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

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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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