The

Papua and New Guinea

Agricultural Journal

Vol. 18 SEPTEMBER, 1966 No. 2

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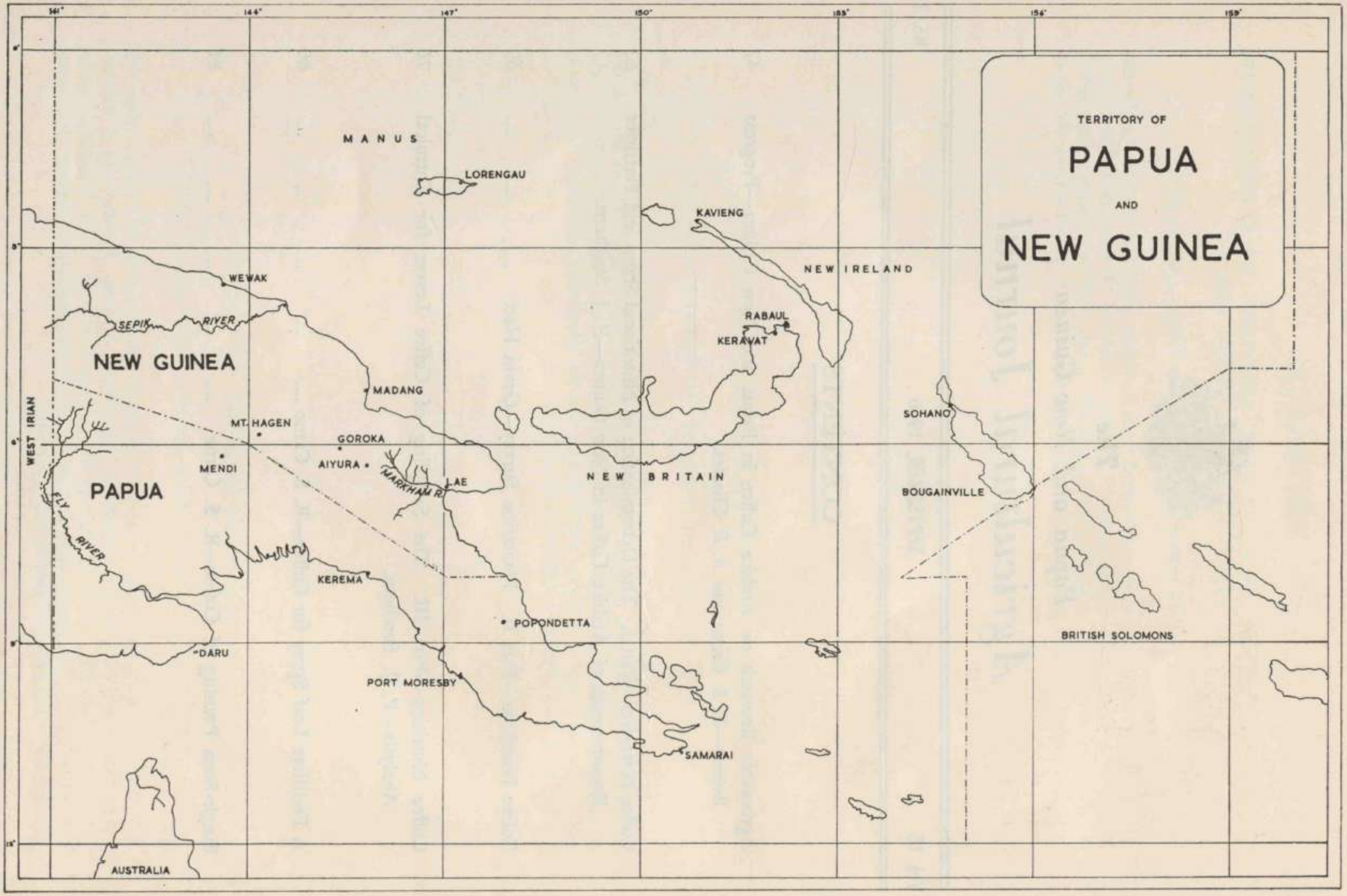

TERRITORY OF
PAPUA
AND
NEW GUINEA
141°
144°
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150°
153°
156°
159°
MANUS
LORENGAU
KAVIENG
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POPONDETTA
DARU
PORT MORESBY
SAMARAI
BRITISH SOLOMONS
AUSTRALIA

Agronomic Research on Arabica Coffee in Papua and New Guinea—Progress Report.

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ABSTRACT.

In the last twenty years, Arabica coffee has grown from negligible production to the second largest earner of export income for New Guinea, with exports in 1965-1966 *in excess of* 10,000 *tons. About half is produced on estates and the other half on small holdings. The crop is singularly free from pests, disease and other serious problems.*

Twelve years ago, the Territory Department of Agriculture, Stock and Fisheries began to lay down extensive agronomic trials, covering varieties, shade, spacing, pruning, mulching, fertilizing and cover cropping. The main trials are at the Highlands Agricultural Experiment Station, Aiyura, with subsidiary trials in other parts of the coffee growing area with markedly different environmental conditions. Interim results can now be interpreted with some confidence and are discussed fully.

INTRODUCTION.

IN a period of less than 20 years, the coffee industry in Papua and New Guinea has grown from virtually nothing until today it rivals cocoa for the position of the Territory's second most important earner of export income (the long established coconut industry retains its lead as highest earner of export income). In 1951-1952, coffee exports amounted to only 34 tons valued at \$20,000. Ten years later, in 1961-1962 exports were 3,444 tons valued at \$4,028,000. By 1964-1965 exports had grown to 8,687 tons valued at \$7,296,000. Future expansion will be slower because of restrictions on planting imposed in accord with the International Coffee Agreement.

Some Robusta coffee is grown in lowlands areas but the greater part of the expansion of the industry has been in the production of Arabica coffee in highlands areas, generally between 4,000 and 6,500 ft. above sea level. About half is produced on estates and about half on village small-holdings.

Faced with such rapid expansion it was not possible for the Department of Agriculture (which itself had to build up from almost nothing after the 1939-1945 war) to keep ahead of the industry in research. Fortunately coffee production has been singularly free from serious problems and most plantings have produced well. The Department's main agronomy experiment programme with coffee got under way in 1954 but, as most field trials are of a fairly long-term nature, it is only now that their cummulative results are reaching a stage where they can be interpreted with some confidence.

Agronomic work with coffee is centred on the Highlands Agricultural Experiment Station, Aiyura, at an altitude of about 5,000 ft. The experiment programme undertaken has been ambitious, and includes variety trials and selection work ; study of the effects of various shades, spacings and pruning methods and their interactions with one another ; and study of nutritional requirements and responses to mulching, fertilizing and cover cropping. Staff available has frequently not been adequate to handle all the work that could be done on these trials, in sampling, testing, recording and analysing results, and often only the most essential work has been possible. Yields in all trials have been recorded as weight of fresh cherry produced and the relation between fresh cherry weight and weight of processed coffee beans has not yet been examined fully. Preliminary studies indicate that the conversion factor (from fresh cherry to processed coffee) differs substantially from variety to variety, and may also vary between different shade and fertilizer treatments and between different times and locations. Quality also may be affected by some treatments. These aspects are now being studied, and results should be fully applicable to the interpretation of the yield

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data already obtained. It must be emphasized that the present review is a progress report only, and many of the conclusions and recommendations are still tentative.

A brief description is given below of all trials which have been laid down up to the present. This is followed by a review of the results under the headings of the various factors involved. Most trials involve more than one factor, so results of a single trial may be discussed under more than one heading. Inclusion of several factors in a single trial permits an accurate assessment of their interactions (such as, for example, whether one variety may give highest yields at a close spacing while another yields its best at a wider spacing; or whether yields at different spacings are affected by presence or absence of shade). The review aims to present an overall picture of the economically significant results of the trials, as they affect management practices and yields. More detailed tabulations of the results of each trial are presented in the Annual Reports of the Department of Agriculture, Stock and Fisheries (1959-1960 et seq.).

LIST OF AGRONOMIC TRIALS WITH ARABICA COFFEE.

Notes.—The letters ACA stand for Aiyura *Coffea arabica*; this is part of a standard nomenclature for field trials used by the Department of Agriculture in Papua and New Guinea.

Spacings quoted as 'triangle' are equilateral triangle, except in a few instances where slight variations were made to fit the land available.

Trials described are located at the Highlands Agricultural Experiment Station, Aiyura; the Agricultural Extension Station, Goroka; and the Agricultural Extension Station, Korn Farm, Mount Hagen.

ACA1. *Shade x Spacing x Pruning Trial, Aiyura.*

To study the effects on coffee yields of four shade treatments (*Albizzia stipulata*—an introduced species; *Casuarina*—a local species; *Grevillea robusta*—introduced; and no shade) three spacings (7 ft., 8 ft. and 9 ft. triangle) two pruning systems (Single-stem and multiple-stem) on two sites (a hillside and pit-pit (peaty swamp) soil).

These treatments were all combined in a single trial in order to save space and also to enable study of any interactions between treatments.

Date.—Planted 1956.

Variety.—Blue Mountain.

Plot size.—Shade plots 0.4 acres, smallest sub-plots 0.1 acres.

Design.—Shade plots split for spacing, spacing split for pruning, four replicates on each site.

As the *Grevillea robusta* did not grow well enough to provide a suitable shade, it was cut out and these plots deleted from the trial in 1956. The deleted plots were used for ACA29.

ACA2. *Variety x Spacing Trial, Aiyura.*

Comparison of yields of five varieties (Blue Mountain, Arusha, Mocha, San Ramon, Bourbon) at two spacings (7 ft. 6 in. and 9 ft. triangle).

The variety Bourbon was planted a year later than the others, replacing a dwarf strain of San Ramon which appeared to have little potential.

Date.—Planted 1956.

Pruning.—Single-stem.

Plot size.—About 0.04 acres.

Shade.—*Albizzia stipulata.*

Design.—Randomized block, four replications.

ACA3. *Mulch—Cover Crop x Spacing Trial, Aiyura.*

To compare the effects on coffee yields of several forms of ground cover (clean weeding, weeds slashed, mulch, *Indigofera* and *Vigna* as cover crops) at two spacings (9 ft. triangle and 14 ft. x 5 ft. hedge).

The hedge spacing was designed to permit the use of cultivating or mowing implements to control ground cover, but the necessity for deep cross drains at the Aiyura site prevented use of such implements.

Date.—Planted early 1957, concluded 1961.

Variety.—Blue Mountain.

Shade.—*Albizzia stipulata.*

Plot size.—0.09 acres.

Design.—Spacing plots split for covers; four replications.

Results of this trial have been published (Schindler and Fraser 1964). Following conclusion of ACA3, the site was used for ACA14.

ACA4. *Omission Method Fertilizer Trial, Aiyura.*

An attempt to determine which elements were limiting coffee growth on this soil by omitting each in turn from an otherwise complete fertilizer mixture.

Treatments were—

- Complete fertilizer, containing N, P, K, Ca, Mg, S, Cu, Zn, Fe, Mo, Mn, B (Ca as $Ca(OH)_2$).
- Complete fertilizer with Ca as $CaSO_4$.
- Complete fertilizer with additional lime at 16 cwt. per acre.
- Omission plots, each one containing the complete mixture except for the omission of Ca, P, N, K, Mg, Cu, Zn, Mo, Fe or Mn.

Date.—Planted 1956, treatments commenced 1957.

Variety.—Blue Mountain.

Shade.—*Albizzia stipulata.*

Plot size.—Six trees (3 x 2), each plot surrounded by a drain, with a line of untreated guard trees between plots.

Design.—Randomized block, with six replications (twelve of complete fertilizer).

ACA5. *First Series Progeny Testing, Aiyura.*

Progenies from 53 mother trees, selected from mature stands of several varieties, were tested for yield in a search for local selections of better than average productivity.

Selections included 41 from Blue Mountain, four San Ramon, four Arusha, two Mocha, one Maragogipe, and one SL10.

Testing was conducted with four types of planting material—

Cuttings—i.e., clonal material from the mother trees.

Grafts—also clonal. As relatively few grafts were successful, this section was incomplete.

Self-pollinated seedlings—seed produced by bagging unopened flowers on the mother trees.

Open-pollinated seedlings.

Self-pollinated seedlings provide the best assessment of the value of trees as parents, and this group therefore served as standard for comparison of the other three sections of the trial.

Date.—Cuttings planted May, 1957, seedlings April, 1958.

Shade.—*Albizzia stipulata.*

Plot size.—Six trees in a single line.

Design.—Randomized blocks, with four replications. Cuttings, grafts and seedlings in separate trials; the seedling plots split for self-open-pollination.

ACA6. *Multiple-Stem Pruning Observations, Aiyura.*

Six methods of handling multiple-stem trees were tested in observation plots. The techniques used were exploratory and the tests were discontinued in 1961 after three years of observation. Coffee used was five-year-old, Blue Mountain and Arusha, under *Grevillea robusta* shade. Being on forest soil on a hillside, this shade tree grew better here than in ACA1.

ACA7. *High Level Fertilizer Trial, Aiyura.*

Testing the three main fertilizer elements (N, P, K) at two levels, the higher being three times the lower. Application rates of the fertilizers were (cwt. per acre)—

Sulphate of ammonia .... $N_1 = 3$, $N_2 = 9$

Superphosphate .... $P_1 = 2$, $P_2 = 6$

Potassium chloride .... $K_1 = 1$, $K_2 = 3$

The following treatment combinations were applied—

$N_1P_1K_1$ $N_2P_1K_1$ $N_1P_2K_1$ $N_2P_2K_1$

$N_1P_1K_2$ $N_2P_1K_2$ $N_1P_2K_2$ $N_2P_2K_2$

The above eight combinations were all combined with a mixture of minor elements.

$N_2P_2K_2$ with no minor elements.

Nil fertilizer control.

Date.—Commenced in 1958 on five-year-old coffee.

Variety.—Blue Mountain.

Shade.—*Albizzia stipulata.*

Plot size.—Twelve trees (6 x 2) with a guard row receiving the same treatment as plot trees.

Design.—Randomized block with two replications of the factorial treatments and four of the $N_2P_2K_2$ without minors and nil control.

In December, 1964, the K_1 and K_2 levels were increased to 2 cwt. and 4 cwt. per acre respectively, and 'nil fertilizer' was altered to P_1K_1 to give a 'no nitrogen' comparison with $N_1P_1K_1$.

ACA8. *Preliminary Diagnostic Fertilizer Trial, Aiyura.*

This was an exploratory trial applied on two sites where young coffee was stunted and making very poor growth, if any. Treatments were various combinations of the following fertilizers:—

Ammonium sulphate (N); sodium phosphate (P); potassium chloride (K); magnesium sulphate (Mg); lime; and a mixture of minor elements.

Date.—Treatments applied August, 1955; trial concluded 1961.

Shade.—*Albizzia stipulata.*

Plot size.—Three trees unguarded.

Spacing.—Nine feet triangle.

Design.—Half replicate of 2^6, compounding on each of the two sites.

ACA9. *Variety x Spacing x Pruning Trial, Aiyura.*

A comparison of the performance of four promising varieties over a range of spacings and two pruning systems—four varieties (Blue Mountain, Arusha, Bourbon, San Ramon)—

Three spacings for each variety (9 ft. square, 8 ft. x 6 ft. and 8 ft. x 4 ft. 6 in. rectangles for the first three varieties; for San Ramon, the 9 ft. square was replaced by 5 ft. square, as San Ramon is smaller framed).

Two prunings (both multiple-stem, one having its frame developed on a capped seedling base (East African), the other on an arched base (Agobiada)).

Date.—Planted early 1959.

Shade.—*Albizzia stipulata.*

Plot size.—0.12 acres.

Design.—Randomized block with three replications for the variety-spacing treatments; plots split for pruning.

ACA10. *Second Series Progeny Testing, Aiyura.*

A comparison of open-pollinated seedling progenies from 23 mother trees.

Selections from the following varieties:—

Group 1.—Bourbon from Raipinka Lutheran Mission (2), Bourbon from Goroka Agricultural Station (4), Bourbon from Korn Farm Agricultural Station (2).

Group 2.—San Ramon (2), Mocha (2), SL10 (2), SL6 (1).

Group 3.—Blue Mountain (4), Arusha (3).

One Bourbon selection from Group 1 was also included in Groups 2 and 3.

Date.—Planted early 1959.

Shade.—*Albizzia stipulata.*

Plot size.—Nine trees (3 x 3).

Design.—Each group in randomized blocks with four replications.

ACA11. *Single-Stem Pruning Trial, Aiyura.*

A comparison of several forms of single-stem pruning, ranging from relatively light or no pruning to a heavy pruning of the orthodox type.

This trial is described fully elsewhere in this issue.

ACA12. *High Level Fertilizer Trial, without Shade, Aiyura.*

The *Albizzia* shade was removed from a portion of the field in which ACA7 was being conducted and an additional small trial was laid down in 1960 to study the effects of the same fertilizers in the absence of shade.

The site did not permit any replication and results were too variable to be of value, so the trial was concluded at an early date.

ACA13. *East African Variety Trial, Aiyura.*

This was the initial planting of six varieties introduced from Kenya in 1958; two standard varieties were included for comparison. Varieties in the trial were—

Dalle Mixed Green, Ke20, Kents, SL14, SL28, SL34, and local Blue Mountain and Bourbon.

Date.—Planted 1959.

Shade.—*Albizzia stipulata.*

Plot size.—Twenty-five trees (5 x 5).

Design.—Randomized block, with three replications on one site and one on another.

ACA14. *Mulch-Fertilizer Combinations, Aiyura.*

This trial aimed to examine more closely the effects of mulch and fertilizer on coffee yields, following up results of ACA3 and ACA29. ACA14 was laid down on the same site as ACA3 after a two-year period during which mulch was applied over the whole area in order to even out former treatment differences and restore poor plots. During this period the site was modified by the removal of *Albizzia* shade in late 1961 and conversion of the coffee trees from single-stem to multiple-stem pruning by a process of removing old laterals and notching the main stem to induce suckers for new upright growth.

New treatments were—

Clean weeding plus fertilizer (NK); mulching plus fertilizer; mulching without fertilizer; and modified mulching differing for the two spacings (see ACA3): 14 ft. x 5 ft. spacing received a 6 ft. strip of mulch along each row of trees, without fertilizer; 9 ft. spacing received mulch in one year, fertilizer in alternate years.

Date.—Treatments commenced November, 1963.

Design.—Randomized block, four replications. Treatments applied orthogonally on ACA3 treatments and blocks.

ACA15. *'Sea Magic' Foliar Spray Trial, Aiyura.*

To compare the effect on coffee yields of the organic leaf spray 'Sea Magic' and inorganic fertilizer treatments.

This trial is described fully elsewhere in this issue.

ACA16. *Fertilizer Trial, Aiyura.*

An experiment involving 24 combinations of the following fertilizers and rates, on a hillside site with no shade:—

Sulphate of ammonia—nil, 1, 2 and 4 cwt. per acre.

Sulphate of potash—nil, 131 and 262 lb. per acre.

Superphosphate—nil, and 2 cwt. per acre.

The levels of sulphate of potash are equivalent to 1 and 2 cwt. potassium chloride, as used in ACA7. Sulphate of potash was used in order to correct a possible sulphur deficiency. Gypsum was added to plots which did not receive sulphur in the other fertilizer combinations.

Date.—Coffee was planted in 1955 and treatments applied in March, 1962.

Shade.—Original *Albizzia stipulata* and *Casuarina* shade was cut out in late 1961.

Variety.—Blue Mountain.

Pruning.—Single-stem.

Plot size.—Thirty-two trees (8 x 4) with treated guard row.

Design.—4 x 3 x 2 factorial, two replications.

ACA17. *Pruning Trial, Aiyura.*

A trial designed to test various systems of pruning coffee grown in hedge rows, a feature being that in some treatments a complete row of coffee is to be stumped each year instead of single uprights on each tree as in conventional multiple-stem pruning.

1. Three seedlings planted in each hole. Not capped or topped. One plant to be stumped each two years making a six-year cycle.

2. Single seedlings, not capped or topped. One row to be stumped each year, on a five-year cycle.

3. Seedlings capped in the nursery at 18 in. to carry four leaders each, not topped. One row stumped each year in a five-year cycle.

4. Seedlings capped, four leaders, topped at 6 ft. One row to be stumped each year, in a five-year cycle.

5. Seedlings capped, five leaders. One leader on each tree to be cut each year, on a five-year cycle.

6. Seedlings arched to Agobiada system, five leaders. One leader cut each year, on a five-year cycle.

7. Seedlings not capped, topped at 6 ft. To be handled initially as single-stem, later converted to multiple-stem. The only pruning in the single-stem stage to be desuckering.

8. Seedlings not capped. Alternate seedlings in each row—

(*a*) Arched to Agobiada, four leaders.

(*b*) Topped at 6 ft. for single-stem.

Single-stem bushes to be cut out when overcrowding becomes evident.

Date.—Planted 1963.

Variety.—Bourbon.

Shade.—*Crotalaria* temporary shade removed 1965, no permanent shade.

Spacing.—9 ft. x 4 ft. 6 in.

Plot size.—One hundred trees (five rows of 20).

Design.—Randomized block, six replications.

ACA18. *Variety Trial, Goroka.*

Test of six varieties under Goroka conditions—

Varieties: Blue Mountain, Arusha, Mocha, San Ramon Tall, San Ramon Dwarf, Hawaiian Kona.

Date.—Planted 1956.

Spacing.—Nine feet triangle.

Shade.—*Albizzia stipulata.*

Plot size.—Twenty-eight trees.

Design.—Randomized block, two replications.

ACA19. *Shade x Pruning Trial, Goroka.*

A much simplified version of ACA1, for Goroka conditions—

Five shades (nil, *Albizzia stipulata*, *A. fulva*—a local species, *Grevillea robusta*, *Casuarina*—a local species).

Two pruning systems (single-stem and multiple-stem).

Date.—Planted March, 1955.

Variety.—Blue Mountain.

Spacing.—Nine feet triangle.

Plot size.—One hundred and twenty-eight trees.

Design.—Shade plots split for pruning; no replication.

ACA20. *Spacing x Pruning Trial, Goroka.*

A study of spacing and pruning effects under Goroka conditions—

Four spacings (7 ft., 8 ft. and 9 ft. triangle, 12 ft. x 6 ft. rectangle).

Two pruning systems (single-stem and multiple-stem).

Date.—Planted 1956.

Variety.—Bourbon.

Shade.—*Albizzia stipulata.*

Plot size.—About 0.04 acres.

Design.—Spacing plots split for pruning, two replications.

By 1962 it was considered that the multiple-stem pruning had fully established its superiority, and the single-stem bushes were stumped for conversion to the more easily managed multiple-stem system.

ACA21. *High Level Fertilizer Trial, Goroka.*

A similar trial to ACA7 at Aiyura, with identical treatments.

Date.—Planted 1955.

Variety.—Blue Mountain.

Spacing.—Nine feet triangle.

Pruning.—Multiple-stem.

Shade.—*Albizzia stipulata.*

Plot size.—As ACA7.

Design.—As ACA7.

ACA22. *Shade x Pruning Trial, Korn Farm.*

A similar trial to ACA19, but including more shade species—

Eight shades (nil, *Albizzia stipulata*, *Casuarina*—local species, *Grevillea robusta*, *Leucaena leucocephala*, *Piptadenia*—local species, *Gliricidia* sp., *Peltophorum* sp.).

Two pruning systems (single-stem and multiple-stem).

Date.—Planted March, 1956.

Variety.—Blue Mountain.

Spacing.—Nine feet triangle.

Plot size.—One hundred and sixteen trees (0.19 acres).

Design.—Shade plot split for pruning, no replication.

ACA23. *Variety x Spacing Trial, Korn Farm.*

A variety trial for local conditions.

Varieties.—Blue Mountain, Arusha, Mocha, Bourbon, San Ramon.

Spacings.—Seven feet and nine feet triangle.

Date.—Planted March, 1956.

Shade.—*Albizzia stipulata.*

Pruning.—Single-stem.

Plot size.—About 0.1 acre.

Design.—Spacings split for varieties, two replications.

ACA24. *Spacing x Cover x Pruning Trial, Korn Farm.*

Similar trial to ACA3 at Aiyura, but including also a comparison of single-stem and multiple-stem prunings.

Date.—Planted 1956, concluded 1961.

Results have been published (Schindler and Fraser 1964).

ACA25. *High Level Fertilizer Trial, Korn Farm.*

A similar trial to ACA7 at Aiyura and ACA21 at Goroka, but with three levels of potassium chloride (1, 3 and 5 cwt. per acre). Rates of sulphate of ammonia and superphosphate the same as ACA7.

Date.—Planted 1955.

Variety.—Blue Mountain.

Shade.—Nil.

Pruning.—Multiple-stem.

Spacing.—Nine feet triangle.

Plot size and design.—As in ACA7, but with three levels K in factorial treatments.

ACA26. *East African Introductions, Korn Farm.*

Small unreplicated plots of the following varieties, planted for observation :—

Planted April, 1959 : Dalle Mixed Green, Ke20, Kents, SL14, SL28, SL34.

Planted March, 1960 : SL6, SL10.

The site proved unsuitable for uniform growth and material was not sufficient for valid comparisons.

ACA27. *Pruning Observation Rows, Korn Farm.*

Several exploratory methods of handling multiple-stem coffee were tried on a bulk area of Blue Mountain coffee. Techniques tried to induce suckers for replacement uprights included bruising, deliberately breaking an upright at its base, and cutting roots on one side of a tree and pushing it into a leaning position.

Date.—Treatments commenced March, 1960, concluded in 1964.

ACA28. *Nitrogen x Sulphur Fertilizer Trial, Aiyura.*

Following indications of response to sulphur in earlier trials, in which sulphur had been included in such fertilizers as sulphate of ammonia but had not been specifically studied in its own right, this small new trial was laid down on a plot of rather poor coffee. All plots were given a basal dressing of muriate of potash to ensure that potassium nutrition was not limiting.

Treatments.—No fertilizer ; nitrogen (as urea, 156 lb. per acre) ; sulphur (as gypsum, 346 lb. per acre) ; nitrogen plus sulphur (same rates).

Date.—Planted 1954, treatments applied 1962.

Variety.—Blue Mountain.

Shade.—*Albizzia stipulata.*

Spacing.—Nine feet triangle.

Plot size.—Fifteen trees (5 x 3), with a single unfertilized guard row common to adjacent plots.

Design.—Randomized block, six replications.

ACA29. *Mulch-Fertilizer Combinations, Aiyura.*

When, in ACA1, *Grevillea robusta* failed to provide uniform shade and as unshaded coffee yielded well, the *Grevillea* was removed and the plots were used for a study of two pairs of mulch and fertilizer combinations. At the same time, fertilizing was commenced on the remaining plots of ACA1, so the 'no shade' plots of ACA1 provide some comparison of yields from fertilized unmulched plots.

Treatments—

On pit-pit soil : No mulch, no fertilizer compared with mulch, no fertilizer.

On hillside soil : Mulch, no fertilizer compared with mulch, plus fertilizer.

Elephant grass (*Pennisetum purpureum*) was used for mulch, spread to a depth of about 6 in., in October to November each year (i.e., end of dry season). Fertilizer (potassium sulphate 2 cwt. per acre and urea 1 cwt. per acre) was applied split into two equal doses per year. Rate of potassium sulphate was increased to 3 cwt. per acre in 1964.

Date.—Planting details as ACA1, mulch treatments commenced November, 1961.

Differential treatments were discontinued on the pit-pit site in 1964, when it became obvious that coffee was dying in the no mulch, no fertilizer plots.

ACA31. *Processing Trial, Aiyura.*

Studies of the effects on quality and final weight of processed coffee of various methods of processing and drying.

ACA32. *Potash Frequency of Application Trial, Aiyura.*

Studying the effect of different frequencies of application of potassium fertilizer to coffee growing on potassium deficient soil. The trial also includes a comparison of two methods of conversion of single-stem trees to multiple-stem pruning.

The site had been used previously for ACA11 and ACA15. These were both concluded in 1964 and the whole area was uniformly fertilized for a period to even out any effects remaining from former treatments.

Pruning conversion.—A comparison of stumping the old tree 18 in. above ground, bringing away five new leaders ; with removal of all laterals on one side of the bush and notching the main stem deeply at a height of 18 in., followed by progressive removal of remaining laterals and the main stem over two years and bringing away five replacement suckers.

Fertilizer frequency.—Application of the same annual total in split applications at intervals of 1, 3, 6 or 12 months.

Fertilizer rates.—Potassium sulphate at 2 cwt. and 4 cwt. per acre per year. In addition a basal dressing of urea at 1 cwt. per acre is applied to all plots in two half-yearly applications.

Date.—Pruning conversions commenced November, 1964, and fertilizer treatments commenced in July, 1965.

Variety.—Blue Mountain.

Shade.—*Albizzia stipulata.*

Spacing.—Nine feet triangle.

Plot size.—Frequency sub-plots of 40 trees (8 x 5) surrounded by a guard row receiving the same treatment.

Design.—Pruning plots split for rate, rates split for frequency ; three replications.

ACA33. *Variety Trial, Aiyura.*

A new trial, planned for planting out in early 1967, which will test recent coffee introductions, including varieties resistant to some races of leaf rust and the more promising selections from progeny testing trials

ACA5 and ACA10. There will be a total of 42 varieties, as follows :—

(*a*) East African varieties from ACA13—6.
(*b*) Selections from ACA5—8.
(*c*) Selections from ACA10—5.
(*d*) Rust Resistant introductions—
1961 planting—7.
1963 planting—14.
(*e*) Controls—bulk Arusha and bulk Bourbon.

Shade.—Temporary *Crotalaria* shade for establishment, no permanent shade.

Spacing.—9 ft. x 4 ft. 6 in.

Plot size.—Fifteen trees (5 x 3).

Design.—6 x 7 rectangular lattice, with six replications.

ACA34. ***Variety Trial, Goroka.***

A trial similar to, but simpler than, ACA33, to test similar varieties in a different location. The 30 varieties to be used will include a smaller number of varieties from each of the groups listed under ACA33.

Design.—5 x 6 rectangular lattice with three replications.

Other details not yet finalized, but plot size will be larger than in ACA33 so as to give about equal total quantities of each variety.

ACA35. *Variety Trial, Korn Farm.*

A repetition of ACA34 at a different site.

VARIETY TRIALS.

A number of introductions have been made of high yielding Arabica varieties from other countries and any which showed promise have been included in varietal yield trials. The following are some notes on the origins of the main varieties which have been grown :—

Blue Mountain.—Introduced to Wau from Jamaica ; brought to Aiyura from Wau in 1937.

Bourbon.—Brought to the Territory pre-war by the Lutheran Mission, and planted at Aiyura in 1956.

San Ramon ; Maragogipe.—Introduced from East Africa pre-war.

Mocha, Arusha (selection "D.R."), *SL6* (selection from Kents), *SL*10 (selection from Harar).—Introduced from East Africa in 1950.

Hawaiian Kona.—Introduced from Hawaii in 1956.

Dalle Mixed Green, *Ke*20, *Kents*, *SL*14, *SL*28, *SL*34.—Introduced from Kenya in 1958.

Since 1960, a further 30 varieties carrying resistance to various strains of coffee leaf rust (*Hemileia vastatrix*) have been introduced from the United States Department of Agriculture, Beltsville, Maryland, and from Centro de Investigacao das Ferrugens de Caffeiro, Oeiras, Portugal.

The main series of variety trials (ACA2, 9, 18 and 23) included the varieties Blue Mountain, Arusha, Mocha, Bourbon and San Ramon. Results are summarized in *Table* 1 ; yields have been converted from the cherry weight actually recorded to dry coffee equivalent, on the basis of conversion factors established at Aiyura.

Precision has been low. Although ranking of the varieties has not been the same in all localities it is uncertain whether this indicates differences in adaptability to different environments. Varieties Arusha, Mocha and Bourbon have all performed better than Blue Mountain which was previously the most widely used variety in the Territory. San Ramon generally performed poorly, although in ACA9 it produced high yields at 5 ft. x 5 ft. spacing. San Ramon was very mixed, ranging from dwarf to fairly normal plants, and selection may produce a more satisfactory variety.

Other varieties have not yet been fully tested. In ACA13, results have been so variable that differences in yield between varieties have not been statistically signficant. All varieties in this trial appear to compare quite well with Blue Mountain, but further testing will be undertaken (ACA33). Hawaiian Kona did not perform well in ACA18.

SPACING OF VARIETIES.

As varieties differ in vegetative vigour, it could be anticipated that they might differ in their performance at different spacings. Accordingly, most variety trials included two or more spacings. Results have been inconclusive because of low precision. In no trial has any interaction between varieties and spacings been statistically significant, nor has there been any consistency between trials ; for example, in ACA2, Arusha and Mocha were the only two varieties to yield more at 9 ft. spacing than at 7 ft. 6 in. in their early years, whereas in ACA23 these same varieties were the only ones to yield more at 7 ft. than at 9 ft. In view of such inconsistency it appears that the varieties involved probably do not differ much in the spacing required for maximum yield or that any such differences are minor in respect to other factors affecting yield.

Trial ACA9 was laid out with the initial assumption that the variety San Ramon, a semi-dwarf type, would benefit from closer spacing than the other varieties, and it was therefore planted over a different range of spacings. Within the two spacings common to all varieties, San Ramon and Arusha show a greater advantage

Table 1.—Yields of five coffee varieties in five field trails.

—		Blue Mountain.	Arusha.	Mocha.	Bourbon	San Ramon.
ACA2 (Aiyura)						
Average Yield 1960-61 to 1965-66	lb. cherry per acre	9,357	11,585	11,796	12,228	8,921
	lb. dry coffee per acre	1,460	1,552	1,675	1,736	1,204
	Yield (dry coffee) as per cent. of Blue Mountain	100	106	115	119	82
ACA18 (Goroka)						Tall Dwarf
Average Yield 1959-60 to 1964-65	lb. cherry per acre	6,543	8,654	7,193	9,483*	4,988 3,256
	lb. dry coffee per acre	1,034	1,186	1,043	1,403*	728 475
	Yield (dry coffee) as per cent. of Blue Mountain	100	115	101	136*	70 46
ACA23 (Korn Farm)						
Average Yield 1961-62 to 1964-1965	lb. cherry per acre	6,780	8,972	9,255	6,519	4,731
	lb. dry coffee per acre	1,071	1,229	1,342	965	691
	Yield (dry coffee) as per cent. of Blue Mountain	100	115	125	90	65
ACA13 (Aiyura)						
Average Yield 1962-63 to 1965-66	lb. cherry per acre	7,044	....	....	8,752	....
	lb. dry coffee per acre	1,078	....	....	1,365	....
	Yield (dry coffee) as per cent. of Blue Mountain	100	....	....	127	....
ACA9 (Aiyura) (8' x 6' and 8' x 4½')						
Average Yield 1961-62 to 1965-66	lb. cherry per acre	10,529	15,532	....	12,789	9,355
	lb. dry coffee per acre	1,779	2,252	....	2,008	1,516
	Yield (dry coffee) as per cent. of Blue Mountain	100	127	....	113	85
ACA9 (Aiyura) (all spacings)						
Average Yield 1961-62 to 1965-66	lb. cherry per acre	8,937	13,866	....	11,710	10,837
	lb. dry coffee per acre	1,510	2,011	....	1,838	1,756
	Yield (dry coffee) as per cent. of Blue Mountain	100	133	....	122	116

* Bourbon was not included in ACA18, but yield from ACA20 alongside is shown here.

at the closer spacing than Blue Mountain and Bourbon, but the difference between the varieties in this respect does not approach statistical significance. These trees are still fairly young and something more definite may emerge as the trees grow older.

SELECTION WORK.

Progenies of individual high-yielding trees of various varieties have been tested in two trials, ACA5 and ACA10. Certain progenies appear to be superior and will be further tested in a new trial, ACA33.

Trial ACA5 studied several aspects of selection and progeny testing work. It included 36 progenies of Blue Mountain selections and also unselected Blue Mountain seedlings. Average yield of the progenies of selections was no higher than the yield of unselected seedlings, indicating that bulk selection of apparently superior trees for seed parents is probably quite ineffective for improving yield. The trial also included comparison of the selections as clones multiplied by cuttings. There was very little correlation between the relative performance of clones and progenies, and it would appear that clone testing would not be an effective method of selecting superior parents. A further comparison was made between self-pollinated and open-pollinated progenies of the selected parents, the main interest being in whether open-pollinated progenies would rank in the same order of yield as self-pollinated progenies. Results indicated that the ranking was the same and that progeny tests based on open-pollinated seed should be as reliable as tests using self-pollinated seed.

SPACING.

Several trials (ACA1, 2, 3, 9, 17, 20, 23 and 24) have studied spacing effects. Most trials have compared planting densities within the range 600 to 1,000 trees per acre, mostly on equilateral triangle or square patterns, but some rectangular (or hedge) patterns have been used.

Results have not been entirely consistent, but within the range 7 ft. to 9 ft. triangle yields have generally been higher at the closer spacing. However, at 7 ft. spacing trees become so overcrowded as they age that they impede harvesting and for triangle planting nothing closer than 8 ft. could be recommended. There has been a trend in some trials, especially in ACA9, for the initial advantage of the closer spacing to be reduced as the trees grow older. This is what would be expected, and there appears to be a good case for close initial planting to give early high yield, with subsequent thinning for ease of access, or hedge planting which may or may not need thinning for maintenance of yields. This will be studied in ACA17 which has been planted at 9ft. x 4½ ft. spacing.

In two trials (ACA3, 20) hedge spacings with wide gaps between rows (14 ft. in ACA3, 12 ft. in ACA20) have not yielded well in comparison with triangular spacing.

SHADE.

Although coffee is grown without shade in some parts of the world, use of shade is almost universal in Papua and New Guinea. Practical experience has shown in some cases that coffee without shade, or from which shade has been removed, has produced very high yields for a few years, but subsequently has shown extensive die-back and in some cases death of trees.

Trials at Aiyura, Goroka and Korn Farm (ACA1, 19 and 22) have compared different shade tree species and have also included nil shade. The unshaded coffee at Goroka has generally yielded poorly and trees have shown pronounced biennial bearing and scorching of the cherries. At Korn Farm, the trial has given inconsistent yield results, but by 1966 the unshaded coffee was very unhealthy in comparison with well shaded plots. At Aiyura, unshaded coffee was slower to commence bearing, but subsequently it has consistently out-yielded shaded coffee. However, it must be noted that this coffee has been fertilized and the trials clearly show that the shade requirements of coffee in the Territory cannot be considered apart from nutrition. At Aiyura, in ACA1, *Grevillea robusta* was originally included as a shade tree, but grew very poorly and the trees were removed in late 1961. These plots then received treatments to study the effects of elephant grass mulch (ACA29) and at the same time regular fertilizing was commenced on all other plots in ACA1. Some trees in the former *Grevillea* plots received no mulch or fertilizer and although yields continued fairly high, in 1963 most trees were completely defoliated and about 15 per cent. dead. Subsequently, mulch and fertilizer were applied in an effort to save the surviving trees and by 1966 they were showing a good recovery. At Korn Farm, although unfertilized trees in the shade trial looked very unhealthy, fertilized trees in ACA25, which has no shade, remained very healthy and productive.

Maintenance costs are probably substantially higher for unshaded coffee, because of greatly increased weed growth. Any overhead shade substantially reduces weed growth while *Casuarina* in ACA1 and *Grevillea* in ACA22 have formed a mulch of leaf on the soil which has almost completely suppressed weeds. The extra cost in weeding unshaded coffee would be only partially offset by savings in establishment and maintenance of shade trees.

In addition to extra maintenance costs, sunburning of cherries probably lowers the quality of coffee produced. This aspect is under study.

Conclusions from this work are still only tentative, but are as follows :—

(1) Growth of coffee without shade in any New Guinea area is somewhat risky, but under conditions of good rainfall (80 in. per year or more) and no severe dry season it could be expected that trees will survive and produce very high yields provided they are mulched or fertilized heavily enough. At Aiyura, over seven years' bearing unshaded coffee out-yielded coffee under *Casuarina* by an average of 600 lb. of dry coffee per acre per annum, worth about $200 at a price of $800 per

ton. With a gross return of this magnitude it is probable that extra costs of maintenance and of higher levels of fertilizing required would be amply reimbursed.

(2) Shade removal could not be recommended for areas experiencing a more severe dry season, or for shallow soils or hillside sites subject to drought.

(3) In any area, temporary shade is necessary for establishment.

Shade Species.—Results have shown that choice of shade tree species must be based on local conditions. *Albizzia stipulata* and the indigenous *Casuarina* are the most generally satisfactory, but *Casuarina* tends to fail at an early age on some soils and *Albizzia* grows so large that shade control is difficult. Silky oak (*Grevillea robusta*) has made excellent growth at Korn Farm but rather poor at Goroka. At Aiyura it failed completely on a shallow hillside soil and grew only moderately on a pit-pit area, but was quite reasonable on a forest clearing at a slightly higher altitude. *Leucaena* is satisfactory at Wau and seems to be fairly satisfactory on several properties near Goroka and Minj, and in a small plot at Aiyura, but at Korn Farm it has been quite unsatisfactory. No general recommendation can be made; planters should be guided by local experience.

PRUNING.

Comparisons between single-stem and multiple-stem pruning have been made in five trials (ACA1 (two sites), 19, 20 and 22). Two have shown a yield advantage for multiple-stem, one for single-stem, and two have proved variable (*Figure* 1). The general conclusion is that neither system is in itself superior as regards yield, but multiple-stem pruning is cheaper in application and therefore probably preferable.

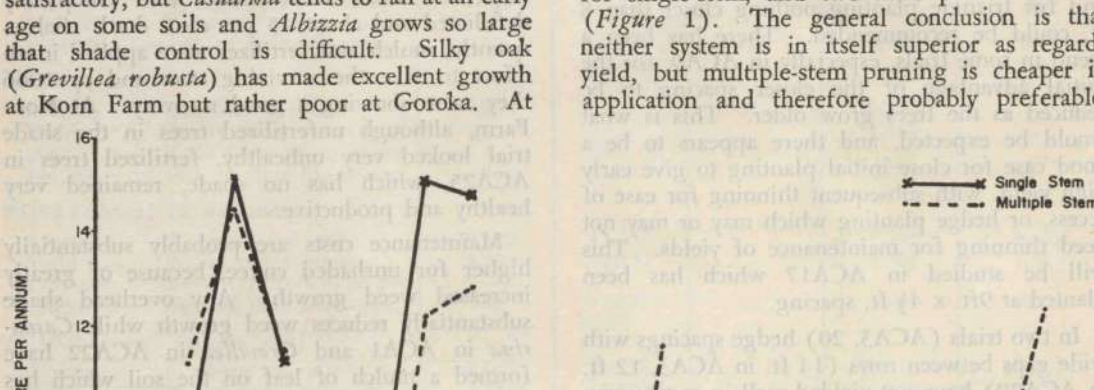

Figure 1.—Yields of cherry coffee (averaged over two-year periods) of single-stem and multiple-stem pruned coffee in five field trials.

This statement however, may be true only of a fairly intensive system of single-stem pruning and results of ACA11 (see paper " Single-Stem Pruning in Arabica Coffee " by R. S. Carne in this issue) indicate that virtually unpruned single-stem trees gave as good yields as more intensively pruned trees over the duration of the trial. Later results may have changed this picture, since unpruned single-stem trees could be expected to decline in yield through excess vegetative growth at the expense of bearing wood. It could nevertheless prove economic on a long-term system to allow trees to grow to a single-stem with little pruning, but later convert to multiple-stem pruning. A comparison is being made in ACA32 of two methods of conversion, and this will give a measure of how much crop is lost in the process.

Pruning for maximum yield is undoubtedly an art, and ideally each tree should be treated individually according to its growth. Under plantation conditions, with pruning performed by relatively unskilled personnel, this is almost impossible. In some of the experiments reported here, multiple-stem pruning has been at a disadvantage because pruning has been applied uniformly throughout a trial and some areas of poorer growth have suffered from pruning too early. This was the probable reason for the poorer performance of multiple-stem plots on the hillside site of ACA1 than on the pit-pit site.

Trial ACA9 compares two systems of multiple-stem pruning, the arch or 'Agobiada' system and the East African system of capping in the nursery to bring away three or four leaders. The East African system gave higher yield initially but subsequently Agobiada made up the difference and yields have been about equal over the course of the trial. Agobiada has proved easier to manage in later years as new leaders come away more readily. In contrast to the ACA9 result, in ACA17 Agobiada is giving better early yield than East African, because the nursery capped seedlings fared very badly after transplanting under unfavourable weather conditions.

Experience at Aiyura has shown weaknesses in most standard pruning methods, and trial ACA17 has been designed to study alternative systems. A problem in multiple-stem systems has been that, on well grown plants, new leaders tend to be long and spindly because of the amount of foliage surrounding them ; sometimes replacement leaders fail to come away at all. In ACA17 methods aiming to overcome this problem include annual stumping of one complete row in five (in contrast to one stem in five on each row) and planting three seedlings per point to be stumped one at a time, with the idea that leaders are more likely to be stimulated when a complete bush is cut back. Another weakness of standard pruning systems is that any pruning before bearing will delay production ; quickest yields are obtained if seedlings are allowed to grow unhindered to a single-stem unpruned tree, although subsequently such a tree may prove unmanageable. In ACA17, various approaches are made aiming to obtain the early yield of an unpruned tree with provision for some subsequent conversion to a more manageable system ; these include the two mentioned above and also a compromise system where alternate trees will be (*a*) pruned to Agobiada and (*b*) left unpruned except for capping at 6 ft., with the unpruned seedlings to be removed entirely when the stand becomes overcrowded. All treatments are planted at 9 ft. x 4 ft. 6 in. spacing. It will be several years before results can be evaluated.

SHADE, SPACING AND PRUNING INTERACTIONS.

Trial ACA1 is a large scale trial to determine whether shade, spacing and pruning treatments interact with each other—that is, whether optimum spacing differs under different shade treatments or pruning systems, etc. It also includes a comparison between two sites at Aiyura, differing in soil type and drainage characteristics.

Figure 2 shows yields for spacings within pruning within shades for the two year periods 1959-1960 to 1960-1961 and 1961-1962 to 1962-1963, and the three year period 1963-1964 to 1965-1966. These graphs illustrate the main treatment effects as well as their interactions.

In general, interactions between the three factors have been fairly small and barely significant statistically. There is some indication that treatments only began to interact as the trees grew older, but this has not been entirely consistent. The most probable explanation for the interactions is that, as the trees reach a size where they compete, yield is largely determined by crowding of the stand and competition for

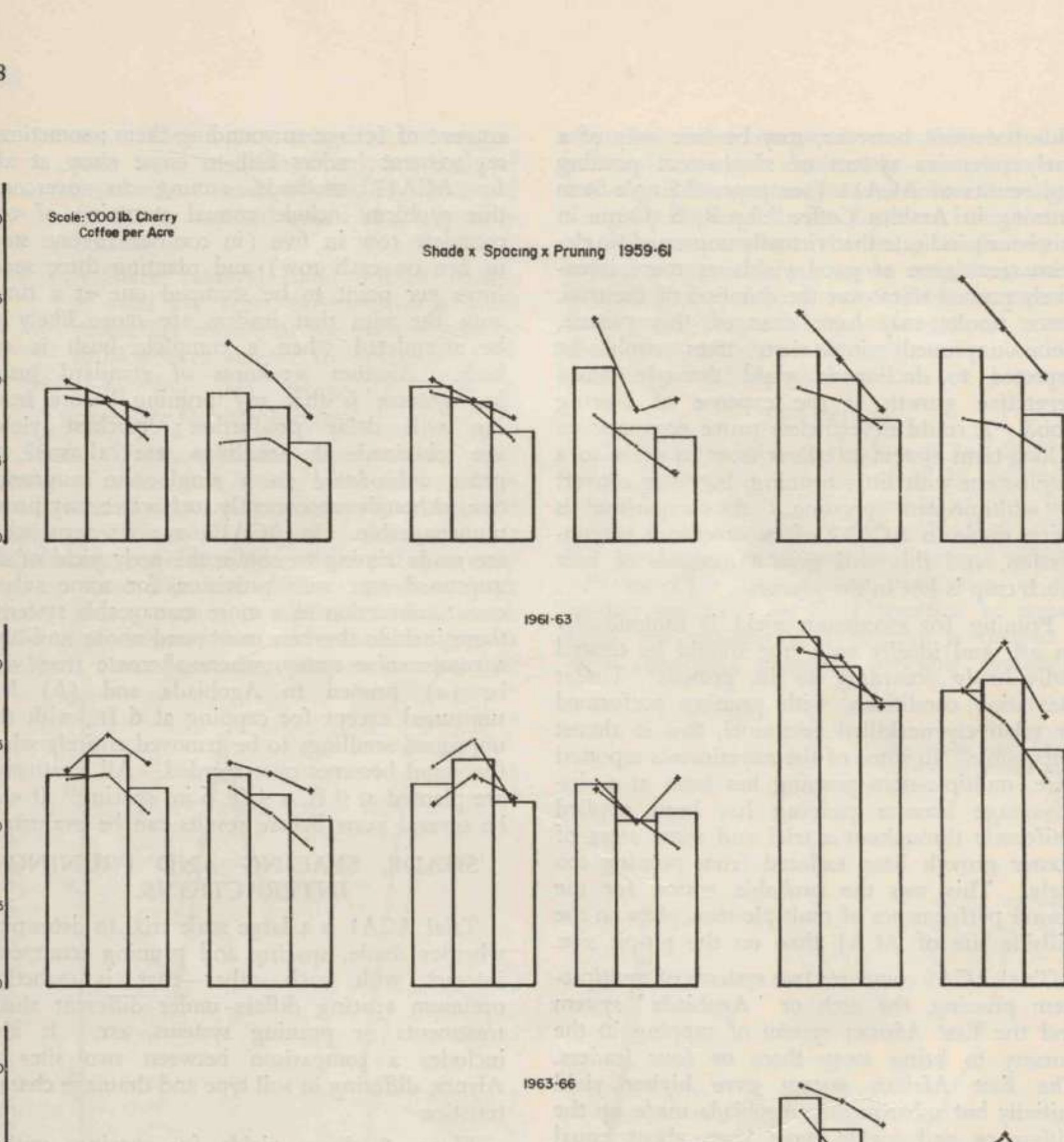

Figure 2.—Yields of cherry coffee in ACA1 Shade x Spacing x Pruning Trial at Aiyura. The histograms show averages over the two sites, while points marked by + and . and connected by continuous lines are average for the pit-pit site and the hillside site respectively.

available light. The effect of spacing on crowding is obvious ; as the trees age, closer spacings become crowded and the initial yield advantage is lost. Multiple-stem pruning can produce a more spreading tree and increase crowding, but the pattern of removal of old stems and replacement with new ones results in variation in size of bushes, hence little consistency in the spacing-pruning interaction. Crowding effects would be accentuated under shade, either because of there being less light available for fruit production or because branches grow longer and leaves larger under reduced light conditions. This would explain why the advantage of closer spacing has been maintained longer under nil shade than under the two tree species. Over the three years 1963-1964 to 1965-1966, consistently higher yield of 7 ft. over 8 ft. and 8 ft. over 9 ft. was maintained only in the single-stem plots of the no shade treatments ; this accords with the explanation given above, as these plots would be least crowded and have most light available for fruit production.

Highest yields have thus been obtained from 7 ft. triangle unshaded, single-stem coffee—the average over the seven years in which this trial has been bearing has been almost 3,000 lb. dry coffee per acre. The highest yield from multiple-stem pruned plots has come from 8 ft. spacing ; over both sites, this yield has been more than 400 lb. lower than from 7 ft. single-stem, but on the pit-pit site the difference amounted to only 200 lb. per acre per year (as has been noted above, multiple-stem has performed rather poorly on the hillside site probably because first pruning was carried out before trees were large enough). Since it could prove more difficult to maintain high yields in later years on the single-stem plots and because of the higher pruning costs, 8 ft. spacing with multiple-stem pruning may prove as economic in the long term.

FERTILIZING.

Several fertilizer trials have been conducted at Aiyura, Goroka and Korn Farm. These will be reviewed only briefly as coffee nutrition is discussed fully in other papers in this Journal. Development of analytical techniques would render some of the exploratory trials unnecessary now, but there is no alternative to a field trial for determining the magnitude of fertilizer response.

The magnitude of yield response depends on soil type and climatic conditions as well as on controllable factors such as variety, management practices and frequency and rate of fertilizer application. The potential for fertilizer response is illustrated by ACA7 where soils are deficient in potassium but other factors (management, climate) are favourable. The response to fertilizer (that is, the difference in yield between fertilized and unfertilized plots) over a period of six years has averaged 7,000 lb. of cherry (more than 1,000 lb. of processed coffee) per acre per annum. Foliar analysis results and trends in yields in the trial itself indicated that even larger response may have been obtained with heavier fertilizing.

On the other hand, at Goroka, where soils are more fertile and where trial ACA21 has shown very little fertilizer response, yields have been substantially lower than in fertilized plots at Aiyura. The difference is probably a result of less favourable rainfall distribution and excessive shade on the trial plot over much of the period. At Korn Farm, in trial ACA25, fertilizer responses have been substantial, averaging 5,000 lb. of cherry (750 lb. of processed coffee) per acre per year over six years, but yields of the best fertilized plots have been substantially lower than those of the best fertilized plots at Aiyura. Again there must be some other factor limiting yield.

It follows, therefore, that although it is often possible on the basis of foliar analysis or some other technique to predict that yields of a block of coffee could be improved by fertilizing, the amount of increase to be expected cannot be predicted with confidence as many other factors are involved.

Another point worth mentioning is that yields and tree vigour may be adversely affected by factors which cannot be ameliorated by fertilizing. Soil moisture is an obvious factor ; at Aiyura, several patches occur where the soil is kept excessively wet through seepage and trees have grown poorly or have died despite all efforts at drainage and fertilizing. In ACA16, by contrast, large numbers of trees died in 1964 and fertilizers did not prevent the deaths ; this was probably a result of drought on shallow soil with no shade protection. In ACA1, the coffee on the pit-pit area has shown very marked biennial bearing whereas coffee on the hillside has not shown any such fluctuating yield. In ACA7, one replicate is planted on pit-pit soil and the other on grassland soil immediately adjacent. Biennial bearing has been extremely pronounced on the pit-pit soil and far less marked on the grassland soil, but the best fertilizer plots have shown as much year to year fluctuation as unfertilized plots.

MULCHING.

Results of initial mulching trials at Aiyura (ACA3) and Korn Farm (ACA24) have already been published (Schindler and Fraser 1964). These trials showed major yield response with mulching, but costs were high and an economic return was not completely assured.

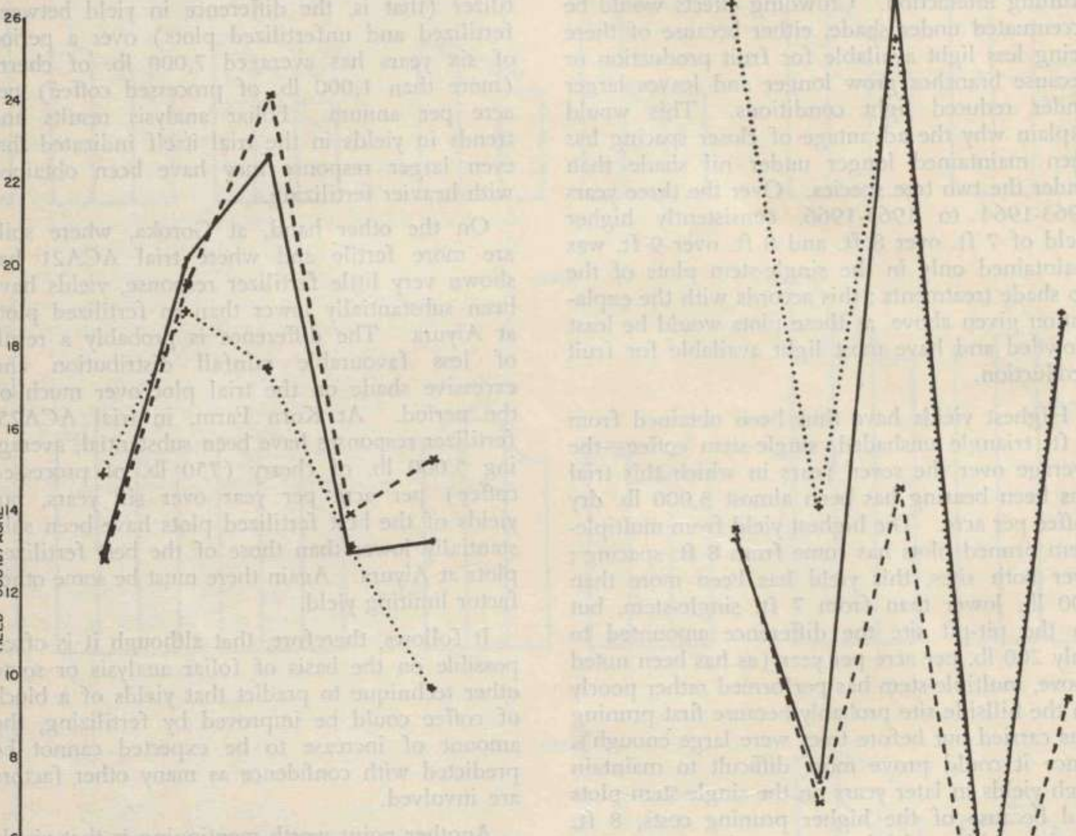

Figure 3.—Yields of cherry coffee in ACA29 Mulch-Fertilizer Trial which compared different treatment combinations on two sites at Aiyura. Note that the "no mulch, no fertilizer" treatment was discontinued in 1964-1965.

Further observations on mulch effects have been made in trial ACA29, superimposed on the former *Grevillea* plots of ACA1. This compared mulch versus no mulch, without fertilizer, on the pit-pit site ; and mulch with and without fertilizer on the hillside site. In both cases comparison was possible with the unmulched, fertilized no-shade plots of ACA1 (*Figure* 3).

On the pit-pit site, before mulching yields of the ACA29 plots were much lower than yields of the ACA1 no-shade plots. Mulching restored yields to a level similar to the no-shade plots (now receiving fertilizer). The unmulched ACA29 plots deteriorated. In 1964, defoliation occurred on all plots but most severely on the unmulched unfertilized plots, and many trees died. A count in June, 1964, showed 14.8 per cent misses in unmulched plots, compared with 2.5 per cent. in mulched plots. Subsequently, all these ACA29 plots were mulched and fertilized as a restorative measure. Yields were still low in 1965-1966 but the trees looked fairly healthy by June, 1966.

On the hillside soil, yields of mulched plots (both with and without fertilizer) rose above those of the unmulched, fertilized ACA1 no-shade plots and have continued substantially higher. There has been an indication of additional benefit where fertilizer was applied with the mulch, but this has not been statistically significant.

Effects of mulching are being studied further in trial ACA14. This should provide a more accurate comparison of the relative value of mulch and fertilizer and it includes also a comparison of combinations of mulching with fertilizing which will be less expensive than mulching alone.

EXPERIMENTAL METHODS.

Precision has been low in all trials, as a result of extreme variability in vigour and yield between plots. This situation at Aiyura could possibly have been ameliorated to some extent by a higher level of fertilizing to ensure adequate nutrition (except, of course, in fertilizer trials) but, as indicated in the discussion on fertilizing, factors other than nutrition were almost certainly involved in the variability, and many of them were uncontrollable.

This indicates that block size should be kept as small as possible (consistent with considerations of inter-plot competition and guarding requirements) and treatments should be replicated as many times as possible. Where large numbers of varieties or selections are to be compared, incomplete block designs should be used.

Where a trial is laid down on established coffee, use of girth x height of the trees as a co-variate in analysis of subsequent yields has substantially improved precision. Yield over periods of a year or less has not proved a useful co-variate.

None of the Aiyura trials has yet run long enough to establish long-term results, but indications from data so far are that, in trials where ageing of the bushes is not likely to affect comparisons (for example, variety trials as opposed to spacing or fertilizer trials), the order of merit of treatments shown in the first three to four years' bearing is not likely to change much in later years. This means that fairly firm conclusions may be drawn after a few years' recording in trials of this type. To some extent a corollary of the above, in trials where treatment differences are not statistically significant in yields from a two-year period because of high variability within treatments, it is unlikely that continued recording over a longer period will appreciably reduce variability. It is therefore not worth continuing such trials unless there is an expectation that treatment effects will increase to the extent where they will attain significance despite the variability.

ACKNOWLEDGEMENTS.

We are especially grateful to Mr. G. A. McIntyre of the Division of Mathematical Statistics, C.S.I.R.O., Canberra, for advice and assistance in design and analysis of trials. Mr. A. W. Charles, Chief of Division of Plant Industry, had a prominent part in planning experiments. Field work and recording have been carried out by Agronomists A. J. Schindler, K. Newton, R. R. Fraser and one of the authors R. S. Carne, with assistance from Messrs. K. H. van Horck, the late H. H. Nitsche, officers of the Extension Division at Goroka and Korn Farm, D. J. Kingston, R. Smythe, J. G. Davis, J. W. Barrie, J. J. Nitsche, and Technical Assistants S. Meara, J. Guguna and G. Seloka. Miss J. O. Vause assisted in computation and preparation of graphs.

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Coffee Nutrition—Part I. The Determination of Nutritional Status and Fertilizer Requirements of Arabica Coffee in New Guinea.

P. J. SOUTHERN.*

ABSTRACT.

Field and laboratory methods used in the study of the nutrition of Arabica coffee in New Guinea are described. Foliar analysis, in particular, has been developed to an extent where it is proving useful in the diagnosis of deficiencies and the assessment of fertilizer requirements of New Guinea coffee plantations. Above normal, normal, subnormal and deficient categories for leaf levels of major nutrients are proposed and values obtained under New Guinea conditions are presented and discussed.

INTRODUCTION.

THIS paper is a summary of papers by Hart and Southern[1] and Southern[2] which are being published in the form of a research bulletin in the near future. The bulletin describes in detail chemical and field work which has been carried out in connection with Arabica coffee nutrition during the past four or five years.

Research on coffee nutrition is still in the preliminary stages in New Guinea. The main aim of the research is to be able to determine the nutritional status of coffee under widely divergent soil and climatic conditions and cultural treatments, to assess the fertilizer requirements and to recommend type and quantities of fertilizers for particular areas.

The methods used in this research are those in general use throughout the world and involve field, laboratory and basic physiological and nutritional studies. Co-ordination of these diagnostic methods is necessary to achieve the most accurate results.

This paper deals in particular with foliar analysis methods and their association with field data and field fertilizer trials. It suggests how plantation managers may obtain technical advice on the nutritional status of their coffee by the means of foliar analysis.

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FIELD METHODS.

Field surveys.—The existence of a nutritional problem can first be established from an examination of coffee areas. Low production, stunted growth, defoliation, die-back and occurrence of deficiency symptoms are some of the results of poor nutrition which may lead to an investigation. If pathological, entomological, environmental or genetical causes can be eliminated, the most likely causes are nutritional or physiological, at times aggravated by poor management, e.g., too much competition, too much or too little shade, wrong use of fertilizer, poor pruning, etc. Providing no poor drainage or drought is present as a limiting factor, the possibility of soil deficiencies, toxicities or nutritional imbalances can then be investigated.

Major infestations of disease or insects have not occurred in the main Arabica coffee areas of New Guinea and field establishment and production problems are mainly associated with soil factors and cultural treatments.

The recognition of deficiency symptoms is a very useful method of diagnosing soil deficiencies. All the essential nutrients, under conditions of seriously inadequate uptake, will produce typical symptoms in the foliage or other organs of coffee trees which can often be recognized in the field.

The visual method is essentially qualitative. For most deficiencies, symptoms do not occur unless deficiency is acute and before this happens, yields and growth may be profoundly affected. The degree of severity of symptoms may indicate whether heavy or light applications of a particular fertilizer are necessary but in general a more quantitative method is necessary for assessment of fertilizer requirements.

Visual symptoms of deficiencies are fairly easily confirmed by chemical analysis of leaves or other plant parts as they are obviously associated with very low uptake of the deficient nutrient.

Symptoms of deficiencies of nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron and zinc have all been recorded as occurring in Arabica coffee in New Guinea. In most cases these symptoms have been confirmed by foliar analysis.

No symptoms of toxicities have been recorded although chemical analysis shows an excessive uptake of some nutrients on occasions.

In some instances, growth and symptoms on associated shade trees, cover crops and other plants in the area may give information on possible deficiencies. However, when symptoms are not recognizable or when poor growth and production occur without typical effects, other methods must be used for diagnosis.

Confirmation trials.—Simple observational trials are often useful in confirming the diagnosis made by visual or laboratory methods. Thus in parts of New Guinea quick responses to the element sulphur have been obtained after a preliminary diagnosis had been made following a field survey and foliar analyses. Micro-nutrient deficiencies in particular can be most efficiently confirmed by application of deficient nutrients in the form of foliar sprays.

Fertilizer trials.—A comprehensive series of field fertilizer finals are at present in progress in the Highlands of New Guinea. Most of these are located at Aiyura in the Eastern Highlands but others are being conducted at Goroka and Mount Hagen.

Both diagnostic and rate of application trials are in progress and these have been useful in establishing the fertilizer requirements in these particular areas. Obviously they are the ultimate method for the precise determination of requirements and particularly in determining the economics of fertilizer application. However, field trials on long-term tree crops are often complicated, expensive and may take many years to yield positive results. The average coffee plantation would not have the facilities to carry out such trials with the necessary precision.

A great disadvantage of these trials in particular areas of New Guinea is that results cannot be directly applied to other localities nor even to areas adjacent to the trial. Thus at Aiyura the response to potassium appears to vary greatly throughout the experimental station. Some other agronomic trials, e.g., shading, mulching, pruning and variety trials are more easily extrapolated to areas of similar climate and elevation, but soil fertility is extremely variable throughout the Highlands and dependent on factors such as previous vegetation and land use, age of crop and previous soil treatments. In nutritional studies field trials can provide information on suitable levels of fertilizer applications and frequency—quantity programmes, but to apply the results more universally another yardstick such as foliar analysis must be used. It is in the application of fertilizer trials results by foliar analysis methods and the use of critical leaf levels determined from such trials that most of the chemical diagnostic work in Papua and New Guinea has been concentrated. This work will be discussed in the section under foliar analysis.

GLASSHOUSE STUDIES.

Basic physiological studies are being undertaken using sand culture experiments in the glasshouse and under open conditions. To date, most of this work has been in the production of typical deficiency symptoms. The analysis of leaves from deficient plants has given important data on the leaf nutrient composition as related to the severity of symptoms and the effect of a deficiency of one nutrient on the content of others. Other experiments which involve the use of pot tests and short-term indicator plants will be used in part confirmation of chemical and field diagnosis.

It is also proposed to study the effects of shade on the uptake and utilization of nutrients in sand culture experiments.

LABORATORY METHODS.

Soil analysis.—The coffee soils in New Guinea are very variable in the constituents which largely determine their chemical fertility. It has been found from the analysis of a large number of samples collected during Hart's survey[3, 4] that many soil analytical measurements bear little relationship to either plant performance or the uptake of nutrients as determined by foliar analysis.

Soil analysis is useful for the initial appraisal of virgin soils and their long-term potential, but is of limited use by itself in assessing the fertilizer needs of growing and producing coffee. The measurement of soil reaction may help to explain the low uptake of some nutrients, e.g., micro-nutrients. It has been found that the phosphorus extracted by sodium bicarbonate correlates quite well with the vigour and rate of growth of young coffee. Determinations of total nitrogen, exchangeable calcium and exchangeable magnesium, specific and constant measurements for a particular soil, have proved of little value in assessing the current nitrogen, calcium or magnesium status. The exchangeable potassium content if high, usually corresponds to a high uptake of potassium, but if low, does not always indicate potassium deficiency. The C/N ratio, if abnormal, has occasionally been able to explain the lack of mineralization of nitrogen and consequent deficiency of this element.

Analysis of New Guinea coffee soils is only able at the best to differentiate between high and low amounts of available nutrients. It would require much correlation of soil analysis figures with field responses on a particular soil type before the degree of fertilizer response could be confidently predicted. This has been accomplished to a certain extent in Europe and the United States where soil analysis or testing is successful on large areas of fairly uniform soils.

It is important to realise that it is not only the absolute or extractable nutrient content of soil particles which determines the availability of nutrients to plants. The texture of the soil and other physical characteristics determine whether the nutrients are going to come into the range of plant roots. The soil/plant moisture relationships may determine whether nutrients will be taken up by the plant. The requirements of the plant will depend on light, temperature and the age and condition of the plant. The chemical balance of nutrients in the soil will also affect the uptake into the plant.

It is therefore quite clear that soil analysis will only achieve a high degree of correlation with plant performance and nutrient uptake if these other factors are fairly constant, i.e., a uniform soil type and uniform growing conditions. It is not surprising that there have been many cases where poor growth cannot be explained by soil analysis and others where healthy coffee with normal leaf contents is growing on soils containing extremely low amounts of essential nutrients as determined by the usual soil analytical methods.

Foliar analysis.—There is no doubt in the minds of research workers in the field of coffee nutrition that foliar analysis is the most convenient and precise method for the determination of the nutritional status of coffee plants growing in widely scattered areas. This method of studying nutritional problems and fertilizer requirements depends on a close relationship between the amounts of nutrient available or supplied, the leaf content of the nutrient and the yield of crop. It therefore uses the plant itself as the extracting agent for the soil nutrients.

There is already a substantial bibliography of research work on coffee nutrition which utilizes foliar diagnostic techniques, both in the confirmation of leaf symptoms and in the assessment of nutritional status by the "critical level" concept.

The critical level has been defined by Prévot and Ollagnier[5] as the percentage of an element in a leaf below which the application of this element in mineral manure form is very likely to increase the yield. Malavolta *et al.*[6] have modified this definition to allow for an economic factor and have defined their critical level as the level of a given element in the leaf which will indicate that further use of fertilizer is no longer economic. Thus the second type of critical level is likely to be somewhat lower than the first.

These critical levels are calculated from the results of many experiments and it is a tribute to the accuracy of this line of approach that coffee research workers have proposed similar critical levels despite the fact that a number of varieties of Arabica coffee are grown and soil and climatic variations are large. It is not likely however, that critical level values which sharply separate the adequate contents from the deficient contents will ever be precisely determined because of many other factors and variables. Thus it would perhaps be better to select a "critical range" which would allow for these other variables.

Nevertheless, research workers usually group the leaf contents they have obtained into three classes, viz., deficient, adequate and excess or high. The critical level should be the point which separates the deficient range from the adequate range, but most workers have not been able to suggest a precise critical level.

The accuracy of leaf content interpretation is limited by several important factors and these have been discussed in relation to New Guinea conditions by Southern and Hart.[1 2 4] It is important to realize that while leaf contents in general are a reflection of the fertility of the soil, other growing conditions affect the uptake and assimilation of nutrients to the leaves sampled. The moisture conditions in the soil, which are mainly determined by rainfall and soil physical characteristics, but which can be controlled to a certain extent by soil treatments such as mulching, shading, cultivation and weed elimination, are vitally important in nutrient uptake. The requirements of the plant must also be borne in mind. These vary according to such factors as light intensity, age and stage of growth, particularly whether coffee is in the vegetative or reproductive stage.

It is obvious also that leaf sampling must follow a standardized technique so that leaves of similar physiological age and condition can be selected for comparision. Nearly all coffee research workers select the third or fourth leaves for analysis and their classifications of leaf contents are based on these samples. It has been shown that there are few differences in chemical content between third and fourth leaf samples. Another factor which must be considered in interpretation of leaf analyses is the effect of nutrient interaction in soil/plant relationships. Thus under potassium deficient conditions there is a strong tendancy for coffee plants to absorb magnesium and vice versa. Often a deficiency of a particular nutrient will affect the absorption or translocation of others. In the case of serious deficiency stunting of plants and leaves may occur which will have the effect of concentrating other nutrients.

In Papua and New Guinea studies have been made of the effect of sampling position on the chemical content of the leaves, nutrient interactions, seasonal variations in leaf content which are mainly caused by climatic conditions, particularly rainfall, and consequent flushing and production cycles.[2] All chemical determinations have been closely linked with field data.

Malavolta *et al.*[6] and Lott *et al.*[7] have summarized published results on leaf analyses in coffee and from these results and our own experience a tentative classification of leaf levels for New Guinea conditions has been proposed. A large amount of chemical work has been carried out in New Guinea in association with coffee fertilizer experiments[2] and a survey of plantations has been made[3 4] concentrating on the foliar analysis approach.

The proposed classification has thus taken into account the following :—

- Leaf contents determined as deficient, adequate and excess by other research workers.
- Leaf contents associated with fertilizer responses or lack of them in trials conducted in Papua and New Guinea.
- Leaf contents associated with healthy, productive coffee on plantations.
- Leaf contents associated with poor growth and particularly leaf symptoms.

Table 1 shows the proposed leaf content standards for five major nutrients in third leaf samples of New Guinea Arabica coffee. A subnormal or "possibly deficient" range has been included to cover the range of contents in the doubtful category. In this class serious deficiencies and visual symptoms are not likely to occur but production and growth may still be somewhat below optimum. Interpretation of values would have to take into account other factors but in most cases trial applications of fertilizers could be recommended.

Insufficient data for trace elements and sulphur is available to classify these nutrients in a similar system. At present the levels of adequacy chosen by Lott *et al.*[7] are used as a guide and these are tabled by Southern.[8]

It is emphasized that these classifications are tentative in nature and are likely to be modified when more data has been obtained to correlate the field and laboratory data.

Some brief comments on the individual nutrients that have been studied are as follows :—

Nitrogen.—No significant yield increases have yet been obtained to applications of this nutrient in the trials conducted but leaf contents are above

Table 1.—Proposed Leaf Content Standards for New Guinea Arabica Coffee (3rd Leaves).

Range.	Per cent. N.	Per cent. P.	Per cent. K.	Per cent. Ca.	Per cent. Mg.	Comments.
Above Normal	3.4	0.19	2.6	1.6	0.7	Indicate a possiblity of toxicity or a high content of a nutrient due to another deficiency.
Subnormal	2.2-2.6	0.10-0.13	1.4-1.8	0.4-0.6	0.3-0.4	Normal range of leaf contents for adequate and balanced nutrition. Current nutritional status good and present fertilizer programme adequate. If fertilizer not used, no responses likely at this stage.
Normal	2.6-3.4	0.13-0.19	1.8-2.6	0.6-1.6	0.4-0.7	Indicates possibility of deficiency but analyses dependent to some extent on shade density, climatic conditions, etc., and condition of trees, e.g., flowering, ripening crop, dormant period. Responses to fertilizers containing subnormal nutrients likely.
Deficient	2.2	0.10	1.4	0.4	0.3	Indicates inadequate or unbalanced nutrition. Serious deficiencies likely. Symptoms often present. Treatment necessary and good responses likely.

2.6 per cent. N for the greater part of the year and often exceed 3.0 per cent. N. There is no doubt, however, that nitrogen deficiency occurs on many plantations and typical deficiency symptoms have been associated with leaf levels of 1.8 to 2.3 per cent. N. Such deficiencies almost always occur under conditions of low shade density.

It is fairly common for yellowing of leaves to occur during the later stages of ripening of a heavy crop. In such cases leaves from non-fruitful branches will have higher nitrogen contents than leaves from branches bearing fruit. The leaves adjacent to coffee berries will lose nitrogen to the fruit and will consequently often turn yellow. Other nutrients, for instance the mobile nutrients, potassium and magnesium may be similarly affected, particularly if the soil cannot supply sufficient nutrients at that stage. Because of these effects, samples of third leaves from non-fruitful branches are usually selected in the standard techniques.

Phosphorus.—Leaf contents have varied between 0.08 per cent. and 0.24 per cent. P. Some deficiency symptoms have been found at this lower level. Mature coffee appears to be able to extract its phosphorus requirements from soils judged low in available phosphorus content and most leaf contents are above 0.13 per cent. P and in the normal range. In one fertilizer trial at Aiyura a phosphorus response has been obtained in mature coffee and here untreated plots have a leaf content varying between 0.11 per cent. and 0.14 per cent. P throughout the year. This is also the only trial where phosphorus treatments have given a significant rise in leaf phosphorus contents.

Potassium.—Considerable success has been achieved in the establishment of the critical level for this nutrient as many of the fertilizer trials are situated on soils where potassium deficiency is the main limiting factor. Under these conditions it has been possible to correlate the annual average leaf contents of potassium with yield responses in the period following sampling. The leaf contents also correlate with the amount of potassium added. Thus no significant responses and little evidence of increased uptake have been obtained when leaf levels are 1.8 per cent. K or higher. Based on experimental results, a summary (*Table* 2) has been prepared of the responses in yield likely and the approximate fertilizer applications necessary to produce maximum yields when the leaf potassium contents are at particular levels and it is known that potassium deficiency is the main

Table 2.—Proposed Leaf Potassium Categories and Fertilizer Requirements, New Guinea Arabica Coffee.

Average Leaf Values per cent. K.	Approximate per cent. of maximum yield likely, assuming K the main limiting factor.	Approximate Amount of potassium to be applied to mature coffee to produce maximum yields, lb. per acre per annum.
Over 1.8	90-100	0-60
1.5 to 1.8	75-90	60-120
1.3 to 1.5	60-75	120-180
1.0 to 1.3	40-60	180-240
0.7 to 1.0	25-40	240-360
less than 0.7	0-25	over 360

limiting factor. These figures apply to New Guinea soils and are taken from the paper by Southern.[2]

Many coffee plantations in New Guinea are deficient in potassium. Symptoms of potassium deficiency have been found associated with leaf levels of 0.8 per cent. K or less. The leaf content of magnesium is invariably high under conditions of potassium deficiency found in New Guinea and it is usually only when the potassium leaf contents are high that magnesium uptake is low and deficiency symptoms of the latter nutrient occur.

Calcium.—The leaf contents of calcium vary in the range 0.6 per cent. to 1.8 per cent. Ca. They are dependent to a certain extent on potassium nutrition and uptake. No fertilizer responses to calcium have been obtained, but a few cases of suspected calcium deficiency symptoms have been associated with low leaf levels (about 0.6 per cent. Ca).

Magnesium.—Deficiency symptoms of this nutrient are common in New Guinea but no yield responses have yet been obtained in the fertilizer trials conducted. This is due to the low potassium status of most of the trial areas which causes a high uptake of magnesium. This antagonism with potassium is very strong in Arabica coffee.

Magnesium deficiency usually occurs in coffee of high potassium status due to a high content of available potassium in the soil or the use of fertilizers containing a high proportion of potassium but no magnesium. The typical interveinal chlorosis caused by magnesium deficiency usually starts occurring at about the fifth or sixth leaf position on the branch, gradually becoming more severe with age. The condition is usually most severe when the crop is ripening.

Analyses of the seventh leaves show that these leaves are preferable to third leaves for the diagnosis of magnesium deficiency. The third leaves usually have a magnesium content a little below normal while the content in deficient seventh leaves is often less than half the content of non-deficient seventh leaves.

The contents of magnesium in the third leaves have been in the range 0.25 to 1.4 per cent. Mg, the higher figures being obtained under conditions of severe potassium deficiency. Magnesium deficiency symptoms are associated with leaf levels of 0.40 per cent. Mg or less.

Sulphur.—This nutrient is important in the nutrition of coffee in New Guinea and there are many suspected cases of sulphur deficiency. Some of these have been confirmed by field responses. The easily reducible fraction of sulphur (probably all sulphate) is determined in the foliar analysis as this gives a much better indication of sulphur nutrition than the total sulphur content. Determinations of this mobile sulphur fraction were made on samples collected during the plantation survey (Hart[3 4]). Many areas of coffee have leaf contents below 200 p.p.m. Most of these areas are making unsatisfactory growth and symptoms, defoliation and die-back occur. Often the leguminous shade trees are also affected.

Sulphur deficiency and low sulphate sulphur contents are usually accompanied by an excessive uptake of nitrogen, in one case the nitrogen content being as high as 4.5 per cent. N. An inverse nitrogen to sulphur relationship exists in this crop as nitrogen deficiency is often accompanied by high sulphate contents.

The wide use of compound fertilizers with a high nitrogen content but containing negligible amounts of sulphur is probably responsible for inducing or aggravating many cases of sulphur deficiency and usually fertilizer mixtures containing sulphur are recommended.

Micro-nutrients or trace elements.—With the advent of new equipment it is now possible to determine most trace elements on a routine basis and data on these nutrients is accumulating. The estimation of manganese has been carried out on hundreds of samples from all plantations and there is little to suggest that manganese deficiency is likely to be a problem in Arabica coffee. In only a very few cases were leaf contents below 60 p.p.m. Mn. In one trial area manganese contents were greater than 1,000 p.p.m., possibly a toxic level.

Iron and zinc deficiency symptoms are quite widespread throughout the Highland areas. They appear to occur chiefly under conditions of stress, e.g., following pruning or extreme climatic variations. Zinc levels are rather lower than usual, but iron absorption is usually adequate.

Boron deficiency is also thought to occur in some areas and the analyses carried out so far support this view.

No symptoms of copper deficiency as described in the literature have been observed in New Guinea. The lowest leaf content obtained has been 6.0 p.p.m., a content well above the 4 p.p.m. Cu considered by Lott *et al.*[7] to be adequate.

SUMMARY.

Field and laboratory methods for diagnosing nutritional problems are described with special reference to their use with New Guinea coffee plantations. The use of foliar analysis has been discussed in detail as it represents a convenient and fairly precise diagnostic tool which can be used to check the fertilizer programmes of plantations and to suggest modifications where necessary.

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Coffee Nutrition—Part II. Plantation Survey.

GAVIN HART.*

ABSTRACT.

The main findings of a nutritional survey of Arabica coffee plantations in the New Guinea Highlands are presented. Widespread deficiencies have been diagnosed using soil and foliar analysis and field survey methods. The important relations between cultural practices and nutrient requirements have been discussed.

INTRODUCTION.

IN the winter months of 1963, leaf and soil samples were collected from 120 *Coffea arabica* plantations in three districts—Western Highlands, Eastern Highlands and Morobe—in New Guinea. Previously only two surveys had been made of these European plantations.[1 2] The first of these[2] provided recommendations on all aspects of coffee production. At this time (1956) the coffee industry was in its infancy and the majority of the present coffee had not been planted. It is understandable, therefore, that some of the predictions of this report have not eventuated and, in particular, coffee soils have proved to be more fertile than this report implies. The second survey[1] was essentially concerned with obtaining " factual, economic information " and reporting " upon the capital investment required for establishment of an efficient coffee plantation in Papua and New Guinea " and contributed few cultural recommendations.

The latest survey was specifically nutritional. Although general data about the plantations were collected, the main purpose was to provide a basis for advice on the use of fertilizer. A technical report of this survey and other coffee nutritional work will be published in a research bulletin.[3] The purpose of this paper is to summarize this bulletin and outline its practical implications.

CULTURAL PRACTICES.

The term coffee nutrition is not synonymous with soil nutrient supply or fertilizer practice. Many other cultural practices such as shading, mulching and pruning exert a strong influence on coffee nutrition.

Most plantations in New Guinea utilize temporary and permanent shade. The shade requirement varies greatly both between and within districts and this may be one reason why unbalanced shade/fertilizer programmes are not uncommon.[3]

Shading requirements and practices in the Wau Valley are distinctly different from those in the Central Highlands. In the Wau Valley *leucaena leucocephala* (formerly called *L. glauca*) flourishes (altitude 3,500 ft.) forming an overhead canopy and providing excellent shade. It is difficult to envisage a more suitable shade tree under these conditions. In the Central Highlands *leucaena* is used with some success on a few plantations. However, the higher altitude (5,000 ft.) results in much slower growth and the trees must be planted in a hedgerow system to provide adequate shade. *Albizzia stipulata* and *Casuarina* sp. are the most popular and probably the most suitable species in this region. *Albizzia stipulata* is favoured in most areas, but *Casuarina* is preferred and is probably more satisfactory in some drier regions. Much has been written about the relative merits of these two species but few, if any, scientifically supported facts have been presented. The two most significant attributes cited are that *Albizzia stipulata* defoliates under very dry conditions and that *Casuarina* has a short life span. While both these facts have been demonstrated in many cases they are far from universal attributes so that the ultimate decision on which shade tree to use depends mostly on the characteristics of the particular locality being considered. Problems of management for both *Albizzia* and *Casuarina* are much greater than for *Leucaena.*

Crotalaria anagyroides is the most commonly used temporary shade tree and this appears to be

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quite satisfactory. Bananas although widely used cannot be recommended. When planted close enough to effectively shade the coffee they rob the soil of large quantities of moisture and nutrients. When planted further apart they offer inadequate shade for the young coffee. Use of *Tephrosia candida* is inadvisable as it competes strongly with the coffee for moisture.

Several of the advantages of shade trees can be obtained by heavy mulching. One factor vital to satisfactory coffee nutrition is adequate moisture conservation and this is achieved at least as efficiently by mulches as by overhead shade. If the seedlings used are healthy, are hardened off in the nursery and provided with a good mulch in the field, temporary shade may not be necessary in some areas where rainfall is high (about 100 in.) and ample cloud cover exists. It is doubtful, however, if there are many areas in New Guinea where it is desirable to grow bearing coffee without some form of permanent overhead shade.

Increased light intensity generally increases nutrient requirement and uptake and tends to produce more crop. Thus coffee grown in the full sun requires a greater supply of most nutrients and particularly nitrogen, to maintain it in a healthy state. Nitrogen deficiency usually occurs under such conditions and can be alleviated by increasing either shade or fertilizer applications. Under dense shade nutrient uptake is greatly reduced, more foliage is produced and crop production becomes minimal. Under these conditions fertilizer application will not be advantageous. As shade is reduced, more nutrient is required and greater responses to fertilizer can be expected. It is of great importance to appreciate that the likelihood of responses to fertilizer is reduced as the amount of shading increases. Even though some form of shade is desirable, overshading is economically detrimental.

Shading must also be designed with reference to the pruning system used. For a progressive multiple stem type of pruning, which has been widely and successfully used and appears to be the system of choice, it is desirable to have flexible verticals (which bend over readily) in the early stage of growth. This is readily achieved with a good shade cover whereas sun-grown coffee develops a stocky habit with rigid verticals and these may split from the main trunk when forced apart.

SOILS.

For coffee growing, "satisfactory soil structure with sufficient aeration and organic content and good drainage are important so that a deep topsoil with a porous sub-soil is desirable".[3] It is very important to draw a sharp distinction between soils which become easily saturated with water due to their fundamental structure and those which are waterlogged due to topographical position, e.g., some swamps. While the former are to be avoided where possible the latter are often favourable for coffee growing. These soils are deep and porous and the problem is to divert catchment from the adjacent hillsides, removing excess water in the soil and increasing soil aeration. Experience has shown that after surface water has been removed it often takes one or two years of cultivation before the soil is sufficiently aerated to support good growth. If coffee is planted it often remains dormant for this period. In some areas extensive deep ploughing has been used successfully in this soil conditioning. Planting sweet potato (the actual crop is probably not significant) for one or two seasons also has a beneficial effect. *Tephrosia* has been used to good effect in several areas. If planted after surface water has been removed, the penetrating root system and rapidly growing plant greatly increase the rate of drying and aeration of the soil. The one or two year old bushes can then be turned into the soil and coffee planted. Under these conditions it is possible that the *Tephrosia* can be used as temporary shade. It has been used successfully on some plantations but insufficient evidence is available for it to be recommended as a standard practice.

When waterlogging occurs due to a heavy clay sub-soil there is little hope of economic correction. These areas should be avoided in planting programmes. Much of the central part of the Wau Valley (*Figure* 1) is rendered unsuitable for coffee for this reason. It must be stressed that fertilizer application on these areas will not improve the coffee and application of other cultural practices will be equally unrewarding. With our present knowledge we are unable to offer an economical solution to this problem.

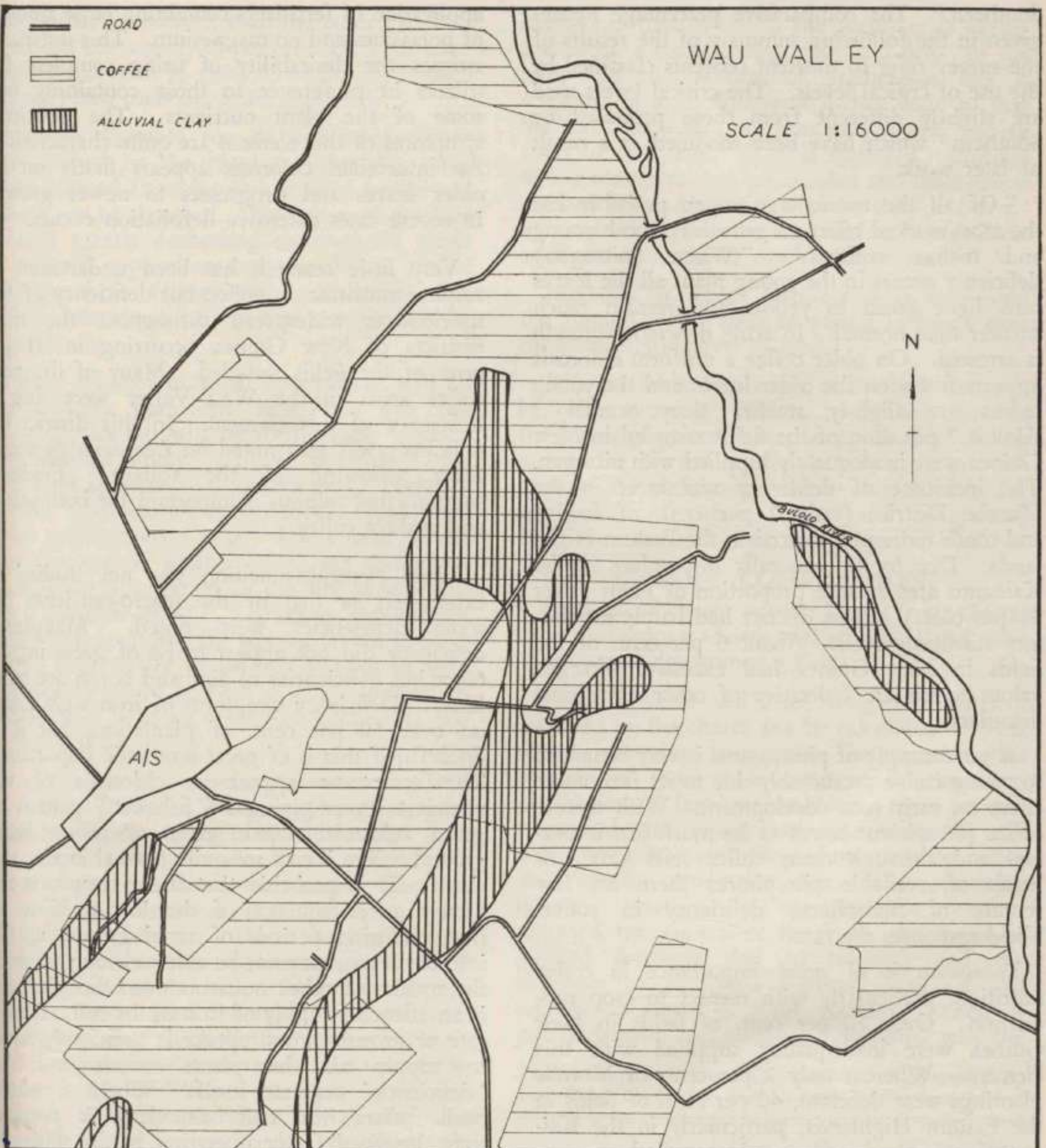

Figure 1.

PLANT NUTRIENTS.

Coffee requires a good supply of both macro-nutrients (nitrogen, phosphorus, potassium, calcium, magnesium and sulphur) and micro-nutrients or trace elements (manganese, iron, boron, zinc, molybdenum and copper). *Table* 1 shows the amounts of the macro-nutrients in various parts of the coffee bush.

The nutritional status of the coffee plantations in the survey has been assessed by methods outlined in the preceding paper by Southern[4] and which have been discussed in detail by Hart and

Southern.[3] The comparative precentage figures given in the following summary of the results of the survey refer to nutrient contents classified by the use of critical levels. The critical levels used are slightly different from those proposed by Southern[4] which have been modified as a result of later work.

" Of all the nutrients nitrogen probably has the most marked effect on growth for both young and mature coffee ".[3] " When (nitrogen) deficiency occurs in the young plant all the leaves turn light green to yellow and remain much smaller than normal. In acute deficiency growth is arrested. On older coffee a uniform chlorosis appears firstly on the older leaves and the young leaves are slightly smaller than normal ".[3] Almost 7 per cent. of the fields sampled in New Guinea were inadequately supplied with nitrogen. The incidence of deficiency was rarer in the Morobe District (only 2 per cent. of fields) and much more pronounced in the Eastern Highlands. Due to the generally low values in the Kainantu area a large proportion of fields (over 21 per cent.) in this district had barely satisfactory nitrogen levels. About 6 per cent. of the fields in New Guinea had excessive nitrogen values which are indicative of other nutritional disorders.

A good supply of phosphorus is very beneficial to young coffee presumably due to its favourable effect on early root development. With mature coffee phosphorus seems to be much less important and although many coffee soils have low levels of available phosphorus there are few reports of phosphorus deficiency in coffee. Yield responses are rare.

Potassium is of great importance in coffee nutrition, particularly with respect to crop production. Over 20 per cent. of fields in New Guinea were inadequately supplied with this element. Whereas only 2 per cent. of Morobe plantings were deficient, 40 per cent. of fields in the Eastern Highlands, particularly in the Kainantu area, were inadequately supplied.

Although the calcium nutrition of coffee is not well understood the significant amount in the leaves and cherry suggest that the coffee plant requires a considerable amount of this element.

Magnesium deficiency is widespread throughout New Guinea occurring in 30 per cent. of fields. This high incidence is partly due to application of fertilizers containing large amounts of potassium and no magnesium. This imbalance stresses the desirability of using complete fertilizers in preference to those containing only some of the plant nutrients. The deficiency symptoms of this element are quite characteristic. An interveinal chlorosis appears firstly on the older leaves and progresses to newer growth. In severe cases extensive defoliation occurs.

Very little research has been undertaken on sulphur nutrition in coffee but deficiency of this nutrient is widespread throughout the three districts of New Guinea occurring in 41 per cent. of the fields sampled. Many of the poor coffee areas in the Wau Valley were due to deficiency of this element. In this district the deficiency was also noted on *Leucaena* as a uniform yellowing of the foliage. Evidence suggests that sulphur is important for both young and mature coffee.

Trace element nutrition was not studied as extensively as that of the macro-nutrients but some deficiencies were noted. Manganese deficiency did not appear to be of great importance but deficiencies of zinc and boron are more likely. Deficiency symptoms of iron were noted on over 50 per cent. of plantations but it is doubtful if this is of great economic importance. The symptoms appear as chlorosis of the youngest leaves giving a " fish net " pattern of green veins on a pale green or yellow background. The leaves are quite normal in size and shape. It is probable that these symptoms are merely a consequence of the low mobility of iron. During periods of rapid growth uptake into the leaves may not be able to keep pace with the uptake of other nutrients even though there is an adequate supply of iron in the soil. As the rate of growth slows, uptake is sufficiently rapid to supply all the plants' needs and the 'deficiency' corrects itself. Where a whole bush suffers iron chlorosis, there is possibly some localized factor operating in the soil such as a high pH due to large deposits of ash. It is doubtful if this can be corrected.

FERTILIZER APPLICATION.

Fertilizer use varies considerably throughout New Guinea. Fertilizer rate varies from 0 to 3 lb. per tree per year and applications vary from 1 to 12 per year. Type of fertilizer used is probably more consistent than the other variables as fertilizer containing 13 per cent. N, 5 per cent. P and 17 per cent. K (i.e., 13 : 13 : 21) is used far more often than any other.

It is not possible for all applied fertilizer to be utilized by the plant as invariably some will be leached from the soil or fixed by the soil before it can be absorbed. The degree of wastage will vary greatly depending on methods, times and rates of application and one should aim at adjusting these factors (in accordance with economic considerations) so that wastage will be at a minimum.

A large number of small applications will be more effective than one large one but, the cost of application will be considerably greater. Some planters apply fertilizer monthly while others limit application to once a year. Probably the most satisfactory compromise is from three to four applications a year. The uptake of the major nutrients is greater under wet conditions and fertilizer application in the dry season will have a minimal effect. The main applications should be given during the wet season but in areas with no definite dry season and periods of very heavy rain it might be best to avoid application when rainfall is at its maximum because of the loss due to leaching.

Young coffee, of course, requires less fertilizer than older coffee. When applying straight fertilizers a smaller quantity should be used than with complete fertilizers due to the greater percentage of one nutrient in the former. There is a popular misconception that unhealthy trees need more fertilizer than healthy ones. Unhealthy coffee has a lowered power of assimilation and if the reason for sickness is not nutritional heavy fertilizer application will certainly be harmful. Even if the problem is nutritional it may well be aggravated if an unsuitable fertilizer is used. When a particular deficiency is proven a mammoth dose of a particular straight fertilizer is not to be recommended. Instead the fertilizer being used should be altered to include the nutrients required.

There are several methods of fertilizer application currently used. The desirable characteristics of any method are that it should be cheap to employ and that efficient use be made of the fertilizer, i.e., losses and harmful effects should be minimized. Probably as good as any other method is that in which the fertilizer is evenly placed on a circle around the 'leaf-drip' of the tree. In the process of application this is scattered in a band several inches wide so that the fertilizer is in close proximity to the feeding roots of the plant. If it is scattered uniformly strong concentrations are avoided and toxic effects are not felt. As the tree grows the 'leaf-drip' moves further from the stem and so the fertilizer application is spread over a larger area.

Methods in which fertilizer is thrown onto the foliage of the trees or placed in heaps near the stem should never be used.

It is convenient to apply some trace elements by foliar spraying. This is particularly suitable for the application of zinc as application of this element to the soil is often not effective in overcoming the deficiency. It is also suitable for application of copper, boron and manganese, but iron sprays do not appear to be effective.

CHERRY COMPOSITION.

Samples of cherry were collected from plantations and from a variety trial at Aiyura and their composition determined (*Table* 2).

From *Tables* 1 and 2 the amount of nutrient removed by the cherry can be calculated. "It is faulty reasoning to assume that because this amount of nutrient is removed by the crop, application of fertilizer containing these proportions and total amount of nutrient to the soil will restore the *status quo* and maintain the coffee in a healthy productive state. This reasoning ignores, among other factors, the nutrient required for growth of the bush, the losses of applied fertilizer due to leaching and the existence of equilibria between available and unavailable forms of some nutrients. There is no fundamental physiological reasoning why the

***Table* 1.—Approximate Composition of Leaves, Pulp and Bean of *Coffea arabica* and *Coffea canephora*.**

—	N.	P.	K.	Ca.	Mg.
Coffea Arabica—					
Leaves	3.0	0.15	2.0	1.00	0.40
Pulp	2.0	0.14	3.8	0.50	0.12
Bean	2.2	0.20	1.7	0.15	0.20
Coffea Canephora—					
Leaves	3.2	0.15	2.0	1.50	0.45
Pulp	2.2	0.11	3.1	0.44	0.08
Bean	2.5	0.20	2.0	0.26	0.24

Table 2.—Composition of Mature Cherry of *Coffea arabica* (from plantations), *Coffea canephora* and varieties of *Coffea arabica* at Aiyura.

——	Per cent. Moisture.	Per cent. Pulp.	Per cent. Bean.	Per cent. Mucilage and Husk.	Cherry Size (No. IKg.).	Bean Size (No. Ig.).
Coffea Arabica (12 samples)—						
Range	62.9-72.6	6.2-11.8	14.4-18.9	5.4-7.6	435-628	5.90-7.69
Average	70.0	7.5	17.0	5.5	555	6.45
Coffea Canephora (2 samples)—						
Average	61.5	11.0	20.0	6.3	554	5.40
Aiyura Variety Trial—						
Mocha	71.6	6.8	14.8	5.8	478	6.45
Arusha	73.1	7.6	13.9	5.4	395	5.71
Blue Mountain	71.7	7.2	15.8	5.3	435	5.48
Bourbon	71.5	8.1	15.2	5.2	480	6.30
Maragogipe	72.4	7.6	14.7	5.3	340	4.60
San Ramon	72.7	7.0	15.0	5.3	443	5.88

proportion of nutrients removed in the crop should bear a close relationship to the proportion of these nutrients required in the soil for optimum growth by the coffee. In any case, the proportion of nutrients applied to the soil in a fertilizer will not usually correspond to the proportion of nutrients which subsequently become available to the coffee roots."[3]

The pulp from six tons of cherry (corresponding to one ton of finished coffee) contains approximately the same amount of nutrient as 200 lb. of complete fertilizer. The wet weight of this pulp will be approximately one ton. "In short, 11 tons of wet pulp contain about the same amount of nutrient as one ton of complete fertilizer. Of course, the nutrients in the pulp are not as readily available as those in the fertilizer and the application of 11 tons of pulp to the soil will have a quite different effect from the application of one ton of fertilizer."[3]

CONCLUSIONS.

There are fewer nutritional problems in the Wau Valley than the Central Highlands. Sulphur deficiency, however, is common and application of this nutrient is essential to the maintenance of production. Sulphur can be conveniently applied as the element or as ammonium sulphate, potassium sulphate, gypsum (calcium sulphate) or magnesium sulphate (Epsom salts). The last is particularly suitable as the magnesium content of most coffee in the Wau Valley is low. The alluvial clay in the central part of the valley is not conducive to coffee growing and time and expense should not be wasted in an attempt to produce coffee on this soil.

Both the nitrogen and potassium content of much of the coffee in the Kainantu area are below normal and some revision of cultural practices in this region is desirable. Undershading and defoliation of shade trees contribute to this unfortunate position There are three major ways by which the harmful effects of this phenomenon can be countered or at least diminished—replacement of shade with another species, increased fertilization (particularly nitrogen) and mulching. The replacement of shade trees is possibly not a very practical solution but defoliation is a characteristic which should be given full consideration when the shade tree species is intially chosen. Fertilizer application will assist coffee to withstand the conditions of exposure which result after defoliation of shade trees. It is generally of little use fertilizing after defoliation has commenced as this usually occurs in marked dry periods when nutrient uptake will be minimal. Since it is not possible to accurately predict when such times of extreme stress are likely to occur, it is necessary to maintain the coffee in a healthy condition so that it is more likely to withstand such periods. The benefits of mulches in these drier areas are not widely appreciated. The conservation of moisture by mulches and the remarkable effect this has on coffee in dry periods have been clearly demonstrated. Mulches not only assist the coffee to withstand exposure but they tend to reduce defoliation of shade trees which makes the exposure less severe. If maintaining a thick mulch throughout the year appears too expensive a heavy mulch (about 1 ft. deep) should be applied uniformly over the coffee block at the beginning of the dry season. Mulching should have additional benefits on soil structure in areas such as Kainantu where the lateritic soils become very hard on exposure to sun and rain. In dry areas where large returns are expected from mulching the claim that it is an expensive practice is a feeble argument. By this reasoning shade trees, fertilizer and labour might be dispensed with, for are not these also expensive commodities of management ? Some planters ask " Can we afford to mulch ? " when the question should really be, " Can we afford not to mulch ? ", for there are some regions where rejuvenating nutritionally weak coffee will be a long and difficult process, even with extensive fertilizer use, unless mulching is used.

On some plantations irrigation is used to counter dry periods. This, of course, is very satisfactory but indiscriminate and excessive irrigation can do more harm than good. It is preferable to use infrequent soakings rather than maintain a steady flow onto the coffee. The latter tends to favour leaching and water-logging on imperfectly drained soils so that unsatisfactory aeration exists.

In assessing precise fertilizer requirements each planting should be considered individually but there are some features of fertilization which have widespread application throughout the three coffee growing districts in New Guinea. Inclusion of sulphur and magnesium in all fertilizers used appears a wise practice. Whereas the effects of magnesium deficiency are generally not noticed until production begins sulphur deficiency frequently prevents suitable growth of young and old coffee alike. The application of a single compound as a fertilizer (straight fertilizer) is not recommended as imbalance is readily produced with other nutrients. It is unfortunate that the so-called " complete " fertilizers are not literally complete as they often do not contain all the essential nutrients. For instance the majority of fertilizers contain neither magnesium nor sulphur. Both these nutrients occur in magnesium sulphate (Epsom salts) and this compound can be used in combination with a complete fertilizer to provide a suitable nutrient supply to most New Guinea coffee.

In the Wau Valley it is doubtful if young coffee needs fertilizer, except in a few regions where sulphur alone could be applied. In the Central Highlands fertilizers for young coffee should contain large amounts of nitrogen and phosphorus and some sulphur. Throughout the three districts fertilizers for mature coffee should contain nitrogen and potassium in large amounts (10 to 20 per cent.) and also magnesium and sulphur. Although trace elements have not been extensively studied there is sufficient indication to recommend use of fertilizers containing all trace elements as a wise practice.

(Received February, 1965)

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Coffee Nutrition—Part III.
The Sampling of Coffee Leaves for Chemical Analysis.

P. J. SOUTHERN.*

ABSTRACT.

A description is given of the method used in Papua and New Guinea for the collection of foliar samples for analysis of essential nutrients. It is stressed that comprehensive field information describing the sample area is essential for accurate interpretation of foliar analysis results and the type of information required is outlined in the paper.

MOST Arabica coffee plantations in New Guinea use considerable amounts of fertilizers each year in their coffee. In general compound fertilizers are used and rates of application vary from a few ounces per bush once a year, to 3 lb. per bush by means of monthly applications.

The preliminary survey of Highland Coffee plantations by Hart [1] showed that there was a great variation in the nutritional status of coffee and the fertility of plantation soils and consequently the requirement for fertilizers was also very variable. The use of fertilizers was seldom based on the requirements of coffee on the plantations; thus in many cases insufficient nutrients were applied, in others some nutrients were being added unnecessarily.

Hart used field data, soil, and foliar analysis for his survey and plantations have had the benefit of advice based on these methods of fertilizer assessment. However, since then conditions may have changed considerably on plantations and follow-up investigations are necessary. Moreover, the Department of Agriculture's chemical facilities have been improved so that a wider range of analyses, including trace element determinations, can now be carried out on a routine basis.

The analysis of representative samples of coffee leaves is the best available method at present for coffee plantation owners and managers to check on the current nutritional status of their coffee areas and to obtain advice on the use of fertilizers. This leaf analysis service is available from the Chemical Section, Department of Agriculture, Stock and Fisheries, Konedobu, Territory of Papua and New Guinea, which undertakes the analysis and the interpretation of results. At present each coffee leaf sample, if it has been collected according to a standardized technique and is in good condition, is analysed for the essential nutrients, nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, zinc, copper and boron. It is hoped to extend the analytical work to sulphur and molybdenum in the near future.

The use of leaf analysis for determination of nutritional status and assessment of fertilizer requirements is discussed by Southern in this journal.[2] The limitations to the accurate interpretation of the results are fully realized and it is usually not possible to recommend precisely the most suitable fertilizer or the quantities required for application. However, it is usually possible to—

(*a*) Diagnose any serious deficiencies or toxicities.

(*b*) Indicate where applications of particular nutrients are unnecessary or too heavy.

(*c*) Recommend trial applications of subnormal nutrients.

It is obviously essential in such a comparative technique that leaf samples should be collected and treated in the standard approved manner and, if samples are forwarded for examination and analysis, the following method of sampling should be followed :—

* Senior Chemist, Department of Agriculture, Stock and Fisheries, Konedobu, Territory of Papua and New Guinea.

SELECTION OF AREAS.

The coffee plantation is first divided up into a number of areas representing good, moderate, or poor production, or healthy and unhealthy growth. Each area selected should be uniform with respect to soil type, age and condition of plants, variety grown, fertilizer, shade or management treatments. At least one area representing the best coffee on the plantation should be included. On plantations with very uneven growth, as many as twelve areas could be selected.

From these larger areas, representative smaller areas should be selected ; these should become permanent sampling areas and might be from one-half to one acre in size. These areas should not be situated close to a plantation road to avoid possible contamination with dust.

COLLECTION OF SAMPLES.

A leaf sample will only be representative of the trees from which it is collected and therefore these trees must be representative of the sampling area. To sample the areas as selected above it is necessary to select 30 to 50 trees well distributed throughout the sampling area. This can be carried out by sampling along the diagonals of the area in an X pattern, but any method which will ensure a random sampling is satisfactory. The minimum size of a leaf sample should be 120 leaves consisting of two pairs of leaves from the 30 randomly distributed trees but it is more satisfactory to collect from 50 trees, making a total of 200 leaves. The leaves selected are the third pairs from the apex or tip of lateral branches on opposite sides of the tree. Outside branches, midway between the ground and the top of the tree, are used. The first leaf pair, or end leaves, are only counted as leaves if they are more than 2in. long. New vertical shoots should not be sampled and branches carrying large numbers of berries should also be avoided. Samples should be collected before 11.00 a.m.

Normally the third leaf pairs are sampled ; however, if symptoms of chlorosis or yellowing are occurring on other leaves of the bushes, these leaves can be sampled (separately), providing another sample of leaves from an area without symptoms is also sampled. The leaves from this healthy area should be of the same age as those from the unhealthy area. It is often an advantage to collect a small sample of typically chlorotic leaves for visual diagnosis.

The separate leaf samples are air-dried to remove dew, rain or surface moisture and then placed in paper bags, or alternatively rolled in sheets of newspaper. Plastic bags should not be used.

CONSIGNMENT OF SAMPLES.

The leaf samples should be forwarded immediately to the Principal Chemist, D.A.S.F., Konedobu, and should be marked "URGENT—COFFEE LEAF SAMPLES". It is essential that they reach the laboratories within four days or the samples will start to deteriorate and lose weight. Telegraphic advice of despatch will ensure that there is no delay in receipt.

FIELD INFORMATION.

It is of the utmost importance to forward the fullest possible information on the areas sampled. The information required is as follows :—

(*a*) Name and address.

(*b*) Altitude of plantation.

(*c*) Date of sampling.

(*d*) Location and marks on container.

(*e*) Preceding type of land use (e.g., forest, grassland, gardens).

(*f*) Variety used.

(*g*) Age of trees (years).

(*h*) Approximate production per acre.

(*i*) Shade (type and approximate density).

(*j*) Ground cover (e.g., bare, mulch, weeds).

(*k*) Condition (e.g., flowering, fruiting, ripening crop, dormant, newly pruned).

(*l*) Pruning and spacing.

(*m*) Soil conditions (e.g., clay, loam, sandy, hard pan).

(*n*) Drainage (e.g., good, poor).

(*o*) Soil moisture (e.g., very wet, moist, dry).

(*p*) Topography (e.g., flat, hilly).

(*q*) General condition of trees (e.g., poor, mediocre, healthy).

FOLIAR ANALYSIS REPORT—ARABICA COFFEE, 3rd LEAVES

NAME.. ADDRESS.. DATE SAMPLED..............................

NUTRIENT CONTENT		%N	%P	%K	%Ca	%Mg	p.p.m. S	p.p.m. Mn	p.p.m. Fe	p.p.m. Cu	p.p.m. Zn	p.p.m. B	p.p.m. Mo	RECOMMENDATIONS
Indicates a possible toxicity, or a high content of a nutrient due to another deficiency.	ABOVE NORMAL RANGE													Use of fertilizers containing above normal nutrients should be avoided
		3.4	0.19	2.6	1.6	0.7								
Normal range of leaf contents for adequate and balanced nutrition. Current nutritional status good.	NORMAL RANGE													Present fertilizer programme adequate. If fertilizer not used, no responses likely at this stage.
TENTATIVE CRITICAL LEVEL		2.6	0.13	1.8	0.6	0.4	200	50	70	4	8	40		TENTATIVE CRITICAL LEVEL
Indicates possibility of a deficiency. Analyses dependent to some extent on shade density, climate, etc., and condition of trees, e.g., flowering, ripening crop, dormant period.	SUB NORMAL RANGE													Fertilizers containing subnormal nutrients likely to give responses in growth and yield, but dependent on growing conditions, e.g., shade, production. Trial applications recommended.
		2.2	0.10	1.4	0.4	0.3	100	25						
Indicates inadequate or unbalanced nutrition. Serious deficiencies likely. Symptoms often present.	DEFICIENT RANGE													Fertilizer containing deficient nutrients should be used. Treatment necessary and good responses likely.

ANALYSIS OF SUBMITTED SAMPLES			%N	%P	%K	%Ca	%Mg	p.p.m. S	p.p.m. Mn	p.p.m. Fe	p.p.m. Cu	p.p.m. Zn	p.p.m. B	p.p.m. Mo
No.	Location	lab. No.												
1.														
2.														
3.														
4.														
5.														
6.														

Note.—1. The current nutritional status is indicated by analysis. Samples should be analysed at regular intervals to give more complete information.
2. Analyses are not likely to represent the true picture if other important limiting factors (e.g., drought, poor drainage, severe disease) are present.

CHECKED

Figure 1.—Foliar Analysis Report.

(*r*) Symptoms on leaves, defoliation, die-back, stunting, disease, insects attack. Performance of other crops. Any other pertinent information.

(*s*) Fertilizer used. Details of type, frequency, quantity, last application.

(*t*) Rainfall, annual.

(*u*) Rainfall, distribution in the two months prior to sampling.

This information is necessarily detailed to aid in accurate interpretation. Questionnaire forms are available which will enable these details to be conveniently recorded.

In addition to foliar analysis, soil analysis is often useful in the diagnosis of nutritional problems and in the determination of soil nutrient reserves. Instructions for sampling soils are also available from the Department.

RESULTS OF LEAF ANALYSES AND RECOMMENDATIONS.

Analytical determinations by modern and accurate methods are carried out for all essential nutrients except sulphur and molybdenum. The results of these analyses are usually available within six or eight weeks.

The results of the analysis are recorded on a printed form (*Figure* 1), which compares the analyses obtained with the classification of leaf analysis contents proposed by Southern [2] for New Guinea conditions. More detailed advice and recommendations accompany the foliar analysis report.

FOLLOW-UP INVESTIGATIONS.

The analysis will only indicate the current nutritional status and plantations are invited to submit regular samples from permanent sampling areas. Information gained from these foliar analyses and field data will provide the most useful information on nutritional status that it is possible to obtain at the present time.

While there is less information available on the use of leaf analysis in connection with lowland coffee (*Coffea canephora*), managers of plantations growing this crop may forward samples collected in exactly the same manner as above.

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A Fertilizer Leaf Spray for Coffee.

R. S. CARNE.*

ABSTRACT.

A trial was conducted on mature Coffea arabica *at Aiyura to determine the effects on yield of fertilizer leaf sprays. 'Sea Magic SM-3' was compared with Urea and a compound fertilizer and the trial extended over three years from* 1961 *to* 1964. *The only treatment to give significant yield increase was the compound fertilizer, 'Nitrophoska Green' with trace elements, applied to the ground.*

INTRODUCTION.

EARLY in 1961 a trial was begun on mature *Coffea arabica* at the Highlands Agricultural Experiment Station, Aiyura, to test the effect of fertilizer leaf sprays on the yield of coffee.

Main interest centred on a proprietary leaf spray known as 'Sea Magic SM-3', manufactured by Chase Protected Cultivation Ltd., England. In order to give a comparison, two other forms of fertilizing were used, one a foliar spray containing Urea and the other a soil application of a compound fertilizer which would have approximately the same cost per acre (landed in the Highlands) as 'Sea Magic'.

MATERIALS AND METHODS.

The composition of materials used and their rates of application are described below.

'Sea Magic' Spray.—This was used at 2 gal. per acre per year, in two applications of 1 gal. concentrate mixed with 80 gal. water, sprayed on one acre of trees each six months. This amounted to about 1½ pints of spray mixture per tree at each application.

Urea Spray.—A Urea concentrate was made up containing approximately the same quantity of nitrogen per gallon as 'Sea Magic', and this was diluted and sprayed on at the same rate as 'Sea Magic'.

Compound Fertilizer.—'Nitrophoska Green' (15 per cent. N, 15 per cent. P_2O_5, 15 per cent. K_2O) at 2 cwt. per acre, plus trace element mixture at 28 lb. per acre, per year were applied to the soil. This treatment also was administered in two applications of 1 cwt. 'Nitrophoska' and 14 lb. trace elements each six months. The trace element mixture contained 5.4 per cent. Mg, 3.4 per cent. Mn, 2.3 per cent. Cu, 1.5 per cent. Zn, 1.4 per cent. Fe, 0.6 per cent. B, 0.4 per cent. Mo, and approximately 12 per cent. S.

The trial was laid down on a block of 'Blue Mountain' variety *Coffea arabica* planted in 1954, spaced on a 9 ft. triangle and pruned to a single-stem system, under *Albizzia stipulata* shade. Design was a randomized block with four replications. Each plot consisted of four rows of 12 trees each, of which only the two centre rows were recorded for yield.

These treatments were continued for three years until mid 1964, when the trial was concluded.

RESULTS.

Yields were recorded over the full period, and a summary is shown in *Table* 1.

Table 1.—Coffee Fertilizer Leaf Spray Trial.

Treatment.	Annual Yields. Pounds cherry coffee from four plots of 24 bushes each. April, 1961-March, 1962.	April, 1962-March, 1963.	April, 1963-March, 1964.	Average Yield. Pounds clean coffee per acre per year.* 1961-1964.
Control—no fertilizer	1,865	1,423	879	1,344
'Sea Magic' Spray	2,316	1,366	1,009	1,513
Urea Spray	1,770	1,498	728	1,289
Compound Fertilizer	2,189	1,987	1,600	1,863
Least difference for significance 5 per cent.	750	350	410	322

* A factor of 15 per cent. was used to convert weights of cherry harvested to weights of clean coffee.

CONCLUSION.

The only treatment to give a significant increase over the control was the compound fertilizer, 'Nitrophoska Green' with trace elements, and it yielded significantly more than all other treatments. Neither 'Sea Magic SM-3' nor the Urea leaf spray gave any significant difference in yield from the untreated control.

(Received January, 1965)

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Single-Stem Pruning of Coffee.

R. S. CARNE.*

ABSTRACT.

A trial to compare several techniques of single-stem pruning of Coffea arabica *was conducted at the Highlands Agricultural Experiment Station, Aiyura, over a five-year period from February,* 1959, *to March,* 1964, *using a field of 'Blue Mountain' coffee planted in* 1954. *The results indicated no significant yield difference between techniques and that there was no advantage in heavy pruning.*

INTRODUCTION.

SINGLE-STEM as a permanent system of pruning coffee is not generally practised in the Highlands of Papua and New Guinea today. However, some plantations have small areas of mature single-stem already established, and other limited areas have been brought into early production by being permitted to grow straight into single-stem, with the idea of converting to multiple-stem after several years' bearing. The trial conducted was intended to discover any yield differences arising from variations in single-stem pruning techniques.

MATERIALS AND METHODS.

The coffee bushes were spaced on a 9 ft. triangle under *Albizzia stipulata* shade, and until the commencement of the trial had been pruned to the single-stem system approximating to treatment number three.

The new pruning treatments imposed on the existing single-stem bushes are described.

Control.—No pruning other than removal of suckers as they appeared at the top of the bush.

Cut head primaries.—Prune top four pairs of laterals only, cutting them back to new growth. Otherwise only cut back skirt growth to clear the ground.

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Single-stem, light.—Remove minimum growth to give orthodox single-stem framework, leaving secondary laterals in pairs.

Single-stem, heavy.—Again orthodox framework, but only one secondary lateral permitted at each node of the primary.

Colombian.—Also known as the umbrella system. In this treatment the upper laterals are allowed to grow unchecked as they curve out and down towards the ground forming a dome-shaped bush. In Colombia, where the system is practised, the lower laterals tend to weaken and disappear, being continually heavily shaded by the overlying branches ; but in this trial several lower laterals were cut out each year to keep the centre of the tree free from congestion. Suckers were removed regularly from the top of the bush.

Treatments were replicated four times in randomized blocks, and plots comprised four rows of 12 trees each, yields being recorded from the centre two rows only.

RESULTS.

Coffee yields over the five-year period on the trial were as in *Tables* 1 and 2, expressed in pounds of clean coffee per acre. A factor of 15 per cent. was used to convert cherry weights to clean coffee equivalent. The 12-month period, April to March, is used for annual production figures.

Table 1.

Treatment.	1959-1960 lb./ac.	1960-1961 lb./ac.	1961-1962 lb./ac.	1962-1963 lb./ac.	1963-1964 lb./ac.	Average five years lb./ac.
No pruning	1,841	1,966	1,841	1,694	1,936	1,856
Cut head primaries	1,849	2,040	2,035	1,383	2,197	1,901
Single-stem light	1,459	1,832	1,804	1,432	2,092	1,724
Single-stem heavy	1,323	1,600	1,820	1,147	2,093	1,597
Colombian	1,513	1,814	1,713	1,374	1,836	1,650

Table 2.—Coffee Yields—Single-Stem Pruning Trial, Aiyura.

Treatment.	Average five years—1959 to 1964. Replicates—				Average lb./ac.
	Rep. 1 lb./ac.	Rep. 2 lb./ac.	Rep. 3 lb./ac.	Rep. 4 lb./ac.	
No pruning	1,806	1,732	1,678	2,206	1,856
Cut head primaries	1,905	2,008	1,661	2,029	1,901
Single-stem light	1,753	1,817	1,382	1,943	1,724
Single-stem heavy	1,659	2,036	1,322	1,370	1,597
Colombian	1,751	2,096	1,470	1,284	1,650

DISCUSSION.

Experiments have been carried out in other countries on the effects of different single-stem methods, and results in both South India and East Africa suggest that optimum yields are obtained with light pruning. In the present trial, although the average yields indicate some differences between treatments, from *Table* 2 it may be seen that there was high variability between replicates of the same treatment. Analysis showed that differences between treatments were not statistically significant. The coffee was too variable for it to be reasonably sure that differences were due to the treatments applied. However, the trial did at least indicate that there was no advantage in heavy pruning. Unless a clear yield improvement could be expected it would not be worth the increased cost involved.

(Received January, 1965)

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