n) exceeded that of year (n-1) was subtracted from each of the 8 year (n) figures that were listed with the 20 (n-1) figures.

To analyse the fifth year, the original block boundaries were reverted to. To make the results comparable with those of earlier years, these fifth-year yields were scaled down by the inverse of the amount by which these 20 plots had outyielded the other 8 in the earlier years.

One of the original plots had its treatment changed in 1969, so that in the fifth-year analysis there were two treatment 'C' plots in block 5 and no treatment 'A'. This was overcome by (a) averaging the two 'C' yields and (b) estimating an 'A' yield by adding the mean increase in 'A' yield of the 5th year over the 4th, as given by block 1-4, to the mean of the relevant 4th year 'A' yields available.

Fiji agric. J. 1973, **35**, 11-14

FURTHER NOTES ON THE WAIMARO COCOA PART 1 SOILS

by

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SUMMARY

The main soil type on the river plain at Waimaro is Serea sandy clay loam, a recent alluvial soil. On the terrace, the main soil type is Koronivia sandy clay loam, including its impeded drainage phase, belonging to the Red-yellow podsolic Great Soil-group. The cocoa is thriving on the alluvial plain and on the free draining terrace soils, but not on the impeded drainage phase of the Koronivia sandy clay loam.

INTRODUCTION

An area of about 1.6 ha. (4 acres) of cocoa at Waimaro has been used since 1968 (i.e. 10 years after planting), for a pruning experiment. As described by Vernon (5), the growth of cocoa in this experiment was found to vary greatly over the topographically uniform plateau that forms the major part of the area. A detailed soil survey was therefore made in February 1973 to see what soil variations, if any, were responsible for this. This survey disclosed the situation now described.

Physiography

The plot is situated on one of the many terraces, remnants of an erosional and levelling process, on what appears to be an old, dissected, elevated flood plain, found at the edge of the alluvial plain of the Wainivesi river. Most of the experimental area is on the nearly level plateau of the terrace, which drops steeply down, about 12 m, to the recent flat area below. The gravel found on the plateau indicates that the soil parent material is of acid origin, most probably rhyolitic, originally deposited there by the Wainivesi river, but since eroded. Soils on the plain are derived from recent alluvial deposits.

SOILS OF THE ALLUVIAL PLAIN

The soils of the alluvial plain are similar to those described by Twyford and Wright (4) as Serea sandy loam and loamy sand; but at Waimaro, the soil texture is finer in the "A" horizon (sandy clay loam) where the ground is slightly higher, and moderately strongly mottled in low lying areas. These we have mapped (Fig 1) as Serea sandy loam mottled phase and Serea sandy clay loam.

Serea sandy loam — mottled phase

This is found only in a small area in the cocoa-planted area, although that part of the station between plot 1C and 5D (See Fig 1 of Vernon (5), is probably of this soil type.

The top 10 cm of the profile is dark, greyish brown with light grey mottling, and of sandy loam texture. Structure is moderately developed medium and fine subangular blocky, friable when moist, and slightly sticky and plastic when wet. It contains many roots.

Underlying this is 18 cm of yellowish brown sandy loam, mottled light grey and reddish brown. It is friable, and has a weekly developed, subangular blocky structure. When wet the soil is nonsticky and nonplastic and contains some fine gravel and fine roots.

Below this is 28 cm of reddish yellow, sandy loam, containing loose, fine gravel, and mottled reddish brown and light grey. The fine gravel and mottling increase with depth. There are no roots present.

Serea sandy clay loam

As mentioned above, this soil type occurs on slightly higher ground than where Serea sandy loam mottled phase is found. The structure is fine, subangular blocky, and when wet it is slightly sticky and slightly plastic. It contains little gravel and many roots.

Underlying this is 15 cm of yellowish brown, sandy clay loam with few, fine light grey and reddish brown mottles, and containing some fine roots and gravel.

This horizon overlies 27 cm of yellowish brown sandy loam, mottled reddish brown and light grey, and containing fine gravel. The mottling and the gravel content increase with depth.

Discussion of the alluvial soils

No chemical analysis has been made of these soils, but they appear to be fertile, and in the Serea area, they were reported to be most suitable for bananas and dairy pasture (4).

The lack of mottling in the top 12 cm of Serea sandy clay loam and its presence throughout the profile of Serea sandy loam, indicates that, whereas the water table rarely rises to the surface of the ground in the case of the former, it is frequently above the ground surface during the wet months, in the case of the latter. This conflicts with the recollection of the cocoa research staff, who think that there are often pools of standing water over a somewhat larger area, than shown as the "mottled phase" in Fig 1. But as they made no exact records, this may be a faulty recollection.

Also the lack of any real gleying as a result of permanent water saturation, further suggests that the level of the dry season water table is well below 50 cm, and that the wet season water-table fluctuates over a large area. The textural sequence from fine (sandy clay loam) in the surface horizon, to coarse (gravelly sandy loam) in the subsoil enables the water table to rise to ground surface and drop to the original level easily and quickly.

SOILS OF THE TERRACE

These soils are of the Red-yellow podsolic group, which is not common in Fiji. The 19 types and phases identified by Twyford and Wright occupy a total area of only 142 sq. miles (4). Only three of these types occur in the wet zones.

The terrace soils at Waimaro closely resemble the Koronivia sandy loam type, which is best known from its occurance on the dissected plateau of the Koronivia Research Station, a similar landscape and topographic location to Waimaro. Also as at Koronivia, soils on the slope below the terrace (terrace-ascarpment) at Waimaro, are closely related to the Koronivia hill soils (38 H of Twyford and Wright).

However, the texture of the surface horizon of soils at Waimaro is mainly sandy clay loam, which is slightly finer than that recognised by Twyford and Wright. Also on some parts of the terrace, the subsoil of this type is high in clay content, more compact and of rather poor internal drainage. This makes it necessary for the recognition here, of an additional soil type within the Koronivia series — *Koronivia sandy clay loam,* as well as a phase of it viz. *Koronivia sandy clay loam impeded drainage phase.* The distinction between these two soils appears to be of considerable importance to the growth of cocoa.

The survey also recognised two other phases, based on slope (steepness), viz. Koronivia sandy clay loam moderately steep phase and Koronivia sandy clay loam steep phase. These soils have shallow top soil.

Koronivia sandy clay loam.

This is the soil of the upper terrace area and the higher northwest end of the station. The profile typically shows 10 cm of dark brown friable sandy clay loam. The structure is well developed, medium, subangular blocky, breaking easily to fine blocks and crumbs. When wet it is slightly sticky and plastic. It contains a few rounded stones and many fine and medium roots. There are many quartz pebbles on the surface.

This horizon overlies 15 cm of greyish brown sandy clay loam, containing few rounded stones and few roots but otherwise similar to the surface layer.

Below 25 cm the colour changes to reddish-yellow with white and light red mottled, and the structure is subangular blocky and prismatic. It contains some weathering gravels and a few stones. Other properties such as texture and consistence are similar to the surface horizon.

The abundance of cocoa roots in the top 10 cm of the profile and free internal drainage, are very important features of this soil type. It is noteworthy that out of a total of 60 pits — 25 x 25 cm, with an average depth of 70 cm, dug during the survey, none held any water 24 hours after a fall of 39.8 mm. of rain.

Koronivia sandy clay loam — Impeded drainage phase

This is found on the south central part of the terrace and also on all the sloping land alongside the King's Road. The profile shows 17 cm of greyish brown, friable sandy clay loam, instead of a dark brown surface horizon which is common in the Koronivia sandy clay loam. The structure is strongly developed medium subangular blocky; slightly sticky and plastic, containing some rounded stones and many roots, especially in the top 12 cm.

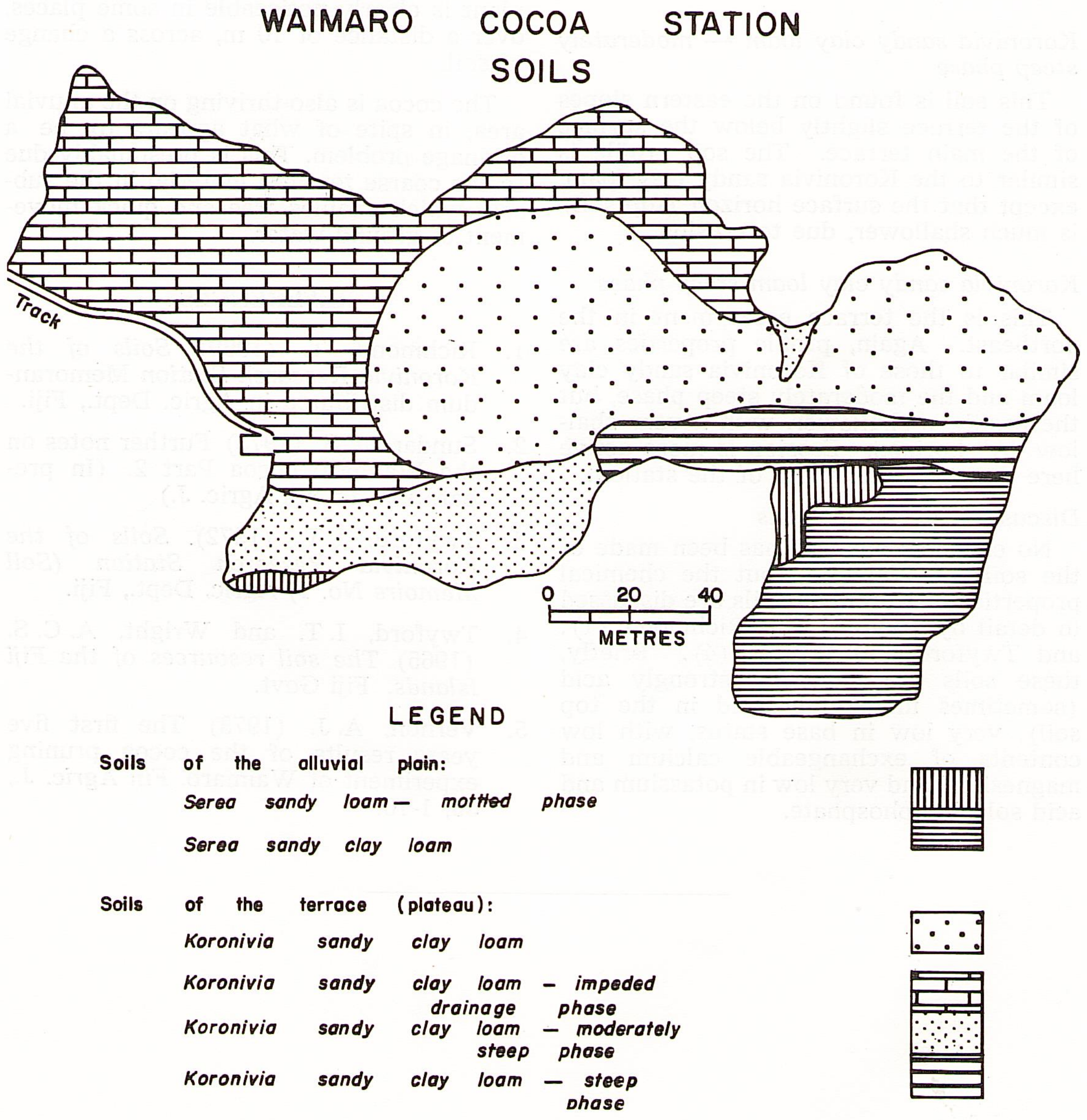

Figure 2.

This horizon overlies 50 cm of light red to reddish yellow, very firm clay which is hard to dig. The structure is strongly developed subangular blocky as well as prismatic. It is sticky and plastic, and contains many stones in some places, but does not contain any roots.

Of the 42 pits dug in this soil, 40 held water to a depth of 25 cm, 24 hours after the rain, indicating that internal drainage is very slow or not free in this soil.

Koronivia sandy clay loam — moderately steep phase

This soil is found on the eastern slopes of the terrace slightly below the surface of the main terrace. The soil profile is similar to the Koronivia sandy clay loam, except that the surface horizon (top soil) is much shallower, due to erosion.

Koronivia sandy clay loam steep phase

This is the terrace escarpment in the northeast. Again, profile properties are similar to those of Koronivia sandy clay loam and the moderately steep phase, but the profile is shallower, with a very shallow "A" horizon. Erosion is more active here than on other parts of the station.

Discussion of terrace soils

No chemical analysis has been made of the soils of Waimaro; but the chemical properties of Koronivia soils are discussed in detail by Twyford (3), Richmond (1), and Twyford and Wright (4). Briefly, these soils are generally strongly acid (sometimes moderately acid in the top soil), very low in base status, with low contents of exchangeable calcium and magnesium, and very low in potassium and acid soluable phosphate.

RELATION OF SOIL TO COCOA GROWTH

This topic will be dealt with in more detail in a paper by Sundaram (2). It was clearly apparent in the course of the survey however, that on the terrace, the cocoa is thriving on Koronivia sandy clay loam, but struggling to survive on the impeded drainage phase.

The change in the appearance of the plant is clearly noticeable in some places, over a distance of 10 m, across a change of soil.

The cocoa is also thriving on the alluvial area, in spite of what appears to be a drainage problem. This is presumably due to the coarse textural material in the subsoil, which enables free and quick movement of ground water.

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Fiji agric. J. (1973), 35 15-25

RAT DAMAGE ASSESSMENT AND CONTROL IN COCOA

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SUMMARY

Rat damage to cocoa in Fiji is widespread, and serious on some properties. Damage occurs as the pods turn yellow at maturity so all pods attacked are a total loss. Attack rates exceeding 9000 pods (400 Kg dry cocoa) per hectare have been recorded.

Damage can be reduced to very low levels by baiting with warfarin impregnated wheat set in paraffin wax (commercial preparation). Two to three applications of poison per year (depending on plantation size) with the first being placed at the start of the harvest season provides very satisfactory control.

INTRODUCTIONS

This study was part of a four year (1969-72) research project aimed primarily at investigating rat damage, ecology and control in coconut groves. The results of the whole project have been briefly reported (23). This paper expands the results of the cocoa damage assessment and control programmes.

Rats have been considered an agricultural pest in Fiji for many years. They were apparently considered a pest of sugar cane as early as 1883, for in that year the mongoose (*Herpestes auropunctatus*) was introducted in the hope that it would control rats. But since the 1920's they have been mainly recognised as a pest of coconuts (11,14,19, & 20). Rat damage to cocoa has received much less attention. Jack (10) and French-Mullen (4) mention rats as a problem in cocoa as does Yelf (24), but a major survey of cocoa growing in 1959 (9) makes no mention of the pest.

Rodent damage, caused by a considerable number of species from the families Sciuridae (squirrels) and Muridae (rats), occurs in most cocoa growing areas of the world. Montserin (13) recorded losses in Trinidad of 2960 pods/ha/year, or about 30% of the total production. Damage was caused by a tree rat, possibly *Rhabdomys* sp. Light to moderate damage (60-1060 pods/ha/year, 0.7-7.0% of the crop) occurs in Ghana at Tafo (8) and Eastern Regions (18), while damage at Gambia, Nigeria, averaged 8.4% in 1966 (3).

Damage in West Africa is caused primarily by squirrels (*Protoxerus stangeri, Heliosciurus gambianus, and Funisciurus spp.*) and the giant or pouched rat (*Cricetomys gambianus*ϙ.

Rat damage appears to be more serious in the Pacific with significant losses being recorded in the Solomon Islands (6), (15), Caroline Islands (12), (16), New Hebrides (21) and Samoa (personal observation). These islands, and Fiji, are all inhabited by the same three species of rat.

Rattus exulans (*Polynesian rat*), the most widespread, is the indigenous rat of the Pacific. It originated in S.E. Asia and is thought (17) to have spread west across the Pacific is association with human dispersal.

Rattus rattus (the roof, ship or black rat) is found throughout the tropical and temperate world and is moderately widespread in Fiji and other Pacific Island groups. It also originated in S.E. Asia but Pacific representatives of the species probably came from North America or Europe, arriving on ships over the last 200 years.

Rattus norvegicus (the Norway or common rat) is also a world wide species

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as a result of shipping but has a very limited distribution within Pacific Island groups. It originated in the Manchurian region of Asia.

Although cocoa has been grown in Fiji since 1890 and rat damage recorded as early as 1936 (10), the problem did not attract attention until recently because the cocoa bearing acreage was insignificant (less than 40 ha). However by 1965 the bearing area had increased to about 500 ha. and rat damage was known to be serious in some localities (24). No formal studies were made at that time because low world prices and poor yields (later known to be due to canker disease (5) to which the Trinitario cocoa then being grown was susceptible) had reduced interest in the crop.

By the late 1960's the better yields of Amelanado (a canker resistant variety) coupled with rising world prices let to renewed interest and initiation of research which revealed appreciable rat damage in some localities. Thus when rat damage assessment in coconuts was started in 1969, cocoa damage assessment was incorporated into the programme.

OBSERVATIONS

Characteristics of Rat Damage

Most rat attack of cocoa takes place as the pods turn yellow at maturity, although in some areas green pods are also attacked, particularly when there are few ripe pods available. Damage consists of a hole chewed in the side of the pod, through which the beans are removed though seldom eaten. The husk remains on the tree and if not removed is often attacked by blackpod (*Phytophthora palmivora*) and is then a reservoir for this pathogen. The husk eventually dries out and remains on the tree for at least a year.

All three species of rat present in Fiji have been trapped on cocoa farms. However their distribution and relative abundance varies considerably. *R. exulans* is ubiquitous and numerous, *R. rattus* fairly widespread, but *R. norvegicus* is of limited distribution, being mainly found in association with human dwellings. *R. exulans* and *R. rattus* are both arboreal species while *R. norvegicus* is, by comparison, a poor climber. Examination of teeth marks on freshly damaged pods, and trapping studies, show that *R. rattus* is responsible for most damage to pods.

Cocoa pods attacked by flying foxes (*Pteropus sp.*) were observed on the islands of Kandavu and Vanua Levu but total damage by this animal is insignificant in Fiji.

Damage Assessment

There seem to be no detailed records of rat damage before 1968, when recording was begun at several sites as part of an overall study of the crop. On these trials pod production was recorded as useable, damaged by blackpod and damaged by rats. Picking was mostly at weekly intervals and there was virtually no overlap of the two damage categories. All pods with holes chewed in the side were classified as rat damaged even if a limited amount of blackpod was present. Rats do not appear to attack ripe pods with sufficient blackpod infection to make them unuseable. Most blackpod loss occurs while the pods are still green, a feature that further reduces the interaction of the two damage categories.

Table la details production and rat damage at four sites for years 1969-71. Records do not cover all years on all plots as rat poison was laid on some properties, and recording was terminated on others.

The level of damage at all sites exceeds 3000 pods/ha. on one or more years with damage at Waimaro in 1971 reaching the very high figure of 9490 pods/ha. These levels of damage are similar to those recorded on Government stations in the Solomon Islands (16).

To investigate rat damage on small holdings a survey was started in 1970. The results, in Table lb, have not been expressed on a per hectare basis, as the spacing, amount of shade etc. vary greatly from farm to farm. There is a notable interfarm variation, with three of the eight properties incurring little damage. The low level of damage on some farms is almost certainly related to the number of *R. rattus* present. There is also limited evidence to suggest that damage levels are dependent on the length of time rats

TABLE 1. CROP LOSS TO RATS (LOSS ASSESSMENT)

	Island	Station	No. of trees	Period	No. of days	Rat damaged pods (R.D.)	Useable pods	Total * production	R.D. as % of Total
				Year		Pods per hectare per year			
TABLE 1a	Viti Levu	Waimaro		1970		4,600	21,600	26,200	17
				1971		9,500	30,500	40,000	24
Exp. farms and larger estates	Vanua Levu	Wainigata		1969		5,800	23,400	29,200	20
				1970		6,900	22,000	28,900	24
	Taveuni	Delaiweni Estates		1968		370	3,830	4,200	9
				1969		3,200	1,900	5,100	64
	Viti Levu	Wainibuka		1969		2,100	21,900	23,900	9
				1970		3,500	30,100	33,600	10
			No. of trees	Start	No. of days	Actual number of pods			
TABLE 1b	Vanua Levu	Wailevu	350	July '70	457	50	12,440	12,490	0.4
	"	Nagigi	350	" "	351	3,320	5,820	9,140	36
Small holdings	"	Natewa Bay	350	Aug. "	446	2,360	4,900	7,260	33
	"	Navonu	450	July "	421	320	8,505	8,370	4
	"	Loa	750	" "	478	4,660	15,920	20,580	23
	Viti Levu	Navua	300	Oct. "	359	2,290	6,220	8,510	27
	"	Namara Rd.	302	June '71	462	970	6,750	7,720	13
	"	Wainibuka	144	April "	127	60	3,040	3,100	2

* Exclusive of black pod

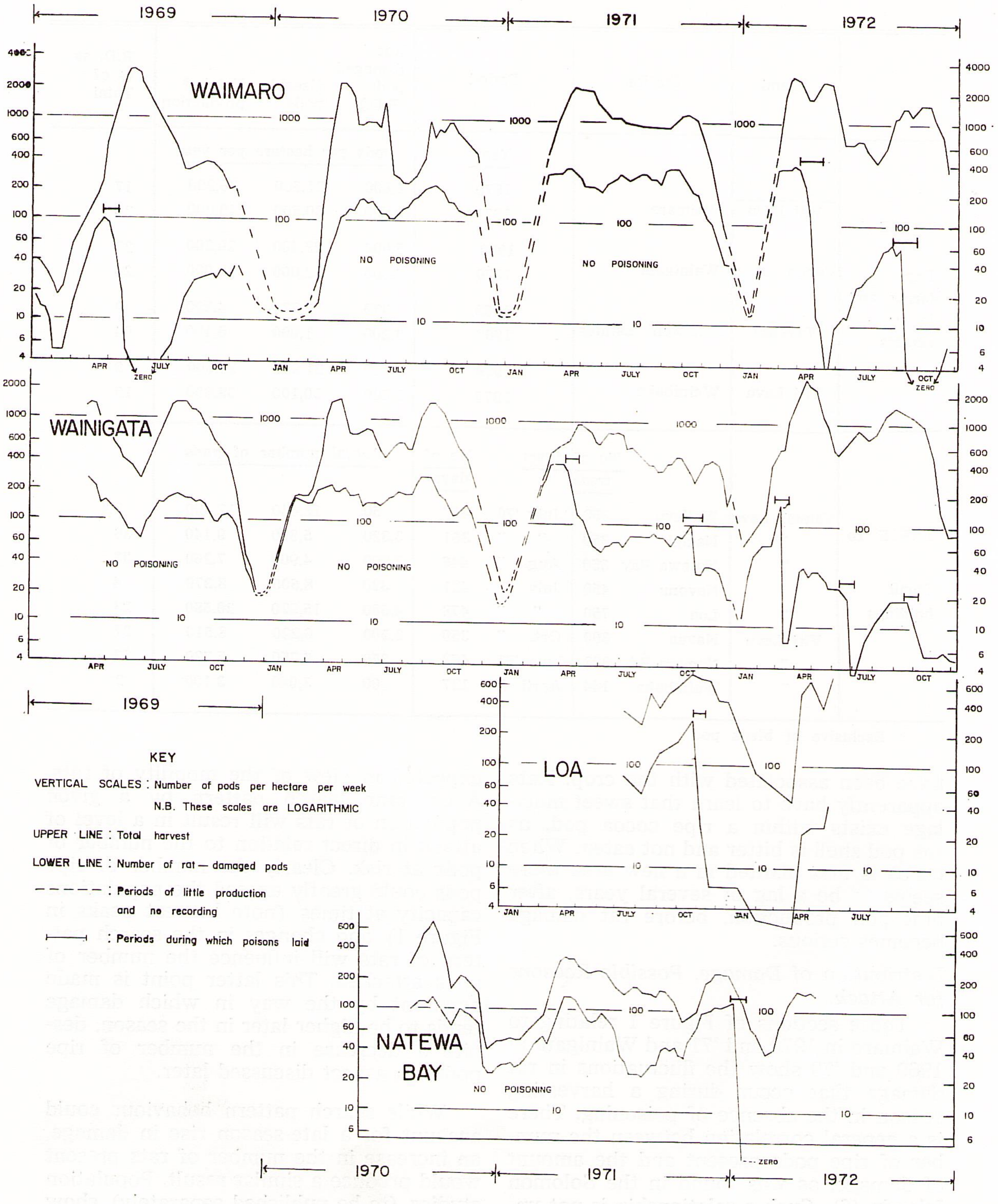
have been associated with the crop. Rats apparently have to learn that sweet mucilage exists within a ripe cocoa pod, as the pod shell is bitter and not eaten. When cocoa is first planted in a new area there seems to be a lag of several years, after first pod production, before rat damage becomes serious.

Distribution of Damage, Possible Reasons for Attack.

Those sections of Figure 1 relating to Waimaro in 1970 and '71 and Wainigata in 1969 and '70 show the fluctuations in rat damage that occur during a harvesting season in the absence of poisoning. There is a general correlation between the number of ripe pods present and the amount of damage, as was found in the Solomon Islands (6). Such a relationship is not unexpected in view of the mobility of rats. A constant search pattern by a given population of rats will result in a level of attack in direct relation to the number of pods at risk. Clearly the number of ripe pods could greatly exceed the populations capacity at times (note harvest peaks in Figure 1) and changes in the search pattern of rats will influence the number of pods attacked. This latter point is made apparent by the way in which damage tends to be higher later in the season, despite a decrease in the number of ripe pods, an aspect discussed later.

While search pattern behaviour could account for a late-season rise in damage, an increase in the number of rats present would produce a similar result. Population studies (to be published separately) show

Figure 1. Seasonal Fluctuations in Rat Damage.



a general relation between rat numbers and damage, but the two factors are not closely linked.

Cage studies suggest that rats do not attack cocoa as a matter of course, even if they have been in contact with the crop for some time. Nine *R. exulans* were trapped in a cocoa grove and, after a period of familiarisation with individual cages, were presented with ripe cocoa pods. Only one pod was attacked in the following seven days. An identical group of animals that had been born in captivity were subjected to the same conditions and no pods were attacked in a seven day period of exposure. In contrast, four out of seven *R. rattus* trapped in a cocoa grove attacked pods under cage conditions.

Although this trial was very limited it does suggest (apart from the fact that *R. exulans* does not appear to favour cocoa) that not even all *R. rattus* in a given population are aware that edible mucilage exists within a cocoa pod and they may have to learn of its existence, either by trial and error gnawing on ripe pods (a few pods in the cage trial showed signs of gnawing) or feeding on pods opened by an experienced rat. As each cocoa season progresses more rats are probably searching for ripe cocoa, but there are fewer pods on the trees hence percentage loss rises. For example at Wainigata in 1970 (A), Waimaro in 1970 (B), and Waimaro in 1971 (C) the numbers of good pods and rodent damaged pods (R.D.) picked in the second and third quarters were:

		1 April-30 June	1 July-30 Sept.	Difference
A	Good pods	28,488	24,060	—4,428
	R.D. "	6,965	7,009	+44
B	Good "	24,323	4,757	—19,566
	R.D. "	2,665	3,337	+672
C	Good "	28,190	12,543	—15,647
	R.D. "	5,435	6,062	+627

Note that inspite of a marked drop in the number of ripe pods produced at all sites (diff. column) damage increased.

Everard (3) found that squirrels and rats attacking cocoa in Nigeria had to learn that sweet mucilage exists within a pod ,and that inexperienced animals under cage conditions had to be introduced to open pods before they would attack unopened pods. The apparent necessity to learn that a crop is edible has also been reported in relation to attack of corn (maize) in Tonga (Yamada pers comm). In this crop, attack does not occur until cattle, bird or pig damage exposes nearly ripe cobs of corn. Following such an "introduction" damage rises rapidly, in its absence damage is light.

Cocoa pod mucilage is clearly not an important food for most rats in a cocoa grove. For those that do attack cocoa the mucilage probably constitutes a "luxury" food and is not a primary source of basic food. This was the conclusion reached by Garrison and Breidenstein (7) in relation to rats eating sugar cane. They found that rats eating this crop utilize only half the actual sugar in the cane stalk material consumed. This apparent favouring of sweet substances by rats is supported by Burright and Kappauf (2) and Young et al (25) who found that concentrated aqueous sugar solutions were the best attractants for rats.

However it is possible that rats eat cocoa mucilage because of some other substance or substances. Barnett (1) cites examples of rats' ability to select foods containing vitamins that are deficient in other sources of food. The whole field of food selection is a complex one and a detailed discussion is beyond the scope of this paper.

CONTROL STUDIES

Frequency of Picking

Vernon and Sundarum (22) compared various picking frequencies. Their chief interest was in the incidence of blackpod disease, which is to some extent controlled by frequent harvest; but they also recorded rodent losses as follows:

Picking interval	Number of pods Useable	R.D.	Total	%R.D. (S.E.)
½ weekly	5,210	410	5,620	7.4 (±2.2)
1 "	5,180	780	5,960	12.8 (±2.8)
2 "	3,270	730	4,000	16.4 (±3.1)
4 "	2,750	810	3,560	22.4 (±3.5)

Notes: (a) "Total excludes the blackpods hence the apparent lower yield with longer pick interval.
(b) Each pick interval occured on six plots of 30 trees each.

Increasing the picking interval to four weeks causes a significant rise in damage, clearly making it advantageous to pick at the shorter interval. The results of this trial are consistent with the rat behaviour patterns discussed above. The longer the pods are at risk the greater the chance they will be located by a rat.

Friend (12) carried out a picking trial at intervals of 2, 4, 6 and 8 weeks in the Solomon Islands and claimed, without confidence limits, little difference in damage levels.

Rat Control by Poisoning: Bait Bases. ...

Legislation governing the use of poisons in Fiji prevents the widespread use, by unskilled personnel, of acute poisons such as zinc phosphide. For this reason all poison trials have utilized the anticoagulant warfarin (one of the cheapest available) in combination with various bait bases.

The type of anticoagulant poison used is generally not as important, in terms of overall efficiency, as the bait base with which it is combined. It is essential that rats feed readily on the bait provided, that is the bait has to be a more desirable food than most other sources immediately available.

Bait base trials have concentrated on testing commercial preparations that are available at a competitive price. I consider that it is difficult for the average farmer to mix baits that will consistently prove attractive to rats. In many areas of Fiji suitable bait bases are not readily available and very few centres have supplies of paraffin wax for producing a waterproof bait.

Table 2 details results of a trial primarily aimed at testing the palatability of grain versus meal based baits. Each bait station (all on the ground) consisted of a V shaped metal sheet covering three dishes containing the baits. Baits were kept in position for 10 days and results recorded daily.

TABLE 2, COMPARATIVE ACCEPTABILTY, AND SLUG AND SNAIL INFESTATION RATE OF THREE BAIT TYPES IN COCOA PLANTATIONS.

Bait	Description of bait	Total weight of bait eaten, Kg. (S.E.)	Total number of slugs and snails removed from baits. (S.E.)
A	"Crest" pigmeal mixed with fat, sugar and sufficient wax to form a block. (experimental block, 0.025% warfarin)	4.1 (±0.28)	1029 (±120)
B	Whole wheat grains impregnated with warfarin (0.05%) and set in sufficient paraffin wax to hold the grains together. (commercial block, produced by Rentokil Ltd, Auckland).	5.4 (±0.40)	743 (±60)
D	Fine wheat germ meal combined with excess paraffin wax to form a hard block. (commercial block, 0.025% warfarin, produced by Messrs Geigy Agchim, Paris).	2.0 (±0.09)	1211 (±74)

Notes: Cocoa plot area = 0.5 hectares containing 46 bait stations with each bait type being present at each station.
Total number of slugs and snails counted each day then removed 10-15 metres from the stations.

Rats clearly favoured bait B of which significantly more than A or D was consumed. The higher consumption of bait B could have been partly due to the significantly higher slug and snail infestation rate of the other two baits. Nonetheless the very marked difference between the consumption of baits B and D indicates that rats clearly did not favour the latter preparation. In the absence of slugs and snails bait A would probably have proved just as palatable. The total amount of bait consumed in the 10 days was 11.5 Kg (9.6 Kg/ha.) which is a very high rate of consumption and is probably a reflection of the cocoa block shape and locality. The cocoa grove was a narrow strip located on a stream flat and surrounded by bush and reed covered terrain. Poison laid in such a block clearly kills animals over a much greater area than that in which it is actually laid, thus the consumption in relation to cocoa area tends to be higher than in a larger block; one of the factors that makes control in a small block uneconomical (refer to section on treatment efficiency).

To summarise; this multiple choice bait trial suggests bait B is superior to either baits A or D but that in the absence of slugs or snails bait A could prove as palatable as B. A subsequent trial, described below, confirmed this and indicated that this meal based bait is an alternative to the commercial preparation when materials and mixing facilities are at hand.

Bait Spacing, Siting, and Rate

To investigate the various aspects of practical rat control in cocoa, Research Stations on Viti Levu and Vanua Levu were systematically treated, and several of the farmers' properties listed in Table lb were treated after the period of damage and production recording.

Population studies provided information on which to base aspects such as bait spacing and siting. Movement data revealed that the least mobile *R. rattus* ranges over a minimum of 0.25 Ha. and that most range over at least 0.5 Ha. On the basis of this information 25-30 bait points per hectare should prove sufficient, for even the most limited home range should encompass at least one bait station. The existence of social hierarchies within a rat population, resulting in subordinate animals not gaining easy access to feeding sites (1) is another reason for not having very widely spaced bait stations. Movement of *R. rattus* is predominantly in the trees, hence the need to place most of the baits in the forks of cocoa trees.

Application of sufficient poison to achieve optimum control with a minimum of waste is one of the most important aspects of any form of crop protection. Therefore poison was applied at several rates on station and farmer plantations in 1971 and 1972.

Table 3 details the results of these trials (excluding bait A, Wainigata 1971). At Wainigata during 1971 bait types A, B and C were used to compare palatability and ease of laying. Bait A had the highest consumption (11.4 Kg) and was little affected by slugs, snails and ants when placed in the first fork. Bait C, having the lowest consumption, possibly reflected an excess of bait points, with *R. rattus* prefering to feed on bait points located in the trees (bait C was placed only on the ground, see notes Table 3). Bait B was most convenient in terms of preparation and laying. Bait A has to be prepared from raw materials while bait C has to be placed in bamboo tubes which need to be collected, cut and distributed through the cocoa.

During 1972 all treatments used bait B, because it proved to be the most suitable preparation readily available. At Wainigata the bait station density was reduced to 17/ha. to reduce baiting labour. To limit waste (ie the bait remaining after most of the resident animals have been killed) initial bait weight was reduced to 57g per station, baits being replaced when nearly eaten. The reduction in bait size reduced waste but entailed more frequent checking of baits to ensure that all stations had a supply at all times.

To determine overall efficiency 30 bait stations per Ha, with an initial application rate of 115g per station, were used at Waimaro during 1972. Waste was greater than at Wainigata but still averaged only 0.55 Kg/ha. Total consumption was considerably higher on both stations at the

TABLE 3. CONSUMPTION OF POISON BAIT ON RESEARCH STATIONS AND SMALL HOLDINGS

Site	Date laid	Duration days	Method	Bait laid, Kg B	Bait laid, Kg C	Bait eaten, Kg B	Bait eaten, Kg C	Total waste	Total con-sumed
Wainigata 2.83 ha	29/3/71	15	(a)	12.0	—	5.8	—	6.2	5.8
	14/10/71	15	(b)	9.4	4.9	7.2	3.6	3.5	10.8
	2/3/72	15	(c)	8.7	—	7.7	—	1.0	7.7
	12/6/72	14	(c)	6.8	—	6.0	—	0.8	6.0
	11/9/72	14	(c)	5.8	—	4.5	—	1.3	4.5
Waimaro 1.7 ha	14/4/72	35	(d)	14.4	—	12.2	—	2.2	12.2
	4/9/72	17	(d)	10.7	—	8.4	—	2.3	
Loa	12/10/71	14	(e)	3.2	1.5	3.0	1.5	0.2	4.5
Navonu	21/10/71	14	(f)	2.3	1.1	1.8	0.9	0.7	2.7
Nagigi	10/11/71	14	(f)	2.8	2.5	1.4	2.1	1.8	3.5
Serua-Namosi	14/10/71	17	(g)	5.7	2.3	4.9	1.5	1.6	6.4

Notes: (a) Each bait type placed at 33 of the 66 bait stations. Two 115 gm baits laid at each point, one in the first jorquette of the cocoa, the other on the ground.

(b) Each bait type placed at 66 stations; bait B (115 gm blocks)in the first jorquette and bait C on the ground in bamboo tubes.

(c) A 57 gm bait in the first jorquette at 50 bait stations.

(d) A 115 gm bait in the first jorquette at 50 bait stations.

(e) A 115 gm block of each type at each of 15 stations, block B in the first jorquette and block C on the ground in bamboo tubes.

(f) As for (e) but with 20 stations.

(g) Bait B in the first jorquette at 25 stations; bait C in bamboo tubes on the ground at 9 stations.

Bait Types: A and B as per table 2.

C = Commercial preparation of whole wheat impregnated with 0.05% warfarin. (produced by Rentokil Ltd, Auckland).

first application, 2.5 Kg/ha at Wainigata in 1971 and 2.0 Kg/ha at Waimoro in 1972. At both stations the consumption declined at subsequent treatments, to as little as 0.64 Kg/ha at the third application at Wainigata in 1972.

Table 3 also details the application and consumption rates on four small holdings. Commercial baits B and C were used on all four and on three of the four bait B was consumed in greater quantities. Wastage was not excessive on any of the properties and would have been lower at Nagigi and Serua if bait C had not been used. Total consumption, ranging from 1.82 to 3.0 Kg/ha, was similar to the initial application on the larger research station plantations.

Treatment Efficiency

Figure 1 shows the effect of poisoning on damage levels at four locations. At Waimaro and Wainigata during 1971 and

1972 poison applications at the beginning of the season produced dramatic reductions in damage. Poisoning was also effective on the well maintained smallholdings at Loa and Natewa Bay, where effective protection lasted three to four months.

Treatments at Waimaro have been more efficient than at Wainigata with losses/ha/week at the former not exceeding 37 pods after the first application, while at the latter they reached 99 pods. The topography and shape of the plantations is probably responsible for this apparent difference. Waimaro is basically a 1.7 ha rectangle surrounded by grazed pasture, stream flats and weed filled small gullies, while the Wainigata cocoa block is a long, narrow, 2.8 ha strip bordered by a stream, and well maintained stands of young coconuts. Narrow plots with a high proportion of edge to centre tend to be more rapidly re-invaded by rats following poisoning, and this could account for the lower poisoning efficiency despite the larger area treated.

Prior to applications of poison in April 1971 and 1972 substantial losses were incurred at Wainigata (1971) and Waimaro (1972). It seems that earlier poisoning, eg in February as at Wainigata in 1972 ,is generally advisable on high yielding Amelonado blocks, such as these, with a history of appreciable rat damage.

Bait containing a dye (fluroscene), that can be detected in gut contents under UV light, was used to determine what percentage of a rat population accepted poison bait. Following the completion of a long term rat population study most resident animals within a 1.2 ha cocoa plantation on Namara road were marked with a numbered ear tag, and therefore formed an ideal base for such a trial. A bait similar to type B was formulated using padi rice, paraffin wax and the dye. It was laid as 60g blocks, in the first jorquette, at 54 sites within the cocoa. Four days after laying, trapping was started using 108 snap traps (ground and tree placed traps at each site) and was continued for nine days. In that period 121 rats (11 *R. rattus* and *R. exulans*) were caught. All the *R. rattus* and 87% of the *R. exulans* had eaten the bait (ie gut contents contained traces of the dye) indicating that very few animals would not be poisoned over a 13 day period.

This trial also showed the effect of a poison programme on rat populations in the terrain immediately surrounding the poisoned area. During the first four days of trapping, 50% of the animals caught carried ear tags and were therefore normal residents of the area; but in the final four days of trapping only 23% of the rats trapped were tagged, showing that rats were migrating into the cocoa area as the resident population was reduced. This movement will clearly increase the cost of controlling rats within a specific area and the smaller the area in which control is attempted the greater the proportional increase in cost.

TABLE 4. ECONOMICS OF RAT CONTROL IN COCOA PLANTATIONS

Site	Pre-treat. loss rate %	Treatment period	Production in treatment periods, pods/ha: Total pods	Expected loss at pre-treat. rate	Actual loss	Estimated saving *	F$ per hectare: Cost †	Net saving
Waimaro	20	9/4/73-27/9/72	26,121	5,224	860	4,360	$8.65	$35.00
Wainigata	22	2/3/72-25/9/72	20,087	4,419	371	4,048	$5.24	$35.25
Loa	22	10/11/71-19/5/72	10,284	2,253	484	1,779	$4.05	$13.75

* Pods valued at one cent each † Including poison at 48.5 cents/Kg, and labour at 42 cents/hr.

Economics of Control

Table 4 shows the economics of control at three sites. For properties the size of Waimaro (1.7 ha) and Wainigata (2.83 ha) there is no doubt that regular treatment is highly economic, while even on smaller properties the return for invested work and capital makes treatment well worthwhile.

The breakeven point for control is when damage exceeds 3-4% of total production. In general damage would want to exceed 5% of total production to make control economical on well managed high producing properties. On small properties with low total production, percentage loss would have to be higher to make control worthwhile.

CONCLUSIONS

Reduction of cocoa yields by rats is clearly serious in some localities and it is evident that control should become an integral part of plantation management where needed. The greater efficiency of control programmes on larger plantations (ie Waimaro and Wainigata) underlines the importance of encouraging farmers, as far as soil and topography allows, to plant cocoa in compact stands of as large an area as possible. Plantings in a given area could be done over a number of years.

The grain based bait set in wax is the most practical for general use and should be made readily available to farmers, particularly early in the year when damage is high as the first of the new seasons cocoa matures.

Farmers with very small plots of cocoa should not be encouraged to invest in poison baits, for control on small properties, for the reasons discussed above, is seldom likely to be economically viable.

ACKNOWLEDGEMENTS

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A DEFICIENCY OF PHOSPHOROUS AND CALCIUM IN CATTLE IN FIJI

by

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SUMMARY

Blood and bone phosphorus and calcium were determined for a random sample of cattle coming to Suva abattoirs. The bone P was 25% below normal, confirming a previous report of P deficiency, based on blood tests. Ca was 50% below normal, a deficiency not apparent in previous work. It seems that Ca, besides P, is generally deficient in soils, hence in pasture herbage, and hence in cattle in Fiji.

INTRODUCTION

In 1970, Newman (5) described the results of a survey of nine farms, well scattered over Viti Levu, that showed conclusively a general deficiency of phosphates in pasture herbage. Whereas the P content of blood serum of cattle, measured as mg/100 ml is normally in the range 4.0 — 7.12, averaging 5.16 (2), in three of the farms surveyed by Newman this figure, as a herd average, ranged from 1.5 to 3.7, on a fourth farm it was 4.4, and on a fifth farm (Koronivia) it had been 3.2 before the introduction of a P-rich feed supplement (coconut meal). A sixth farm kept only sheep, which showed severe clinical symptoms of P deficiency until supplementary coconut meal feeding was introduced. On a seventh farm the P serum figures were satisfactory at the time of the survey, but all the older animals either were then receiving, or had received, phosphate supplements, which had been introduced to the farm because symptoms of P deficiency had been apparent. Thus on only two of the nine farms was the P status of the pasture apparently satisfactory. Newman (5) then discussed methods of relieving the deficiency, and suggested the use of the proprietary product "Ultraphos", or phosphoric acid mixed with molasses in roller drums.

Newman (5) also quoted from (2) figures for the normal range (9-12) and average (11 mg/100ml) calcium of cattle blood serum; but he gave a herd average serum Ca figure for only one of his nine surveyed farms, and that quite normal.

Work in progress in Australia (D. Little, pers. comm.) suggests that bone analysis is a better indication of P and Ca deficiency, than blood analysis. Most of the total Ca content of an animal is in the bone, and when there is a nutritional deficiency of Ca, blood Ca may be kept at normal levels by de-mineralization of bone. As yet there is little published work on this subject, to establish norms; but the average P and Ca content of "steamed bone meal", as used for fertilizer or feeding livestock is well known. Observation of dairy and village cattle having led us to suspect Ca deficiency, we undertook the bone sampling and analysis now described, to compare Ca levels in cattle-bone in Fiji with this standard.

At the same time, the Koronivia herd was re-examined. Since the feeding of supplementary coconut meal had ceased, infertility had been a problem there. Many cattle had poor cycling rhythms, and seemed to retain the corpus luteum. Young heifers were not reaching sexual maturity until 28-30 months, and their sexual organs were immature and ovaries inactive.

RESEARCH

Survey method

A random sample of 128 animals was taken from cattle delivered to Suva slaughterhouses during July-October 1971. Of these, 12 were from the Koronivia herd. The others came from all parts of Fiji and comprised dairy cows, working bullocks, and beef males and females.

TABLE 1

ANALYSIS OF BONE AND BONE SAMPLES

Section I. Slaughterhouse samples.	No.	Mean age years	Bone P %	Serum P mg/100 ml.	Bone Ca %	Serum Ca mg/ml.
Cows — From Fiji Pastoral Company	10	8.1	9.3	5.6	18.8	9.7
Cows — Others — Above average weight.	30	6.2	9.9	5.7	15.9	10.3
Cows — Others — Below average weight.	35	5.8	9.4	5.3	13.0	10.1
MALES — Steers.	21	3.1	9.1	7.2	14.0	10.5
MALES — Bulls.	6	4.5	9.0	7.0	15.6	11.0
MALES — Working Bullocks.	26	7.8	9.5	6.8	14.8	10.5
TOTALS AND MEANS	128	5.1	9.4	6.0	14.8	10.2
Section II.						
K.R.S. Herd.	87		4.0			10.1
Bark Chewers (before treatment)	4	6.2	2.5			
" " (after treatment)	5	10.7	N/A			

Blood and bone samples were taken by Government meat inspectors. The blood was collected while the animals were being bled and the serum separated within twelve hours. The bone samples (compact bone) were taken with a ¾-inch trephine from the medial aspect of the middle third of the twelfth rib. Section 1 of Table 1 shows the results of the analysis of these samples by the Chemistry Section, of this Department. Analysis of the bone was based on a dry, fat free basis.

Blood and bone samples (the latter by rib biopsy) were also taken from four living animals at Vunidawa showing signs of pica and bark-chewing, and 87 blood samples from the Koronivia herd only. Section 2 of Table 1 shows the results of analysis of these samples.

Discussion of survey results

All the blood Ca values were well within the normal range, as were the blood P of the slaughterhouse samples. Indeed the average value of these samples is above the 'normal' average of 5.16 (2). This apparent contradiction of Newman's results may have been due to a fault of method. As noted by Newman (5) serum analysis can give inconsistent results if the samples are not centrifuged within a few hours of collection. In some of our batches of slaughterhouse samples the serum was not supernated off immediately after clotting. This can cause a spurious increase in serum P. The Koronivia herd figures are more reliable, and there the P level is just on the border-line of the normal range, being above the figure (3.2) recorded in 1962, but below that (6.2) recorded in 1968 when coconut meal was being fed lavishly. The 'bark-chewers' serum P is definitely sub-normal.

The chief interest, however, is in the bone analysis. These compare with standard figures (4) for steamed bone meal (a product similar to the material analysed) as follows (all figures in mg%).

	P	Ca
Normal steamed bone meal	14.53	30.14
Fiji survey	9.4	14.8

It seems that the bones of cattle in Fiji are generally deficient in P and highly deficient in Ca.

Experiment

The four bark chewing animals were fed with a proprietary brand of high-phosphate food supplement for three months. The bark chewing stopped, and bone P rose from 6.2 (± 0.8) to 10.7 (± 0.8), i.e. from being significantly less than the slaughterhouse mean of 9.4 (± 0.15) to being significantly greater.

GENERAL DISCUSSION

Soil analysis and manurial responses

Although there are no well-established criteria, Twyford & Wright (8) suggested that 1.7 mg acid-soluble P per 100g soil may be taken as a critical level; and their survey showed that the majority of soils in Fiji have a value of less than 1.5, and many less that 0.9 mg P/100g. Soil Ca also appears to be severely deficient. Most work on this mineral has been done on soils used for crops and little attention has been given to pasture soils. The majority of soils are low to very low in Ca and are very acid (A. Singh, pers. comm.)

In pot trials of typical pasture soils there have generally been big responses to P and, in so far as the point has been studied, there have generally been responses to Ca applied at a 'nutrient' (rather than an acid-correction) level (7).

Pasture Analysis

Typical leaf P deficiency symptoms have been observed on a wide range of plants on many soils in Fiji. McIntyre (pers. comm.) found a content of 0.13% or less in most pasture plants. In Para grass (*Brachiaria mutica*), the mainstay of the dairy industry in Fiji, the P content is generally 0.13% or less, and it has been suggested that average values for the year are below 0.1%.

According to O'Moore (6), 0.26% P in pasture is necessary for maintenance plus 3 gallons of milk a day, while 0.2% is adequate for a store cow. Animals at pasture with less than 0.15% develop sub-clinical aphorphorosis, and at lower levels clinical signs of 'pica' syndrome and general reluctance to move develop.

Animal Nutrition

As an animal grows from birth it assimilates from its diet the necessary minerals for bone mineralization and a mature animal would normally have at least 12.7 mg% P and 25-27 mg% Ca. Demands of parturition, lactation and metabolism will lower this level if the animal's diet is deficient. The withdrawal of minerals from the bones results in Osteomalacia (weakness of the bones) together with lameness and reluctance to move (Oestrodystrophy).

The animal loses condition, has a harsh staring coat, develops an abnormal appetite and is seen chewing bark, sticks and fenceposts. Digestive upsets often occur. Within any herd of animals it is possible to have clinical and sub-clinical cases, the variation mainly depending on the season of the year, stage of lactation and the level of mineralization before lactation commences.

Dental abnormalities and rickets have not been observed in young animals.

CONCLUSION

The average daily maintenance requirements of Jersey and Friesian cows has been estimated (1) at 15 and 26g respectively of P and Ca, plus 8g P for each gallon of milk. The Ca requirement is up to 40g daily for a heavy milker. It is evident, from the soil and plant analysis and our bone analysis, that Fiji pastures generally are severely deficient in P and Ca, and inadequate to supply the needs of lactating animals. It is also possible that the high iron and manganese content in some Fiji soils is interfering with the absorption of Ca by the animal.

It is possible that in some circumstances P and Ca manuring of pastures will give both an economic increase of dry weight of leaf and an adequate P and Ca leaf content. Pending further study of this solution, supplementary P and Ca should generally be given to farm stock, in the forms suggested by Newman (5).

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THE TOXICITY TO FISH OF HERBICIDES RECOMMENDED FOR WEED CONTROL IN THE REWA

by

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SUMMARY

Laboratory tests of the toxicity to fish (test species *Poecilia mexicana)* of a herbicide mixture recommended for water-weed control in the Rewa river showed the copper sulphate component to be highly toxic and the diquat (paraquat in the tests) component less so.

INTRODUCTION

As described by Hughes (5), in recent years water weeds chiefly *Hydrilla verticillata,* have created severe problems in the Rewa river, choking side channels and seriously impeding water traffic. Hughes (5) obtained good control of *H. verticillata* with a 1:4 mixture, by weight, of diquat and copper sulphate in glasshouse trials and with a 1:20 mixture in a river trial. She considered the toxicity of copper sulphate and diquat to mammals, including people, who might drink treated river water, and concluded that at the suggested concentrations they would be harmless.

But the effects of these chemicals on aquatic animals must also be considered. Copper, in particular, is well known to be highly toxic to fresh water organisms (6). Molluscs, such us Kai *(Unio sp)* and fish such as ika-droka *(Khulia sp)* and tilapia *(Tilapia mossambica)* form an important source of protein to people living near the Rewa. In the study now described *Poecilia mexicana* was used as the test fish Although not an important food species, this introduction from Central America is now widespread in the streams and rivers of Viti Levu, including the Rewa, and its abundance and small size (6 cm) make it an ideal experimental animal.

Instead of diquat, as used in the trials of Hughes (5) we used paraquat. This is a closely related herbicide (both have a bipyradil base) that is currently much more widely used in Fiji. Diquat is less toxic to animals, its oral LD_{50} (to rats) being 400-440 mg/kg compared with paraquat's 150 mg/kg (1), and is generally recommended rather than paraquat for aquatic used; but there is some danger of paraquat being misused in its place.

EXPERIMENTAL DETAILS

Method

A static rather than a continuous flow testing system was used. Two-litre glass tanks each fitted with an aerator were filled with tap-water (a chemical analysis of Suva tap-water and of Rewa water is shown in Table 1), the toxins added in appropriate amounts and ten fish then put in each. During the experiment fish were removed as they died and the time of their death noted. After 24 hrs the total number dead at each concentration was noted and the percentage mortality calculated. Water temperature during the

TABLE 1
RESULT OF WATER ANALYSIS ON 17 DEC. 1971

	Suva tap water	Rewa river
p^H	6.8	7.2
ppm $CaCo_3$*	32.0	42.0
" Cl	10.6	12.4
" Fe	0.28	0.43
" Ca	3.2	6.0
" Mg	5.8	6.5
" Cu†	0.1	—

* A measure of hardness

† Analysed separately 2/11/72.

trial ranged from 23°C to 25°C, about as in the Rewa itself.

The copper sulphate used in the experiments was anhydrous and of technical grade with the following impurities : -

Fe ; 0.1%
Zn ; Trace
Pb ; 0.008%

The paraquat was commercial Gramoxone (I.C.I.N.Z.) containing 2 lbs of active constituent (1, 1 dimethyl 4,4 bipyridylium dichloride) per gallon.

Statistical Analysis and results

Percentage mortalities were transformed to probits, the linear relationship of which to the logarithm of concentration gives the $L.C._{50}$ the concentration required to kill 50% of a population in 24 hours:

		$L.C._{50}$	
Copper sulphate,	p.p.m.	1.42	± 0.03
Paraquat,	p.p.m.	12.53	
Mixture,	p.p.m.	1.32	

As the time of death of each fish was known it was also possible to calculate, for each concentration of each toxicant, the $L.T._{50}$, the time required for 50% of a population to be killed by that concentration, as shown in Table 2.

DISCUSSION

It is apparent from these results that the paraquat component of the mixture is relatively harmless; and from what is known (1) about paraquat and diquat, the latter would be safer still. But the copper sulphate effect is serious.

Copper is well known for its toxic effects on fresh-water organisms: consistent levels of 1-2 p.p.m. suffice to eliminate all animal life (6). Fresh-water fish are particularly susceptible, levels of 0.01 p.p.m. being lethal to any species (3). The copper precipitates as an organic complex when it comes into contact with the mucus covering the fish's gills leading to clogging and death from respiratory failure (2). In this sense fish are very sensitive indicators of the damage likely to be caused to the river ecosystem by various concentrations of copper. There is little literature on the topic, but it is reasonable to believe that low concentrations of copper will have

TABLE 2

L.T. 50 OF VARIOUS CONCENTRATIONS OF THREE TOXICANTS

	Concentration ppm	$L.T._{50}$
$CuSO_4$	1.8	17.5
	2.0	12.2
	3.0	8.2
Paraquat	14	15.0
	15	7.8
	17	3.0
Mixture*	1.4	18.5
	2.0	11.0
	3.0	7.5

* 4 parts $CuSO_4$, 1 part paraquat, by weight.

similar results on the gills of fresh-water molluscs such as the Kai.

It is curious that although sea water contains relatively high concentrations of copper (up to 0.01 p.p.m.) it is not toxic and marine animals may even accumulate it without ill-effect (7). Similarly, in fresh water systems, the toxicity of dissolved copper decreases as the hardness of the water increases. Our experimental results are, however, applicable to the Rewa because Suva tap-water is of about the same hardness as the Rewa (see Table 1).

To relate our experimental results to the field situation is complex and difficult as many variables will affect the concentrations of herbicide in the area sprayed; current speed, degree of turbulence, depth of the water, density of weed growth, etc. As a first approximation we may consider a static segment of the river with no current flowing. Hughes (4) presents a profile through a bed of *Hydrilla* at Nausori bridge which is suitable for such an analysis. The bed stretched 55 metres into the river sloping gently at low water from dry land to a depth of 2.5 metres. An acre (4047 m^2) of the bed will be covered, at low water, by about 5 x 10^6 litres. Hughes (5) recommends spraying at low water at a rate of 9 kg of copper sulphate and 450 grams of the active constituent of diquat per acre. If these mixed quickly and completely with the water on the beds the concentration of copper sulphate would be about 1-2 p.p.m. while that of diquat or paraquat would be about 0.1 p.p.m.

Thus the initial concentration of copper sulphate in this simple model would be high enough to do serious damage to *Poecilia* and to populations of other aquatic animals. Two hours of exposure to a concentration of 2 p.p.m. of copper sulphate and paraquat will kill about 15% of a population of *Poecilia.* In the real situation uniform mixing will not take place and animals will for some time be exposed to much higher concentrations. On the other hand, the herbicides will be dispersed and diluted by the incoming tide and eventually swept out to sea.

CONCLUSION

The concentrations resulting from spraying as suggested by Hughes (5) are high enough to be very toxic to fresh water animals. Such spraying with copper, can be recommended only when it is absolutely necessary; and then only small areas should be sprayed at any one time, with sufficient time between sprayings for a thorough flushing away of copper salts to the sea.

ACKNOWLEDGEMENTS

Our thanks are due to Geological Survey for the estimation of copper levels in Suva tap-water. Dr J. MacInerney read the paper and made helpful suggestions. The U.S.P. computer was used for the probit analysis, it now being programmed for this.

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THE EFFECT OF HURRICANE "BEBE" ON AGRICULTURE IN FIJI: PART 1, DESCRIPTION OF HURRICANE

by

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SUMMARY

This hurricane was unusual in its time of occurrence (October; the usual season being November-April) and the 65 km (35 miles) width of the eye of the storm, about two and a half times the normal width. The track of the storm centre passed by Rotuma, through the middle of the Yasawa group, and south-eastward across the centre of Viti Levu. Maximum gusts recorded at Suva (on the windward side of Viti Levu, relative to winds on the leading edge of the storm) and at Nadi Airport (on the leeward side) were about 88 and 85 knots respectively. It is believed that somewhat higher gusts struck the Yasawas, the north coast, and some interior locations; the cyclone weakened as it passed across the island.

The hurricane was also unusual in that although there was heavy rainfall on the southeastern side of the storm, generally totalling about 400 mm (16") in 24 hours there was little rain on its northwestern side. Many rivers flooded to levels higher than any hitherto recorded, and the Rewa at Nausori reached a peak level only 12 cm (5 inches) lower than in 1965; but the Rewa flood was of shorter duration than in previous floods.

INTRODUCTION

Definitions

There is some confusion between "hurricane" used as a name for the type of tropical circular storm also called a "cyclone" or a 'typhoon', and "hurricane wind speed" which is defined, by international convention (World Meteorological Organization), as a "sustained" (for at least 10 minutes) wind speed of 64 knots or more. The hurricanes of the South Pacific are generally less intense than those of the Caribean area (where the name originated from the Spanish word "hurrican"). As there are few officially maintained wind-speed recording instruments in the South Pacific (there are only two in the Fiji group; at Nadi Airport and at Laucala Bay, Suva) it is often not known exactly what the wind speed has been in any particular hurricane.

Barometric pressure is a more easily recorded indication of hurricane intensity, and there are always many more records (e.g. from ships at sea) of this parameter. Typically the lowest pressures (in the "eye") in Southwest Pacific hurricanes are about 980 mb and as low as 940 mb may be recorded. In a severe hurricane in the western N. Pacific (460 miles east of Luzon), a pressure of 886.3 mb has been recorded.

In the southern hemisphere the wind direction is clockwise around the centre, and the greatest wind-speed is in the left forward quadrant just outside the "eye"

* on secondment from N.Z. Met. Service.

(e.g. in a hurricane moving toward the southeast the strongest wind would be from the north or northeast and in a southward moving storm the maximum wind would be easterly to northeasterly.

The "eye" of a hurricane is the area in the centre with little or no cloudiness or precipitation and light winds.

The "eye wall" is a solid wall of cloud surrounding the "eye" of the hurricane. The "eye wall" contains the strongest winds and heaviest precipieation.

Associated Rainfall

Some of the world's heaviest rainfalls have occurred in connexion with hurricanes. These rainfalls are likely to be heaviest on windward sides of mountainous islands, where orographic effects greatly increase the resultant rainfalls. Amounts of 500 mm (20") are not uncommon and at Silver Hill, Jamaica (in November, 1909) 2400 mm of rain was measured in a four day period associated with a hurricane.

Hurricanes in Fiji

In the past 50 years, Fiji has experienced 13 severe hurricanes (including Bebe) but records of many of these are incomplete. A brief description of what appears' to have been the most destructive of these follows.

1923, March 15: Munia, Lau — very destructive.

1929, December 11-13: began developing near the southern part of the Ellice Islands from where it moved southward over eastern Viti Levu, Makogai and Gau. Structural damage at Labasa estimated at £60,000.

1930, November 30: moved across the northeast coast of Viti Levu and Lomaiviti, causing severe damage to buildings at Levuka and Penang. Levuka recorded a minimum pressure of 955.3 mb with hurricane force winds; Suva measured winds to 62 knots. Three lives and four trading vessels were lost.

1931, February 16 - March 3: probably the most destructive hurricane on record. Lautoka was practically demolished and flooding in many areas was the worst for 50 years. The Rewa rose to 50 feet at Nausori and the Ba River rose to a record 40 feet at Rarawai. Approximately 200 lives were lost in the storm.

1941, February 19-20: affected central Lau, Lomaiviti and Viti Levu. Suva's worst hurricane since 1910; winds to 87 knots were measured at Suva with a minimum pressure of 955.6 mb. At Laucala Bay the anemometer measured winds to its limit, 97 knots.

1958, January 28: this was a small diameter but very intense hurricane which began to form south of the Solomon Islands. It moved eastward and then south-eastward, reaching the northern part of the Yasawas on the early morning of the 28th, after which it continued toward the southeast, crossing the coast of Viti Levu in the Tavua-Rakiraki area. It then cut a 20-mile wide swathe of destruction along the Wainibuka valley. It passed Suva at midday (with a minimum barometric pressure of 958.4 mb), causing very extensive damage.

1965, February 6-9: this was one of the largest diameter hurricanes on record in Fiji. It began to develop near Samoa as a weak depression and moved slowly westward, deepening steadily. It skirted the north coast of Vanua Levu and became nearly stationary near the northern end of the Yasawas, at which time it had developed into a severe hurricane with winds probably exceeding 100 knots and with widespread, heavy rainfalls. Wind and flood damage was extensive in the Yasawas (where a minimum pressure of 973.2 mb was recorded at Yasawa-i-Rara) but fortunately the rest of Fiji was spared its full fury as it moved southward off the west coast of Viti Levu. There was, however, widespread damage due to flooding over much of Fiji, with record floods in many areas.

BEBE — TRACK AND WIND SPEEDS

Development

This hurricane was exceptional in its timing, well outside the recognized hurricane season of November to April. A few hurricanes, most not severe, have occurred in November, but none has previously been recorded in October, in and northward of the Fiji area.

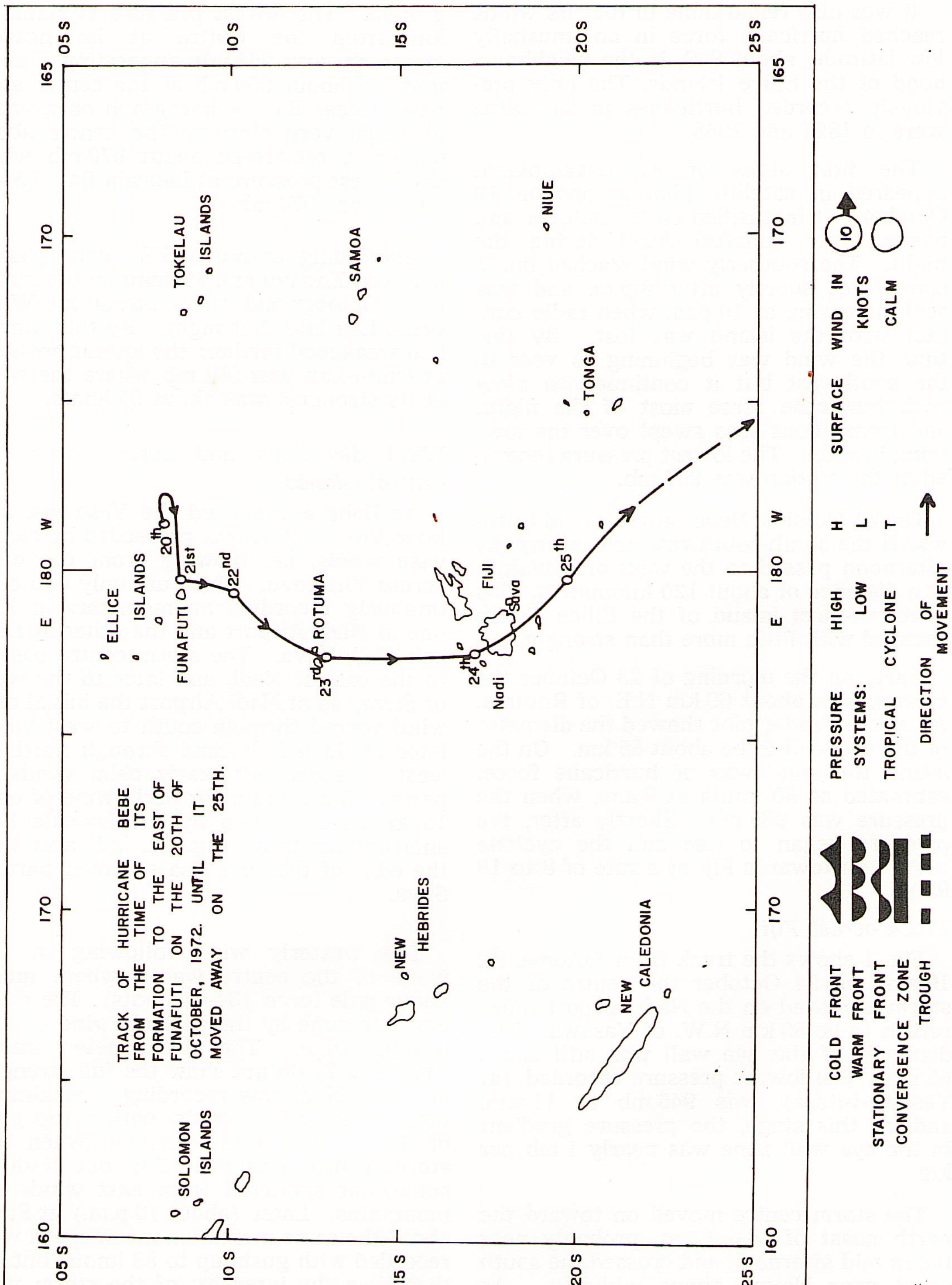

TRACK OF HURRICANE BEBE FROM THE TIME OF ITS FORMATION TO THE EAST OF FUNAFUTI ON THE 20TH OF OCTOBER, 1972. UNTIL IT MOVED AWAY ON THE 25TH.
SOLOMON ISLANDS
NEW HEBRIDES
NEW CALEDONIA
ELLICE ISLANDS
FUNAFUTI
ROTUMA
FIJI
Nadi
Suva
TOKELAU ISLANDS
SAMOA
NIUE
TONGA
20th
21st
22nd
23rd
24th
25th
160
165
170
180
170
165
05 S
10 S
15 S
20 S
25 S
E
W
COLD FRONT
WARM FRONT
STATIONARY FRONT
CONVERGENCE ZONE
TROUGH
PRESSURE SYSTEMS:
HIGH H
LOW L
TROPICAL CYCLONE T
DIRECTION OF MOVEMENT
SURFACE WIND IN KNOTS
10
CALM

Figure 1.

It was also remarkable in that its winds reached hurricane force in an unusually low latitude, about 8°S, in the neighbourhood of the Ellice Islands. The only previously recorded hurricanes in this area were in 1891 and 1958.

The first signs of its development appeared in satellite photographs on 19 October. It intensified on 21 October and passed over Funafuti Atoll during the night. The southerly wind reached hurricane force shortly after 8 p.m. and was still increasing at 10 p.m. when radio contact with the island was lost. By this time the wind was beginning to veer to the southwest but it continued to blow with hurricane force most of the night, and tremendous seas swept over the low-lying island. The lowest pressure recorded at the station was 957 mb.

On 22 October Bebe moved steadily towards the south-southwest and during the afternoon passed to the west of Niulakita at a distance of about 120 kilometres. This southern-most island of the Ellice Group escaped with little more than strong gales.

Early on the morning of 23 October the cyclone was about 60 km N.E. of Rotuma. An aircraft radar plot showed the diameter of the eye wall to be about 65 km. On the island the wind was of hurricane force, estimated as 80 knots at 9 a.m. when the pressure was 965 mb. Shortly after, the pressure began to rise and the cyclone moved on towards Fiji at a rate of 8 to 10 knots.

Track across Fiji

Fig. 1 shows the track from Rotuma. At 10 a.m. on 24 October the centre of the storm appeared on the Nadi Airport radar screen to be 55 km N.W. of Yasawa. The diameter of the eye wall was still about 65 km. The lowest pressure recorded (at Yasawa-i-Rara) was 945 mb at 11 a.m. and, at this stage, the pressure gradient in the eye wall zone was nearly 1 mb per km.

The storm centre moved on toward the north coast of Viti Levu, probably near Ba, in mid afternoon and crossed the south coast near Navua about midnight. As would be expected the hurricane lost intensity as it passed over the high ground. The lowest pressure at Nadi, 35 km from the centre at its nearest approach, was 961 mb, suggesting a minimum of about 950 mb at the centre as it passed near Ba. A barograph on a yacht at Beqa, very close to the centre about midnight, registered about 970 mb while the lowest pressure at Laucala Bay, 35 km away, was 974 mb.

Continuing to move S.E., Bebe passed between Kadavu and Matuku on the morning of 25 October and was about 80 km W. of Ono-i-Lau late that night. By this time it had weakened further: the lowest pressure at Ono-i-Lau was 991 mb where the wind at its strongest was about 55 knots.

Wind directions and speeds over the central islands

As Bebe approached the Yasawas, and later Viti Levu, it was preceeded by clockwise winds, i.e. blowing from the east, across Viti Levu. There are only two continuously recording anemometers in Fiji, one at Nadi Airport and the other at Laucala Bay, Suva. The storm centre passed to the east of Nadi, and later to the west of Suva; so at Nadi Airport the initial east wind veered through south to west while later at Suva it backed through north to west. Reports of nearly calm winds in parts of Suva and a northerly wind of only 15 knots, as shown by the Laucala Bay anemometer trace (fig. 2), indicates that the edge of the "eye" passed over part of Suva.

The westerly wind following in the wake of the centre was nowhere much above gale force (34-47 knots). The damage was done by the easterly wind on the leading edge. The anemometer traces (Fig. 1 & 2) do not show the full strength of this. Nadi was recording a maximum mean speed of 60 knots, with a top gust of 85 knots in mid afternoon when the storm centre was near Ba; but Nadi is somewhat sheltered from east winds by mountains. Later (about 10 p.m.) at Suva about the same maximum mean speed was recorded with gusts up to 88 knots, but by that time the intensity of the storm was less (as shown by the barometric pressures, mentioned above).

It seems certain therefore that the easterly winds that struck the Yasawas and the Ra-Ba coast exceeded 60 knots (mean speed), with gusts exceeding 100 knots. The damage to coconut palms, present in all areas, shows clearly that wind speed was greater around Ba (where there was considerable defoliation) than around Suva (where there was little), and even greater in the Yasawas (where most palm foliage was lost, and some palms lodged).

But it is equally certain that many "estimates" of wind speed that were reported on the radio and in the press were greatly exaggerated. The pressure exerted by wind on a perpendicular plane surface is proportional to the *square* of the speed. Thus a wind of 141 knots exerts twice the pressure of a 100 knot wind, and one of 173 knots, three times as much. It is obvious from the buildings and vegetation that were still generally standing after the storm that Tavua, Ba, and Lautoka were not hit by 140 knot gusts, nor Yasawa by 170 knot gusts, as some reports suggested.

Inland, topography must be taken into account. If gusts along the north coast of Viti Levu exceeded 100 knots, then in some inland localities where the air stream moved over high ground or was 'funnelled' in valleys, gusts in excess of 120 knots must have occurred.

HYDROLOGY

Sea waves and spray

Storm waves were most severe on Funafuti. In the Fiji group there was some foreshore damage in various places, but nothing serious. In some places, however, salt spray was blown inland damaging crops. Coconuts in the Yasawas were severely affected by this, as was sugarcane in some parts of northern Viti Levu.

Rainfall

There was almost continuous heavy rain over all the Fiji group during the 23-24 October, i.e. preceeding the passage of the storm centre. A remarkable feature of this hurricane, however, was that in general there was little or no rain on the northern side of the system, i.e. following the centre. On the northern coast, rain ceased about 1900 hrs. on 24 October in the Tavua to Lautoka area while in Nadi it was about 2000 hrs. with further light rain after 2100 hrs. At Vaileka heavy rain eased by 1700 hrs. but light rain persisted much longer. On the southern coast rain ceased about 2130 hrs. 24 October at Navua and 2330 hrs. at Suva where only light intermittent rain occurred afterwards.

Accurate recording of rainfall is impossible with standard raingauges during high winds because the horizontal area of the rim presents less area to the driving rain than does vegetation-covered ground. The recorded rainfall may be up to 30% less than actual. More error may come from overflow. A standard gauge takes only 510 mm (20.1 ins) rain, whereas more than 600 mm (23.6 in) may fall in 24 hours. Observers should check their gauges several times a day during hurricanes; but not all do. The following figures, therefore, to some extent may underestimate actual rainfall.

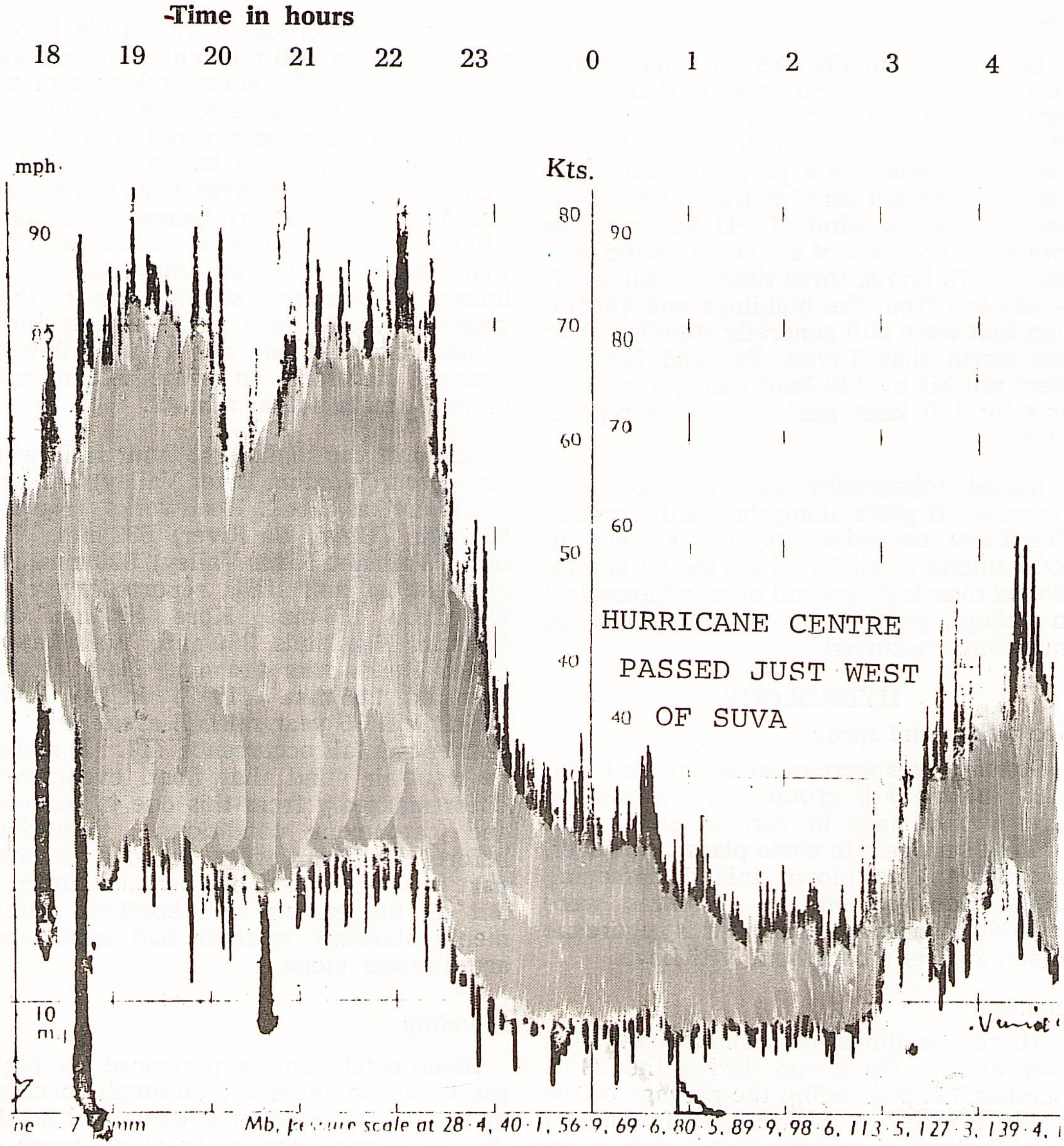
Some of the highest 48 hour falls were Naseuvou (Waidina River Valley) 753 mm, Wainikavika Creek. Headworks (Navua) 668 mm, (Upper Ba River) 632 mm, Waibau (Waimanu River Valley) 620 mm. The greatest 24 hour falls reported were — Naseuvou 466 mm., Koro 464 mm. and Nausori Highlands 360 mm, Wainikavika Creek Headworks 444 mm. Nadi Airport reported 265 mm. (10½") in 24 hours which is a 35 year rainfall event or a 3% chance rainfall occurrence (1). It should be kept in mind that flood events will differ markedly from this due to seasonal and catchment conditions. Conditions before the storm were dry over a large part of western and northern catchments; but on the eastern and southern catchments showery weather had kept large areas rather moist.

Flooding

Some catchments experienced the highest floods in memory; although, because of the short period of documented levels, there is some uncertainty about some of these. But there was generally a rapid rise and fall, hence a short duration of peak levels, because of the short duration of storm rainfall. Had there been any appreciable rainfall on the northern side of the storm system, the floods would have been much worse.

A contributing factor to the extreme flood levels of rivers flowing southward, was the storm's movement in the same direction, concentrating the rain downstream as the flows proceeded that way. This is particularly noticeable in the Rewa River where the peaks of all tributaries almost coincided on reaching the lower estuary.

FIGURE 2: ANEMOMETER CHART SHOWING WIND SPEED AND DIRECTION DURING A PERIOD OF THE HURRICANE.



HURRICANE CENTRE PASSED JUST WEST OF SUVA.

At 1000 hrs. on 25 October the Rewa at Nausori pump station reached a peak of 23.35 ft. on the gauge, 21.17 ft (6.44 m) above mean sea level, which is 0.43 ft. (0.13m) less than the peak of February 1965. From the surface velocity of floats the discharge at the peak was estimated as 415,000 cusecs. Nausori bus station was under about 3.25 ft. (1m) of water, Nausori airport terminal building about the same, and the main store at Naduruloulou Research Station under about 4.75 ft. (1.45 m). By 2200 hrs. that day all these levels had fallen by about 1.5 ft. (0.46 m).

The flood hydrograph at the Rewa River at Nausori usually exhibits a rather flat or broad peak, but this flood had a shorter time peak than usual, the flood wave most likely producing higher mean velocities even though the bed-load would be high. There were visual reports that velocities of the overbank flow in the shopping area at Nausori were greater than previously. Further support to this theory was the limitation of flow down the drainage channel to Waindamu Creek thus confining more flow in the main channel. This is corroborated by reports that levels in the Creek were lower, and levels at Nausori Town were higher, respectively than the 1965 flood. This latter fact conflicts with the Pump Station which is on the opposite bank but separated by a low-lying island. Therefore although the peak flood discharge was estimated higher than the 1965 flood the overall flood volume could be lower.

Of the three main tributaries of the Rewa, the Wainimala was the only one to exceed 1965 levels, with the highest flood in memory. At Nairukuruku gauging station it reached about 40 ft (12.19 m) at 0100 hrs. on 25 October. The Wainibuka reached a peak of 57 ft. (17.37 m) at Nayavu at 2230 hrs. on the 24 October, about 10 ft (3m) below the 1965 flood. The Waidina at Nagali bridge reached about 33 ft. (10.06 m) over the deck at 0545 hrs, 25 October, about 1.5 ft. (0.46M) below the 1965 level.

The Sigatoka River at Nalembaleba gauging station reached a 45 ft. peak at 0200 hrs. 25th October. The estimated peak discharge is 190,000 cusecs. Downstream near Naduri the time of the flood peak was 0430 hrs. 25th October. The level here was stated by local people to be about 0.5 ft. lower than the 1964 flood. At Sigatoka Town the flood peak occurred at 0600 and is estimated at 240,000 cusecs. Any flooding was due mainly to backwater around the Town.

The Nadi River at Votualevu gauging station not far upstream of the Pumping Station, reached approximately 40 ft. some time between 22-2400 hrs. This is several feet higher, from local knowledge, than the 1965 flood. An estimate of the peak discharge is 95,000 cusecs. A downstream tributary, Namosi Creek, reached 20.2 ft. at Namulomulo which is not considered exceptionally high. Peak flood levels in Nadi Town reached 4' 6" at the A.N.Z. bank occurring at 2100 hrs. 24th and other levels were somewhat lower than 1965. This may be attributed to Nawaka Creek which meets the Nadi River downstream of the Town. This stream reached a peak level of 18 ft. at Vatutu Pumping Station somewhat earlier than the main river which would mean that the local floodwater had receded prior to the arrival of flood crest in the main river. There are reports of local flooding around Nadi which was higher than that from the main stream. Other contributing factors may have been the shorter flood peak combined with an out-going tide and S. winds of the storm preventing any tidal build-up in Nadi Bay, the reverse of places on the South-east Coast.

The smaller streams Varange, Vitogo and Sabeto in the Lautoka area experienced severe flows which could be called quite rare flood events, particularly the Varange Creek where an estimate in relation to rainfall gives about a 1 in 40 year flood or a $2\frac{1}{2}\%$ chance flood (1). The Sabeto River at Naboutini reached a peak of 25 ft. about 2000 hrs. 24th, the estimated peak discharge being 47,000 cusecs.

The Ba River at Qerelevu gauging station reached a 39.2 ft peak at about 2400 hrs. 24th. This gives an estimated peak discharge of 164,000 cusecs. In Ba Town the level reached 1 ft. in the Book Depot near the Taxi Stand, about 3 ft. below that of the 1956 flood.

The Nasivi River experienced major flooding, but levels were not exceptional near Tavua. Around the town of Vaileka the smaller streams Nakauvandra and Nayoka Creeks covered extensive areas with 3 ft. of water. Similar conditions existed at Korovou Town, Tailevu where water reached the step of several shops.

The Wainibuku River at Nayavu reached a peak of 57 ft. at 2230 hrs. 24th, which is about 10 ft. below the 1965 flood.

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DESIGN AND ESTABLISHMENT OF A COCOA SPACING TRIAL AT WAIDRADRA

by

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SUMMARY

Between December 1971 and June 1972 sixteen blocks of a cocoa spacing trial were planted at Waidradra Research Station, Fiji. The planting points in each block were the interception points of 11 radii with 14 concentric arcs, the outermost radii and arcs being guard rows. The distances between points on an arc ranged logarithmically from 0.95 m (3 ft 2 in) in the innermost non-guard arc to 4.3 m (14 ft) in the outermost. Site preparation, planting, and establishment were hampered by much rainfall; and the hurricane of October 1972 caused some damage; but by March 1973 84% of the plants were growing well.

INTRODUCTION

As discussed in a recent review (12) little is known about cocoa spacing. Few trials have been reported, most with inconclusive results. There is some evidence that Amelonado cocoa yields decline with spacings wider than about 3 m square, but no hint as to the point at which yield starts to fall appreciably with too-close spacing.

One reason for this lack of knowledge is inadequate replication of most trials. With conventional experimental designs, using uniformly-sized plots with guard rows, a trial must be vast to secure good replication in terms of tree-numbers of the wider-spaced treatments. In a trial at Tafo, Ghana (described by Smith [8] but with erroneous analysis: see [10]) the widest treatment had only 16 trees per net plot, and 112 in the seven replicates. This is inadequate; but the only better-replicated cocoa spacing trial reported to date, is the spacing x variety x shade factorial at Bunso in Ghana (11), not yet in full bearing, which covers about 60 acres overall.

Systematic designs of the type developed by Nelder (6) save space in two ways: guard rows are needed only round blocks, not between plots; and all treatments have equal plant numbers, so that the wide-spaced treatments can be adequately replicated without over-replicating the closer ones. These space-spacing advantages are so much more important in tree crop work than in working with arable crops in general, and vegetables in particular, that it is strange that these designs have till now been used most in agriculture for vegetables, and least for tree crops. They have been used for a coconut spacing experiment in the Gilbert and Ellice Islands (V. Onions, pers. comm).

PLANNING

Location

The trial is at Waidradra Research Station, a recent acquisition of the Department of Agriculture, about 25 miles inland from Suva. This is a very wet area (nearby Vunidawa has an average annual rainfall of 3.5 m, 143 in) and severe black-pod loss is therefore to be expected. But a cocoa spacing trial here can nevertheless serve its primary purpose, as yield can be recorded as total pod production including black-pod; and it can also be used for the super-imposition of short-term black-pod control trials.

The station is very hilly and it was only with difficulty that a few hectares of flat-tish land, seemingly well suited to cocoa, were discovered about 80 m apart on either side of a ridge in an hitherto un-

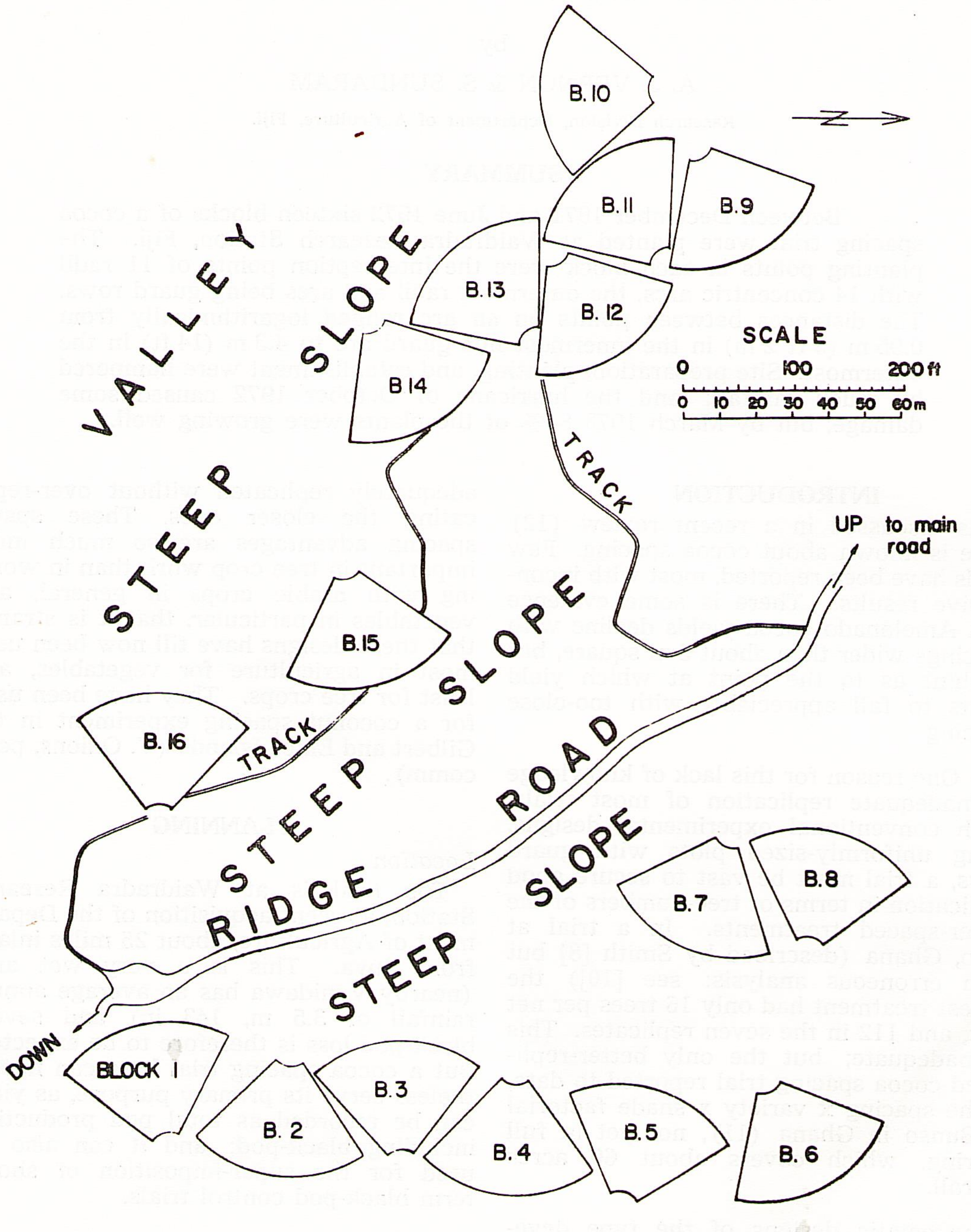

FIGURE 1. PLAN OF SITE.

opened sector of the station (Fig 1). The soils of the station have been described by Chandra (2), who also gives further details of location, climate, and topography. The soils of the experimental areas are predominately Waidina clay loam, with the 'hilly' phase of this soil type on the gently sloping patches, and the 'rolling' phase on the flatter patches. The soil drainage is generally moderate but bad in places. The top 75 mm of soil of both phases are acid, with the 'hilly' phase having a high, and the 'rolling' phase a low, percentage base saturation. Deeper than 75 mm this base saturation is low to very low.

The dense forest vegetation is 'secondary', i.e. modified by human influence. The main plant species are yaqona ni onolulu *(Piper aduncum)*, molau *(Glochidion claciphilum)* and lolo *(Ficus vitiensis)*. The under storey comprises sour grass *(Paspalum conjugatum)*, mile-a-minute *(Mikania micrantha)*, uvi *(Dioscoria alata)*, gaga *(Dioscorea bulbifera)* and *Nephrolopsis exaltata.*

Treatments

Despite the before-mentioned evidence of decline in yield of Amelonado with spacing wider than 3m (10 ft) square, the recommendation of spacing 3.7 m (12 ft) square, and wider, is still to be found in some text-books and recent advisory pamphlets (e.g. in place of). It is desirable therefore for the widest treatment to be about 4 m square. At the other end of the scale, 1.3 m square in one trial yielded nonsignificantly less than any wider spacing (8) so it seems that a closer spacing (say 1 m) must be tried to find the point of definite decline in yield with too-close spacing.

Assuming that yields at 4 m and 1 m square are substantially below the yield at optimum spacing, then it is necessary to have at least three, and better four, intermediate spacings to describe the curve through the optimum with reasonable precision. With a conventional design it would be undesirable (because of inflation block size) to use more, so that six treatments in all would probably be used. By contrast, with a systematic design it is necessary to use a comparatively large number of treatments, to make good the assumptions (a) that differences between neighbouring rows are so slight that guard rows are unnecessary, and (b) that the discrepancy between exactly square layout and the slightly off-square of the experiment can be disregarded in interpreting results. This does not unduly inflate block size: on the contrary this remains smaller than in conventional designs because the plots are small and unguarded.

At Waidradra, the patches of suitable land in the site area were so irregular in shape that it was decided to use a relatively large number of relatively small blocks, by making the number of treatments as small as seemed consistent with assumptions (a) and (b). Somewhat arbitrarily this was fixed at twelve; and it was only later realized that application to this situation of the also arbitrary rule of Nelder (5) on this subject, gives a lower limit of fourteen treatments. This disagreement is not serious.

The earlier statement that the extreme treatments should be 1m and 4m square, assumed a good determination of yield at these points. The systematic design multiplies number of treatments at the expense of replication per treatment, so using 12 treatments we arranged that the two closest should average about 1m square and the two widest about 4m. Thus the along-arc distance (which closely approximates to the square root of the space available to each plant in the arc) was fixed at 0.95m for the closest treatment, and at 4.3m for the widest, the intermediate ones being given by the logarithmic progression from 0.95 to 4.3 in eleven steps (see column 1 of Table 1).

Block layout

Fig 2 pictures this, and Table 1 shows the distances involved. The calculations required, first described by Nelder (6), and simplified by Bleasdale (1), can be further simplified by calculating only the distances, and not the angle between radii. The within-arc distances are calculated as a logarithmic progression between the desired extremes and the between-arc distances are a similar series in which each term is the logarithmic mean of the corresponding terms in the first series. (See footnotes to Table 1).

TABLE 1. DIMENSIONS OF BLOCK

	DISTANCES BETWEEN PLANTS IN METRES				DISTANCES FROM CENTRE ALONG RADII	AREA PER TREE
	Logarithms		Anti-Logarithms			
	Along arcs	Between arcs	Along arcs.	Between arcs.	Metres	sq. metres
	b	c	a	d	e	f
Inner guard		[-1].9479 (c_1)		0.887 (d_1)	6.0 (e_0)	
1st treatment	[-1].9777 (b_1)		0.950 (a_1)		6.9 (e_1)	0.91 (f_1)
		0.0075 (c_2)		1.017 (d_2)		
2nd "	0.0373 (b_2)		1.090		7.9 (e_2)	1.20 (f_2)
		0.0671 (c_3)		1.15 (d_3)		
3rd "	0.0969 (b_3)		1.250		9.05 (e_3)	1.57 (f_3)
		0.1267		1.35		
4th "	0.1565		1.432		10.35	2.06
		0.1863		1.5		
5th "	0.2161		1.644		11.85	2.72
		0.2459		1.75		
6th "	0.2757		1.887		13.6	3.59
		0.3055		2.0		
7th "	0.3353		2.164		15.6	4.72
		0.3651		2.3		
8th "	0.3949		2.482		17.9	6.21
		0.4247		2.65		
9th "	0.4545				20.55	8.17
		0.4843		3.05		
10th "	0.5141		3.267		23.6	10.76
		0.5439		3.5		
11th "	0.5737		3.747		27.1	14.15
		0.6035		4.0 (d_{12})		
12th "	0.6333 (b_{12})		4.300 (a_{12})		31.1 (e_{12})	18.64
		0.6631 (c_{13})		4.6 (d_{13})		
Outer guard					35.7	

Notes

(a) The calculations start with a_1 and a_{12}
The other (a) figures are the anti-logarithms of b_2 to b_{11}, calculated as follows.

(b) b_1 and b_{12} are the logarithms of a_1 and a_{12}
Then $B = b_{12} - b_1 = 0.6333 - [-1].9777 = 0.6556$
$\beta = B/11 = 0.6556/11 = 0.0596$
Hence $b_0 = b_1 - \beta = [-1].9777 - 0.0596 = [-1].9181$
$b_2 = b_1 + \beta = [-1].9777 + 0.0596 = 0.0373$
$b_3 = b_2 + \beta$, etc.

(c) These are the antilogs of the (c) figures between which they lie
e.g. $c_3 = (b_2 + b_3)/2 = (0.0373 + 0.0969)/2 = 0.0671$

(d) These are the antilogs of the (c) figures
e.g. $c_2 = 0.0075$. Anti-log $0.0075 = 1{,}017 = d_2$

(e) Once any one of these values is calculated the rest follow from the (d) values. The first calculation should be to great accuracy if it is desired to calculate (f), otherwise only field marking accuracy is needed.
Any one value can be obtained by considering the similar triangles formed by adjacent radii and lines representing appropriate (a) values
e.g. $e_1/a_1 = (e_1 + d)/a_{12}$ hence $e_1 = d(a_1)/(a_{12} - a_1)$
i.e. $e_1 = (24.27 \times 0.95)/(4.300 - 0.950) = 6.883$
Then $e_0 = e_1 - d_1$ i.e. $e_0 = 6.9 - 0.9 = 6.0$
$e_2 = e_1 + d_2$ $e_2 = 6.9 + 1.0 = 7.9$
$e_3 = e_2 + d_3$, etc

Angle. The angle between radii is conveniently calculated at this stage. The *sin* of half this angle is ½ a_1/e_1 i.e. $0.475/6.883 = 0.06901$
Thus in this case the half angle is 3.966°, and the angle itself is 7.933°.

(f) Two adjacent plants are assumed to have a boundary mid-way between them. As the distance between inner guard and 1st treatment, (d_1), is 0.887m, and the latter is 6.883m from the centre (see calculation above; rounded in table to 6.9), the boundary between these is an arc of radius

$$6.883 - ½\,(0.887) = 6.440\text{m}$$

Similarly the boundary between 1st and 2nd treatments is an arc of radius

$$6.883 + ½\,(1.017) = 7.392\text{m}$$

If these two boundary arcs were extrapolated to form full circles these would have areas of:

outer circle, $\pi\,(7.392)^2 = 171.663\ m^2$
inner circle, $\pi\,(6.44)^2 = 130.293\ m^2$
with a difference in area $41.370\ m^2$

Each plant occupies a fraction of this area equal to the fraction of 360° occupied by the angle between radii, ie. $7.933/360 = 0.0220$
Hence the area of one 1st treatment plant is

$$(41.37 \times 0.022)\ m^2 = 0.910\ m^2$$

As the relationship of f to a^2 is constant this calculation need be done only for the 1st treatment, for which the constant
$K = f/a^2 = 0.910/0.95^2 = 1.0083$ is calculated

Hence $f_2 = 1.0083 \times a^2_2 = 1.20$
$f_3 = 1.0083 \times a^2_3 = 1.57$ etc.

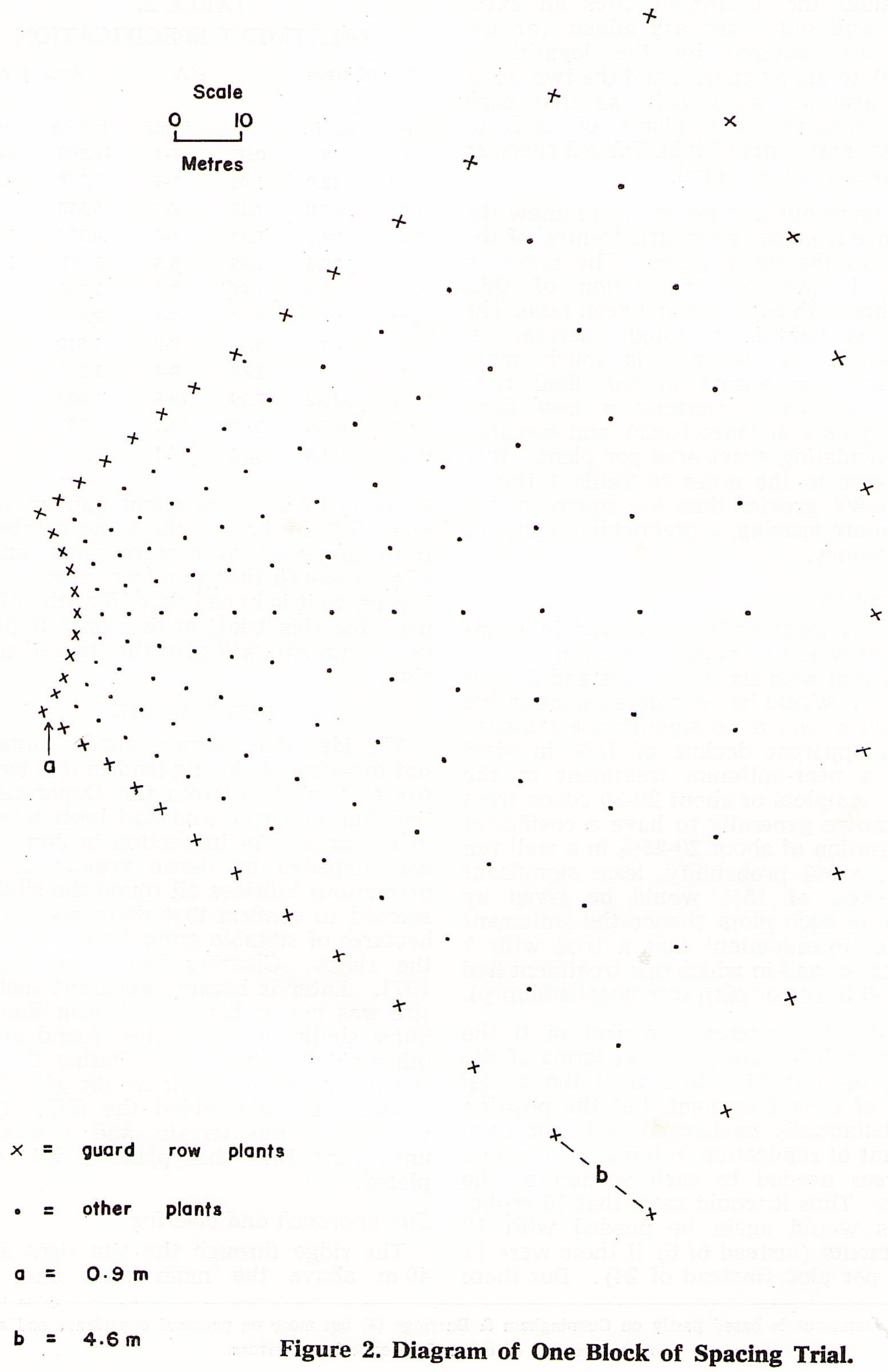

Figure 2. Diagram of One Block of Spacing Trial.

Besides the 'treatment' arcs an extra inner and outer arc are added (at the distances required by the logarithmic series) to act as guards, and the two outer radii also act as guards, so that each block consists of 9 plants of each of twelve treatments (Fig 2). Table 2 specifies the treatments in detail.

To mark-out it is necessary to know the distance from the geometric 'centre' of the block to the inner guard. The notes to Table 1 give the calculation of this, together with the angle between radii. The latter is helpful in rough marking-out (although, as distance is much more accurately measured in the field than angle, the exact marking is best done entirely on a distance basis) and essential for calculating exact area per plant. But, as shown in the notes to Table 1 this is only 0.8% greater than the square of the within-arc spacing, a practically negligible discrepancy.

Replication

This is most easily conceived in terms of what would be needed for a randomised block trial with six treatments and 24-tree plots. It would be considered undesirable in such a trial if no significance attached to an apparent decline of 15% in yield from a near-optimum treatment to the next. As plots of about 20-30 cocoa trees are known generally to have a coefficient of variation of about 20-25% in a well run trial*, a 5% probability, least significant difference, of 15% would be given by about 16 such plots (hence the statement in the 'Introduction' that a trial with 7 replicates, and in which one treatment had only 16 trees per plot, was unsatisfactory).

With 12 treatments instead of 6 the results will be interpreted in terms of the curve of best fit rather than the actual yield of each treatment, but the position is substantially unchanged as to the total amount of replication in terms of numbers of trees needed to each section of the curve. Thus it would seem that 16 replications would again be needed with 12 treatments (instead of 6) if there were 12 trees per plot (instead of 24). But there

TABLE 2.
TREATMENT SPECIFICATION

A		$\sqrt{A}$		No. of trees Area per tree	
m²	sq. ft.	m	ft-ins	per ha	per acre
0.91	9.8	0.95	3-1	11,000	4,460
1.20	13.0	1.09	3-7	8,330	3,370
1.57	17.0	1.26	4-1	6,370	2,580
2.06	22.2	1.44	4-8	4,854	1,960
2.72	29.4	1.65	5-5	3,670	1,490
3.59	38.8	1.89	6-2	2,790	1,130
4.72	51.0	2.17	7-1	2,120	860
6.21	67.1	2.49	8-2	1,610	650
8.17	88.2	2.86	9-4	1,220	484
10.76	116.2	3.28	10-8	930	377
14.15	152.8	3.76	12.3	707	286
18.64	201.3	4.32	14.1	536	217

is likely to be some slight gain in treatment S.E. by having the same number of trees dispersed over more plots, and in effect some further gain from a systematic layout, so it is hoped that 16 of the blocks used for this trial, having only 9 plants per treatment, will give the 'target' precision.

FIELD WORK

The idea that there might be sufficient not-too-steeply sloping land in this part of the station came from the Departmental Soil Survey team who had been working in the area. An inspection in June 1971 was impeded by dense vegetation, and precipitous hillsides all round the site, but seemed to confirm that there were a few hectares of suitable ground on one side of the ridge. Clearing began in October 1971. Later it became apparent that the site was not as big as had been thought; but a similar site was then found on the other side of the ridge. During the first seven months of work at the site 3.0 m (118 in) of rain added the difficulty of working in this terrain, and it was not until June 1972 that planting was completed.

Site approach and clearing

The ridge through the site rises about 40 m above the main road and then

* This statement is based partly on Cunningham & Burridge (3) but more on personal experience and an unpublished review of cocoa field experiment errors.

switch-backs, predominatly downward, towards the Waidradra creek. In August-October a road was made, by heavy crawler bulldozer, up to the ridge top then 300 m along the ridge down to the site. It later washed away, in places, several times but was re-made each time and now seems to have achieved a precarious stability.

On the first-selected area the few large trees were felled, sawn, and removed for timber use. This left a fairly even stand of small to medium sized trees, with a dense undergrowth of vines and shrubs, and with some patches entirely of reeds. Most of the undergrowth was removed by hand slashing, and then the smaller trees were selectively thinned so that everywhere at least 60% light was reaching the ground.

In places where there was much less shade than this, particularly the patches originally in reeds, stakes about 2 m long of dadap *(Erythrina lithospermum)* were stuck into the ground about 5-10 m apart. These grew quickly, and are now providing shade. The same procedure was later followed on the second area.

Surveying and marking

When the first site was sufficiently clear, a chain-and-compass boundary survey was made. On the outline plan thus produced, similarly scaled cut-outs of Fig 2 were moved around, to get as many blocks into the area as possible. As shown in Fig 1 this usually involves orientating adjacent blocks in opposite directions, which is also desirable in that any soil-trend in one block tends to be reversed in the next.

When it was realized that the first-cleared area was too small, work on clearing and surveying the second area proceeded concurrently with marking and planting the first.

Block location on paper was only approximate. The final, exact location was decided while marking the planting sites in the field. For each block, a post was first placed approximately at the geometric centre. Eleven non-elastic strings were then led from the post, spoke-fashion, in the approximate direction shown by the paper plan. Each string had cloth tags at the planting points (ie the distances from the centre given by col. 5 of Table 1). The radii were located at exactly correct distances from each other by point-to-point measurement of the outermost points on the strings. (After the first block had been done entirely by measurement it was found better to use a primatic compass for approximate alignment of the strings, at 8° intervals; but the final alignment was always by the more accurate tape-measuring).

When the strings were finally located, and check-measured, a marker-stake was planted by each tag and the strings removed to mark the next block.

Planting

This followed marking as soon as field conditions were suitable. Some blocks were marked and planted in one day. But because of clearing delays the whole operation took over six months. Two methods of planting were used, the dates and methods being:

Block	Date Planting		Method
1 - 7	1- 9 Dec.	1971	Transplanting
8	- 1 March	1972	"
11 - 13	-15 March	1972	"
14	18 May	1972	Direct seed
10, 11, 15, 16	17-19 June	1972	" "

The transplanting was of Amelonado seedlings raised in polythene bags in a nursery for about 4 months. This method was abandoned because establishment of blocks 1-7, was poor and it was thought that direct seeding, which had given better results than transplanting in some recent experiments (9) might be better under these conditions. The direct planting was of Amelonado seed, 3 seeds per position (about 10cm apart), on small mounds to counter water-logging.

Growth and maintenance

The transplants took well initially, but there were soon many deaths, possibly due to persistent wet weather and soil water-logging. By the end of June about 350 dead plants had been replaced, mostly in blocks 1-7. To correct the water-logging the shade was further thinned, and surface drains dug. By September some of the plants in blocks 1-7 had made excellent growth (the best were jorquetting) but there was great irregularity of stand (within, rather than between, blocks).

The direct seedings had the benefit of slightly drier winter conditions. They germinated well, were thinned to one-per-point at 2-3 months, and such few replacements as were necessary were made by repeat seeding.

Hurricane damage

The hurricane of October 1972 brought wind gusts of up to 90 knots to this part of Viti Levu. On the windward (east) side of the ridge most of the seedlings were largely defoliated. On the leeward side damage was generally not so severe, although blocks 11, 12, and 13 were badly hit. Many of the worst damaged plants later died, and were replaced. In all blocks except 6, 12, 13, and 14 there is now at least an 80% stand of flourishing plants (see Table 3) and although, in blocks 1-7 the age difference between the original plants and the supplies now appears as a serious irregularity, in a few years time this will not be noticeable. In Blocks 12, 13, and 14 where many survivors are still sickly, further replacement in the next few months will not cause serious irregularity, because the oldest plants there are not yet a year old.

TABLE 3

SITUATION ON 8 MARCH 1973

Block No.	Number of plants		
	Flourishing plants		Sickly or dead plants *
	Survivors Hurricane	Post-hurricane supplies	
1	107	24	23
2	78	52	24
3	79	56	19
4	79	61	14
5	57	66	31
6	42	56	56
7	88	35	31
8	88	43	23
9	109	25	20
10	130	5	19
11	76	58	20
12	63	46	45
13	78	43	33
14	93	23	38
15	150	1	3
16	132	15	7

* Mostly hurricane survivors that are not well recovered. The few dead at the time of counting have since been replaced by seedlings.

ACKNOWLEDGEMENTS

The technical staff and labourers were working under exceptionally difficult conditions and it is to the credit of them all, Senior Technical Assistant M. Hassan in particular, that the trial is now well established.

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GINGER PRODUCTION IN FIJI

by

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SUMMARY

Although the export of ginger from Fiji (733 metric tons, valued at F$333,000 in 1972) accounts for only about 1% of the country's export crop earnings, only sugar and coconuts earn more. Production, which was centred on the Suva peninsula, is now mainly along the Sawani-Serea road, in Naitasiri, where about 32 ha (80 acres) are grown. Surveys of cultural practices show that these are advanced in some respects (e.g. use of fertilizers) but undesirable in others (e.g. erosion danger, high hand-work costs). World prices fluctuate greatly and while the crop is always profitable for the better farmers there is risk of loss with less efficient production in low price years.

INTRODUCTION

Although the cultivated ginger, *Zingiber officinale,* seems to have been introduced to Fiji in the early days of European settlement, grown for export about 1890 (1), and for domestic consumption by Indian farmers early this century (7), it was only in the 1950s, at the initiative of Chinese growers, that regular export production began. By 1965 the annual export had reached 181 metric tons (mt) and since then has been:

1966	363 mt
1967	546
1968	726
1969	907
1970	1,179
1971	723
1972	733

The area in the crop is still small—at most 50 ha (125 acres) in 1970—but with the world market price ranging between 9 and 26 c./Kg (4 to 12c/lb) it is a valuable crop, earning $333,000 in 1972. The only crops whose export earnings exceeded this were sugar ($33 million) and coconuts ($4 million).

Ginger is traded on world markets in two forms, the fresh root known as 'green ginger' and in dried form. Fiji exports mainly the former, but in recent years small quantities of the dried form have been exported.

Survey methods

The industry was examined by one of us (I.J.P.) in 1969 and by the others (P.H.H. and P.S.) in 1973. On both occasions, areas of production were visited and over 25% of the growers interviewed. Their accounts of production practices, expected yields, and production costs were checked on the spot wherever possible. With the relatively high proportion of farmers interviewed, and the general consistency of production practice it is believed that this account is representative of the industry.

Attempts were made in the second survey to identify areas for research. For this purpose, practices which deviated from normal principles of agronomy were noted as were the more costly production items. Information about the industry was also collected from the Government Produce Inspector and from managers of export agencies.

PHYSICAL AND SOCIOLOGICAL SETTING

Location

In 1964 the industry was centred on the Suva Peninsula particularly Tamavua, Colo-i-Suva and Tacirua. By 1969 new

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plantings had been made along the Sawani-Serea Road, reaching up to Mataisuva. The main new areas were Sawani, Waibau and on the feeder roads off main roads like Nabukaluka and Viria. By 1973, the shift in location was more definite, as shown in Table I. The decline in the Suva Peninsula has been largely due to insecure leases leading to evictions arising from demand for building land. Pressure for this change has also been due to the decline in soil productivity consequent on intensive cropping over a long period.

Ethnic origin of growers

The pioneers of ginger as an export crop were the Chinese. The industry is still dominated by growers of Chinese origin; but Indians and Fijians have recently taken to the crop, and now account for 11% of the acreage (Table I).

The Chinese growers have a highly professional approach to production, many adopting intensive horticultural practices. The newer growers base their production on the Chinese methods and show a reluctance to deviate, even when the technique may be unsound. The practice of cultivating up-and-down rather than across slopes is a vivid example of this point. In general the Fijian farmers appear less appreciative of commercial practice. They are nonetheless interested in the crop and with help and encouragement could supply useful quantities for export. Future increases in production will probably come from among Indian and Fijian growers.

Numbers and sizes of farms

Out of 42 growers in Central Division in 1973, 14 had plantings of more than 0.8 ha, with a combined area of 22.9 ha, or more than two-thirds of the total area of 30.6 ha. A further 10 growers had plantings in the 0.4-0.8 ha range, with a combined area of 6.2 ha, and the remaining 18 grew only 1.5 ha among them.

Ecological requirements

It is generally accepted that ginger requires high rainfall and freely draining soils. Many of the farmers interviewed held this view, and said daily rain was ideal for the growth of the crop. Preference was also expressed for planting after a fallow period of at least two years. Where land is being intensively used a grass fallow is permitted. In other areas, the land is allowed to revert to bush. Ginger is generally followed by one or two crops of dalo prior to fallow. Occasionally vegetables may be planted.

Almost always the crop is grown on slopes or on undulating land, often on steep hillsides. Cultivation is in the direction of the slope, to provide adequate drainage. There is, however, much evidence of soil erosion in the form of rills and soil wash. Of the farmers interviewed, only one expressed concern about soil erosion consequent on the cultivation of sloping lands.

TABLE 1 NUMBERS AND TOTAL AREAS (HECTARES) OF GINGER FARMS BY DISTRICT AND ETHNIC ORIGIN OF FARMERS

	CHINESE		INDIAN		FIJIAN		TOTAL	
	Number	Area	Number	Area	Number	Area	Number	Area
Waibau	8	11.8	—	—	5	0.9	13	12.7
Tamavua Colo-i-Suva	7	8.5	1	0.1	2	0.3	10	8.9
Sawani Viria	7	5.3	7	1.9	—	—	14	7.2
Batiri Baulevu	2	1.6	—	—	—	—	2	1.6
Navuakece	—	—	—	—	3	0.2	3	0.2
	24	27.2	8	2	10	1.4	42	30.6

Soils

Richmond (3) found that ginger is planted mainly on humic latosols particularly in the hilly phases of the Waidina clay, Waimaro clay, Sote clay and Lobau clay. It is also grown to some extent on nigrescent soils particularly on Samabula clay and Wailoku clay in the Suva peninsula. Claims have been made by some farmers that ginger yields better on the dark, than on the red soils. This may be due to higher initial organic matter and fertility in the dark soils, but with frequent cropping, yields on these soils may fall rapidly. This has been the experience of farmers growing ginger on dark soils in the Suva peninsula. On the red soils, with adequate fertilization and good management, some farmers obtain high yields.

PRODUCTION PRACTICES

Land preparation

The natural vegetation is cut and the material cleared and burnt. The soil is then prepared by digging with a hand fork. Shallow openings are made into which ginger is planted.

Planting

Small portions of the rhizomes in sound condition are regarded as ideal planting material. These may be selected from unsaleable rejects. Care is taken to ensure the use of clean material with good growth potential. The 'seed pieces' are planted at variable distances from 75 by 75 cms (30 x 30 ins) to 60 by 30 cms. (24 x 12 ins). The most frequent spacing appears to be 75 by 60 cms. (30 x 24 ins). Much of this variation results from attempts to relate planting distance to soil productivity. On more productive soils ginger tillers profusely and wide spacing is preferred, but on less productive soils a closer spacing is adopted to ensure canopy cover and consequent weed control.

Manuring

The use of chemical fertilizers appears universal among ginger growers. Two types are used: 13: 13: 13 and 13: 13: 21. The latter appears to be gaining in popularity. This trend is based on the farmers' own observations of results obtained with such mixtures as are readily available locally. Rates of application vary, but most are high. One farmer said he used 5mt/ha. (2 tons/ac.) Split applications are frequent. This is consistent with the intensive horticultural practices adopted by many farmers. In this system up to five applications may be made based on the appearance of the crop and a judgement of its requirements. Two to three applications are usual. The first at planting, the second between 6 and 8 weeks and the third about 15 weeks after planting. For crops to be harvested in the August-October period the last application is never made after April.

Weed Control

The crop may be hand weeded up to four times to ensure weed free production. Frequently casual labour is employed, and may be a high cost item of produc tion.

Ridging

As the ginger grows, rhizomes may protrude from the soil. These are covered by ridging with hand hoes. This operation may follow fertilizer application or may be combined with hand weeding.

Planting season and time to maturity

Ginger is planted from September until December and harvesting normally starts in August. For the high quality green-ginger trade, exports are restricted from 1st January to 31st May inclusive. The reasons for this are sound. At the start of this period the old crop is over-mature, coarse and fibrous, whereas at the end of the period the crop has not developed its full flavour and the rhizomes are too tender for packing and shipping. Some less discriminating markets accept ginger throughout the year.

Harvesting and packing

The crop is ready for harvest when the foliage dries and separates from the rhizome. This stage may be hastened by cutting off the tops a little above the ground about two weeks earlier. The rhizomes are lifted, usually by contract labour, temporarily packed as free from soil as possible into crates, and taken to a convenient source of water for washing and re-packing prior to sale.

Both in the field, and later on purchase by the exporter sub-standard-size rhizomes are culled. Conflicting estimates were given for the proportion so rejected; but it seems that normally about 10% are culled in the field (not entirely a loss, as some may be used for planting material) and another 10% at the second grading, which is controlled by the Government Produce Inspector to maintain the quality of Fiji export ginger.

Diseases and Pests

The main diseases of ginger in Fiji have been described by Graham (2) and the pests by Swain (6).

Root knot nematode (*Meloidogyne incognita*) infestation causes rejection of ginger for export, and may also reduce yield. Symptoms appear as galls on feeder roots, cracks on the outer layer of the rhizomes and small, light brown, water soaked areas in the rhizome flesh. The disease can be kept under control by planting clean seed pieces and rotating ginger with tolerant crops such as dalo. The normal ginger-dalo-fallow rotation is useful in keeping disease at a low level.

Soft rot (*Pythium gracile*) may become a problem during wet season on poorly drained land. Plants become yellow and stunted, and pockets of soft rot develop on the rhizome. The disease can be kept under control by planting on well drained sites and using clean seed pieces.

Tuber scale (*Aspidiella hartii*) may occasionally occur in large numbers on ginger rhizomes if planted with or following a yam crop. These scales cover the outside of the rhizome, where they cause the surface layers to dry out. Yams should not be interplanted with ginger nor should they enter the ginger rotation sequence.

Leaf damage by other insects are sometimes seen as holes or tears on the leaf but they appear unlikely to cause any economic loss.

MARKETING AND ECONOMICS

Some implications of trade standards

Earlier reference has been made to the maintenance of a high standard in Fiji ginger by grading controlled by the Government Produce Inspector. All ginger for export must be firm dry, mature but not coarse and free from shrivelling, sprouting and soil. Material which consists of whole roots without broken pieces and no smaller than 14 cm (5½ in) are sold as 'fancy' grade—the only grade permitted for export to the N. American market. The commercial grade on the other hand may contain up to 20% broken pieces not less than 7 cm (3 in).

How to dispose of the rejects resulting from this rigid grading is a matter of concern for growers. Some are sold on the fresh market in Suva but this outlet is limited. From the remainder, attempts are being made to develop a dried ginger product. Assurances were given by one entrepreneur that Fiji dry ginger was acceptable overseas. If this is so, then this outlet could well be exploited. Problems with this product may, however, occur depending on variation in conditions of growth. The product grown here is essentially 'green ginger', characterised by Sills (4) as 'young tender succulent rhizomes, free from fibre and of mild pungency'. Dry ginger on the other hand is 'a hard, peeled dry product possessing much fibre and pungency'. Clearly these two products require different growing conditions. Excellence in green ginger is obtained after rapid or 'forcing' growth whereas dry ginger is better after slow growth. In Fiji 'forcing' growth is used to produce the tender succulent rhizomes required for the green ginger trade. For these reasons dry ginger of consistent quality is unlikely from local green ginger rejects. The Tropical Products Institute has reported that Fiji dry ginger is unacceptable because of a lack of pungency and the presence of a lemon like flavour.

Cost of Production

We saw little evidence of formal systems of accounting, but most farmers, particularly the Chinese, had some idea of the cost of production. Estimates of total cost varied from $1230-1803 per ha ($500-730 per ac.), with the clearing of land from bush (put by some as high as $540/ha, i.e. $220/ac.) and hand weeding (up to $500/ha, $200/ac.) generally identified as the high cost items.

These estimates are suspiciously high, even allowing that the weeding charges may include some ridging costs. Some informants may have exaggerated their costs somewhat, to avoid disclosing their true income.

The relative costs of the various items, however, are probably well estimated, and the identification of bush clearing and weeding as the main items are correct. It is worth noting that clearing land from grass was estimated to cost as little as 25 per cent of the cost of bush clearing, and herbicides would cost less (in materials) than 25 per cent of the estimates of hand weeding cost. Thus there is scope for great reduction in cost by changes in practices.

Expected returns

From among farmers interviewed the yields claimed ranged from 25-50 mt. ha. (10-20 tons/ac.) in the better areas and from 12 to 25 mt. per ha. (5-10 tons/ac.) in less favoured locations. This is consistent with the national export in 1972 of 733 tons from an estimated 84 acres, i.e. 8.6 tons exportable ginger per acre or, allowing 20 per cent reject, a gross mean yield of 10.7 tons/ac. (26.8 mt. ha). It is also consistent with the results of the field experiments of Sivan and Prasad (5).

The cash return to the farmer depends on the world market price of ginger, which has fluctuated according to world supply and demand in recent years between 9 and 26 c per kg. An about-average yield of 25 mt./ac. (10 tons/ac.) gross, i.e 20 mt./ac. (8 tons/ac.) exportable, would give a return of between $1800 and $5200 per ha ($730 to $2100 per acre) with this range of price.

DISCUSSION

Because of the wide price fluctuations the industry works in a state of uncertainty. The export earnings were $161,000 in 1971 and $333,000 in 1972, although the quantity exported was about 730 tons in each year. A grower achieving an about-average yield of 25 mt. per ha. (10 tons gross per acre) and with typical costs (according to the estimates given earlier in this paper) of about $1,500 per ha. ($600 per acre) will have a profit of anything between about $250 and $5000 per ha. ($100 and $2000 per acre) according to the price he gets. A grower with less than average yield may even make a loss some years, particularly if his costs are above average.

The recent decline in production is of some concern in view of the latent-earning capacity of this crop.

To some extent this reduction is due to a reduction of acreage in the Suva peninsula not being balanced by new acreage inland. Comments from some growers, in the 1973 survey, suggested a decline in confidence in the exporters. This is further indicated by the growing reluctance of farmers to sign early contracts for their crop. Undoubtedly, wide price fluctuations create problems for the growers and exporters alike. To overcome these difficulties a two stage payment system could be introduced. In this scheme growers would receive an initial payment based on long term market prices, followed by a final payment based on the actual income from sales for the particular season.

It is estimated that Fiji can export up to 1000 mt. of ginger a year without affecting the world price structure. It would be in the national interest to maintain production at this level, while new outlets are explored. The quality of the Fiji product is high and could compete with 'green-ginger' from elsewhere. At the same time, should freight conditions improve, outlets could be found in the European Common Market countries. These possibilities should be closely watched and the industry would be advised to be ready for expansions whenever this is warranted. In 1968, a local company exported green ginger in brine to the Japanese market. Losses in shipping and storing were great and in 1969 the company started crystallising ginger locally. A product of satisfactory standard was not produced and the operation discontinued.

The possibility of producing "dry" rather than "green" ginger also merits consideration. The processing of the sub-standard-size rhizomes into dry ginger, as mentioned earlier, would only be marginal to green ginger production, and could not expand into a worthwhile industry, as the two products require different varieties and growing conditions. But there is scope for dry ginger in the lower rainfall areas of the country and some suitable varieties are already being multiplied.

While some research effort might be made in this last field, it is clear that the main efforts in the near future should relate to the cutting of costs in the present methods of green ginger production. As regards the use of herbicides to cut hand weeding costs, there should be little difficulty. The reduction of the dependence on bush fallowing is more complex, but more important. The substitution of a grass break in the rotation could be worth investigating.

ACKNOWLEDGEMENTS

We are grateful to the staff of the Extension Division of this Department, particularly of the Nausori office, who helped in many ways. Table I, and the section on "Numbers and sizes of farms" were compiled from their reports. Mr A. Hazelman, Government Produce Inspector, was most informative on aspects of grading and export.

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TECHNICAL NOTES*

SEASONAL PRICE VARIATIONS OF SOME CROPS IN VITI LEVU

Since July 1968 the Bureau of Statistics as part of its monthly calculation of the Consumer Price Index, has been ascertaining once each month in the markets of Suva, Nausori, Nadi, Lautoka, and Ba the current price of the 13 fruits and vegetables listed in Table 1, and of tubua, rourou, lemons, and coconuts. The hurricane of October 1972 disrupted normal price trends for several months, which will complicate future calculations of long term trends. This is therefore an opportunte time to analyse the four years of uncomplicated records that are available.

With the permission of the Government Statistician the prices of the 13 more interesting items were abstracted and, with the help of the students of this College and Mr. A. J. Vernon of Research Division, analysed as follows. First each Suva price was averaged with the corresponding Nausori one to get a wet-zone average figure, and similarly the Lautoka-Nadi figures were averaged to get one for the dry zone. For each crop the linear component of time-trend was calculated for the four-year period Oct. '68 to Sept. '72 and actual monthly prices adjusted in compensation (i.e. an appropriate addition was made to each figure in the first half of the period, and an appropriate subtraction from each figure at the second).

Table 1 shows the time trends in each zone for each crop. Some prices (e.g. pawpaw, tomatoes) have almost doubled in the four years, others (e.g. bananas, cabbages) have remained relatively static. In general the trends are exponential: the overall rise is about 6% per year. But the present purpose is served by using linear terms (i.e. cents per lb rise in price per month, rather than % rise in price).

For each crop the figures for each month of the year were then averaged over the four years, first for Suva-Nausori, then for Lautoka-Nadi; and then, to smooth out remaining irregularities, moving 3-month averages were taken (i.e. the Dec.-Jan.-Feb. mean to represent January; the Jan.-Feb.-March mean to represent February; etc.) The figures so obtained for beans, cassava, kumala, and pawpaw showed no apparently significant seasonal variation. For the other products there were seasonal trends as now shown in Fig. 1.

No formal significance tests were made of the variance due to the seasonal patterns, but it was obvious that the seasonal trends were highly significant in all cases shown in Fig. 1, with the exception of pumpkins at Lautoka-Nadi and cucumbers at Suva-Nausori. In some cases, however, there was substantial variation from year to year in the timing of the seasonal peaks and troughs, together with considerable erratic variation. These graphs must be regarded therefore only as approximate indicators of seasons of above and below average prices, and no more than this should be read into them.

TABLE 1

MEAN ANNUAL PRICES

in cents/lb of various crops at
Suva-Nausori (S N) and Lautoka Nadi (L N)

		1969*	1970	1971	1972
Beans	SN	9.4	10.6	11.8	13.8
	LN	8.9	9.0	11.9	11.2
Dalo	SN	4.5	5.0	5.2	6.2
	LN	6.3	6.5	7.7	8.3
Cassava	SN	1.8	1.8	2.3	2.9
	LN	1.6	1.7	1.6	2.7
Kumala	SN	2.6	2.4	2.7	3.4
	LN	3.5	4.1	4.0	4.4
Carrots	SN	11.5	9.5	16.1	20.5
	LN	16.5	17.1	18.6	24.5
Cabbages	SN	9.7	9.2	9.2	10.5
	LN	9.2	7.4	9.3	10.6
Cucumber	SN	4.2	4.7	5.1	7.1
	LN	5.8	5.0	6.0	5.4
Pumpkins	SN	3.1	2.9	3.8	4.9
	LN	2.2	2.4	2.2	3.1
Tomatoes	SN	10.9	18.1	24.3	23.6
	LN	11.7	12.3	18.3	21.0
Eggplant	SN	3.0	3.8	5.4	6.3
	LN	4.9	4.7	8.1	8.7
Chillies	SN	14.5	16.4	22.5	32.6
	LN	20.1	23.8	30.1	33.4
Bananas	SN	4.3	4.8	5.0	5.3
	LN	5.8	6.5	6.8	6.9
Pawpaw	SN	2.5	3.4	3.6	5.3
	LN	2.7	2.7	3.6	4.1

*October 1968 to September 1969: similarly for other years.

* Notes of this type and style, and length not exceeding two pages of text, will be a regular feature of this journal in future. Submissions are welcome. Editor.

The trends can be to some extent explained as follows :—

Beans: Various types can be grown throughout the year in both the wet and dry zones. They do rather better in dry areas and the west coast prices are generally slightly less than the east.

Dalo: A 9-12 month crop, planted throughout the year but yielding highest when planted at the beginning of the wet season. Generally cheaper in the wet zone but imports from the islands bring down the price in the west

Cassava: Prices were fairly steady for the first three years but increased in 1972. Cheaper in the east coast.

Kumala: Little variation but the wet zone prices always less than the east.

Carrots: A 2½-3½ month wet zone crop. During shortages carrots are imported, fixing a maximum price at just over 20 cents/lb.

Cabbages: Showed a pronounced seasonal pattern during the last three years but had an anomalous first year. This category includes both Chinese and English cabbages. The former can be grown throughout the year and do well in the wet zone. English cabbage heads well only in the cold weather and it is an abundance of this type that accounts for the cheap prices in the west in the dry weather.

Cucumber & Pumpkins: Can be grown throughout the year, pumpkins doing rather better in the dry zone than the wet.

Tomatoes: This crop is easy to grow in non-wilt areas in the dry weather and so tends to be cheap from June to December. In the wet season the maximum price tends to be controlled by the price of imports.

Eggplants: A more 'tropical' vegetable, does best in the wet zone in the wet season and is cheap from October to March.

Chillies: A crop with a wide price range owing to lack of harvest in the dry season. There should be a lot of money to be made in growing off-season chillies with irrigation if necessary.

Bananas: A wet zone crop, generally 1½ cents more expensive at Lautoka/Nadi.

Pawpaw: This crop has shown an average increase in price of 31.2% per year over the period probably owing to heavy demand by hotels.

Other crops: It should be appreciated that this review excludes all the products of extreme seasonality (e.g. duruka, mangoes, avocados), because the Bureau of Statistics takes no account of these in its Consumer Prices Index.

Markets: Kumala, carrots, eggplant, chillies and bananas are always noticeably cheaper in Suva/Nausori, and cassava, pumpkins and tomatoes cheaper in Lautoka/Nadi.

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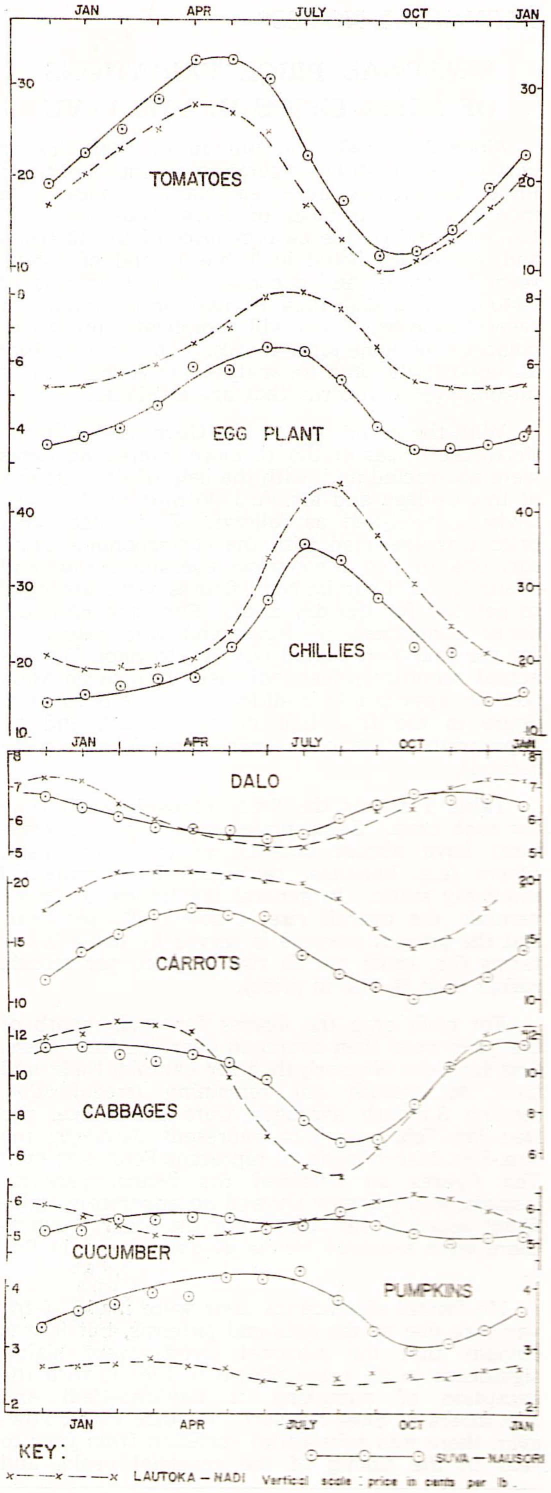

Figure 1. Seasonal Price Variations of Some Crops.

RESEARCH ABSTRACTS

Unless otherwise stated, authors are on the staff of the Research Division of the Department of Agriculture, Fiji.

I.D. FIRMAN*. Black leaf streak of bananas in Fiji. *Ann. appl. Biol.* (1972), **70**, 19-24.

Black leaf streak of bananas, caused by Mycosphaerella sp., prevented fruit of export quality forming and bunches maturing. Some infected leaves lived less than 50 days and were seldom retained until harvest. Maneb or benomyl applied in oil/water emulsions gave good control and benomyl was so effective that plants had ten leaves at harvest and some leaves survived for 245 days. Plants sprayed with maneb or benomyl flowered 1 month early. No benomyl residues were detected in the fruit exported to New Zealand.

The control of black leaf streak by sprays containing oil has caused other leaf diseases to become more prevalent and the ensuing complex disease situation is discussed.

*Present address: School of Biological Sciences, University of Bath, England.

I.D. FIRMAN*. Susceptibility of banana cultivars to fungus leaf diseases in Fiji. *Trop. Agric.* (*Trinidad*) (1972), **49**, 189

The reaction of 41 banana cultivars to black leaf streak, black cross spot and rust was studied at the Koronivia Research Station in Fiji. Cultivars of AA, AAA, AAAA, AAB and ABB genetic constitution were represented in the banana collection. The commercial triploids were very susceptible to black leaf streak while some of the diploids and some of the local cooking bananas could be classified as moderately susceptible. None of the cultivars showed any very marked resistance to black leaf streak and results were generally similar to those reported from a study in Hawaii. Only cultivars containing the B genome were susceptible to black cross spot. Rust was particularly prevalent on some of the diploids but is not considered to be a serious disease problem.

*Present address: see above.

K.H. McINTYRE*. Use of supplements to grazing for dairy cows in Fiji. *Trop. Agric.* (*Trinidad*), (1973) **50**, 17-23.
Thirty cows were allocated to three comparable groups, based on previous milk-yield, age, and liveweight. The cows in Group 1 did not receive any feed supplement to grazing, but the cows in Groups II and III received coconut meal and molasses respectively, fed according to the amount of milk produced in the previous week. The differences between groups in total milk production, after adjustment for differences in previous yields, were significant. The cows in Group II and III produced more milk and butterfat than those in Group I. The cows in Group II produced more than those in Group III. The same differences were apparent in butterfat production. Although coconut meal feeding produced greater responses in yield, feeding molasses for butterfat production was economic at current prices but coconut meal feeding was not. Coconut meal and molasses were both economic for whole-milk production.

*Present address, Roche Products Ltd., Dee Why, New South Wales.

S. SUNDARAM. The establishment of cocoa by direct seeding compared with transplanting. *Turrialba* (1972) **22**, 354-7.

Amelonado seedlings grown from seed in the field and aged 1-2 years, were much bigger than transplanted seedlings of the same age raised in nursery and then transplanted. This observation was made at two sites whereas at a third site there was no difference between two types of seedling.

The problems of climate, pests and weeds are discussed in relation to Fiji conditions. It is suggested that under Fiji conditions it would be advantageous to plant cocoa soonest in the wet season, particularly in localities subject to rose-beetle (*Adoretus versutus*) infestation. The choice of method would depend on the prevailing conditions, and the growers ability to overcome forseeable problems.

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Scope of papers. Reports and reviews of research in the fields of agriculture, veterinary science, forestry, fishery, and allied subjects in Fiji, or elsewhere if relevant to agriculture in Fiji, will be considered for publication. This will not necessarily be in order of receipt; papers that need little editing are likely to appear earlier than those that involve much.

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- Annual Report of the Department of Agriculture for recent years at 50 cents a copy.
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Book

Plant Diseases of Fiji by K. M. Graham,
Published and Sold by Her Majesty's Stationery Office,
P.O. Box 569, SE1, London, England, at £Stg.2.50 each.

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