THE NITROGEN, POTASSIUM, PHOSPHORUS, CALCIUM, MAGNESIUM, SODIUM, MANGANESE, IRON, COPPER, BORON, ZINC, MOLYBDENUM, AND ALUMINIUM CONTENTS OF TEA LEAVES OF INCREASING AGE

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In many crops the nutrient contents of the leaves or other organs have been analysed. This is done firstly to determine the actual contents of nutrients and secondly, to see whether fluctuations occur under the influence of differing environmental conditions and cultural practices. For instance, by analysing the N, P and K contents of the leaves and branches of tea plants Eden (1958) was able to calculate how much N, P and K were removed in crop and prunings. In this study the contents of 13 elements have been determined in tea leaves of increasing age. It is well known that the content of elements like N, K and Mg in leaves of other plants decreases with increasing leaf age. The magnesium figures presented in Table 1 were obtained by a spectrographic technique of which the details are not known. Assuming that they are valid then the tea bushes under investigation appear to accumulate magnesium in the old leaves instead of in the young ones. This apparent trend will be studied further because it may be an indication that the plant takes up amounts of magnesium in excess of its requirements. Such a condition is often referred to as luxury consumption and it may well be that too much Mg is applied in the fertilizer mixture.

Introduction

Foliar analysis consists of sampling leaves, analysing them for their mineral constituents, and interpreting the results (Prevot *et al* 1963). Foliar analysis can be a useful tool in furthering fundamental knowledge of plant nutrition, whilst its results may be utilized to recognise or confirm mineral deficiencies, as well as serve as the primary source of information for determining fertilizer practices. The mineral composition of plant tissues is an unstable equilibrium influenced by many internal and external factors. These factors need to be segregated and evaluated in relation to their effect on the nutrition of the plant.

The first step in the use of foliar analysis is to standardize the technique, so that it is possible to get results which can be reproduced. This means that the fluctuations in mineral contents have to be studied in relation to, for instance, age, type and part of the plant sampled, effect of seasonal variations, soil type, time of sampling *etc.* In an attempt to obtain some idea about the fluctuations in mineral content of tea leaves, leaves of increasing age were sampled from two similar clones, grown under differing conditions of shade, fertilizer, soil and elevation. Chemical analysis of the samples was performed by Dr A. L. Kenworthy under the International Plant Nutrition Program. The purpose of this paper is firstly to place on record the analytical results and secondly to discuss the trends obtained in respect of the contents of 13 mineral constituents of leaves of increasing physiological age.

Materials and Methods

1 Field experiments

Leaf samples were taken in two shade *cum* fertilizer trials laid out at St Coombs Estate (elevation 4500′) and St Joachim Estate (elevation 100′) respectively, and planted with TRI clones 2025 and 2023 respectively. These two clones are similar in yield and quality potential (Keegel 1962 ; Richards 1964). Both trials were plucked at weekly intervals, but copper spraying to control Blister blight was done at St Coombs only.

1.1 *St Coombs trial*

This trial was laid out in a randomized block design and consisted of 12 blocks. Four blocks had no shade while eight blocks were artificially shaded so that light intensity was reduced to approximately 60% in 4 blocks and to approximately 40% in the remaining 4 blocks. Each block consisted of 4 plots, *ie* 0 (control), N, K and NK. These treatments received fertilizers at the following rates per acre per annum:

0	=	100 lb N as sulphate of ammonia and 50 lb K_2O as muriate of potash
N	=	200 lb N as sulphate of ammonia and 50 lb K_2O as muriate of potash
K	=	100 lb N as sulphate of ammonia and 100 lb K_2O as muriate of potash
NK	=	200 lb N as sulphate of ammonia and 100 lb K_2O as muriate of potash

50 lb P_2O_5 and 40 lb MgO per acre per annum were applied to all plots. Each plot contained 9 plants (clone TRI 2025). The trial was commenced in April 1962 and leaf samples (100 leaves per sample) were taken from each of the 48 plots on 12th June, 17th July, 15th August and 11th September 1962. The area was planted in June 1954.

1.2 *St Joachim trial*

This trial had the same treatments as that of St Coombs (**1.1**) but consisted of 8 blocks only. Half of these were unshaded, the remaining 4 blocks receiving approximately 70% of the daily sunlight only. The experiment was started in April 1962 and samples (100 leaves per sample) from each of the 32 plots were taken on 25th July, 22nd August, 19th September, 17th October and 14th November 1962. The number of plants (clone TRI 2023) in each plot varied between 10 and 18. The area was planted in March 1956.

2 Sampling Method

Samples (100 leaves per sample) were taken in the morning and dried at 75°-80°C within 24 to 48 hours after they were collected. The leaves sampled were:

F	=	the flush (two leaves and a bud, the parts of the tea bush plucked at each harvesting round)
F+1	=	third leaf on pluckable shoot or the leaf above the fish leaf
M	=	mother leaf from the axil of which the present pluckable shoot has emerged
M+1	=	leaf below mother leaf from the axil of which the previous pluckable shoot has emerged
Mt	=	maintenance leaf, as low down in the bush as possible, but still green (generally between 5 to 10 leaves below the M+1 leaf).

10g of each of the dried and ground leaf samples were put in polythene bags, which were then sealed air-tight. Hence, 4 (plots) × 12 (blocks) × 5 (plant parts) = 240 samples were prepared per sampling date at St Coombs and 4 (plots) × 8 (blocks) × 5 (plant parts) = 160 samples at St Joachim.

3 Chemical Analysis

The samples were analysed at Michigan State University according to the following methods: Nitrogen was determined by the Kjeldahl method, potassium by flame photometery and other nutrients spectrographically using a photoelectric spectrometer, *ie* a quantograph as manufactured by Applied Research Laboratories, Glendale, California, USA. Aluminium, copper and manganese contents of above 1,700, 250 and 1,200 ppm (on dry matter) respectively, could not be determined.

Results and discussion

The age of the leaves sampled was characterized by their position on the bush, the flush (F) consisting of the youngest and the maintenance leaves (Mt) of the oldest plant parts sampled. No attempt was made to estimate leaf age in a time factor, owing to large differences in growth rate in different seasons and on different soils (Hasselo 1964; 1964a). The relation between physiological age of the leaves, so defined, and their nutrient contents is shown in Figures 1-4. The nutrient contents of each leaf shown in these graphs are the means of analyses made in each of the 192 samples (4 fertilizer treatments × 3 light intensities × 4 different soils × 4 consecutive months: June to September 1962) collected at St Coombs, and in each of the 160 samples (4 fertilizer treatments × 2 light intensities × 4 different soils × 5 consecutive months: July to November 1962) collected at St Joachim Estate. In other words, some 430 to 450 bushes were sampled every month at St Coombs and St Joachim respectively.

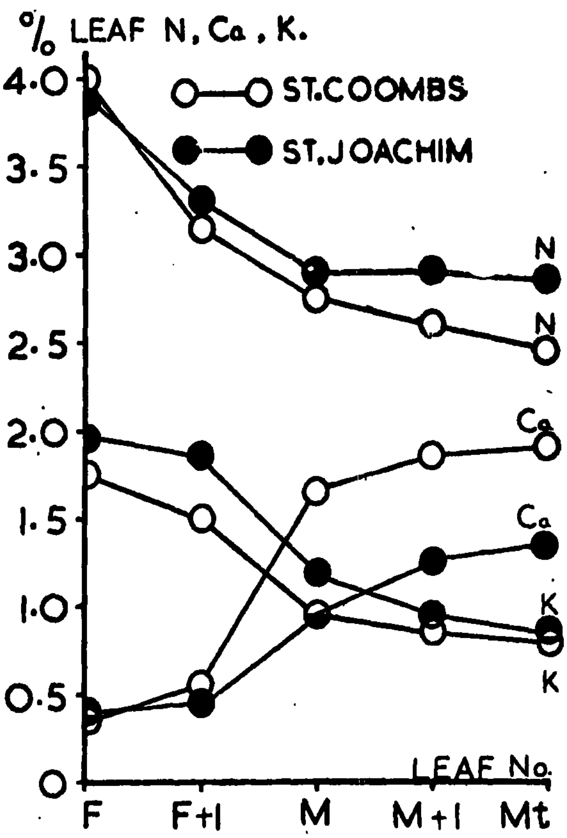

FIGURE 1 — *The relation between leaf position (F = youngest; Mt = oldest leaf) and percentage (on dry matter) leaf N, Ca and K*

It will be seen from Figures 1–4, that with increasing age, leaf N, K, P, Na and Cu decreased whereas leaf Ca, Mg, Al, Mn, Fe, B and Mo increased. The changes during maturation were large in respect of leaf K, P, Ca, Al and Mn, but relatively small for leaf N, Mg, Zn, B and Cu. It is of interest to note that leaf Mg increased with age (Table 1). It might have been due to luxury consumption of Mg, as the same explanation has been given for a similar trend observed in the leaves of oil palms (Broeshart 1955; Coulter 1958).

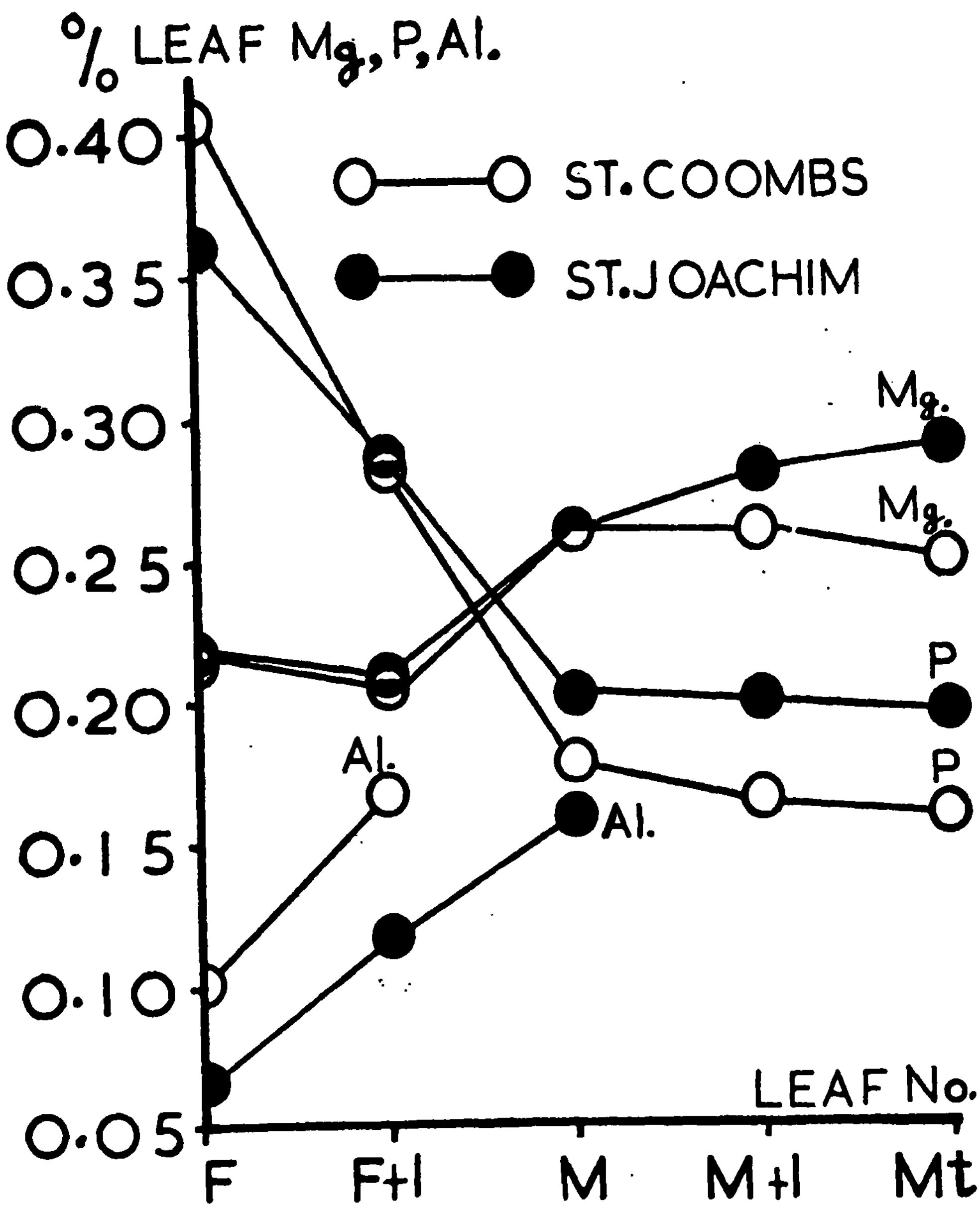

FIGURE 2 — *The relation between leaf position (F = youngest; Mt = oldest leaf) and leaf P, Mg and Al (% on dry matter)*

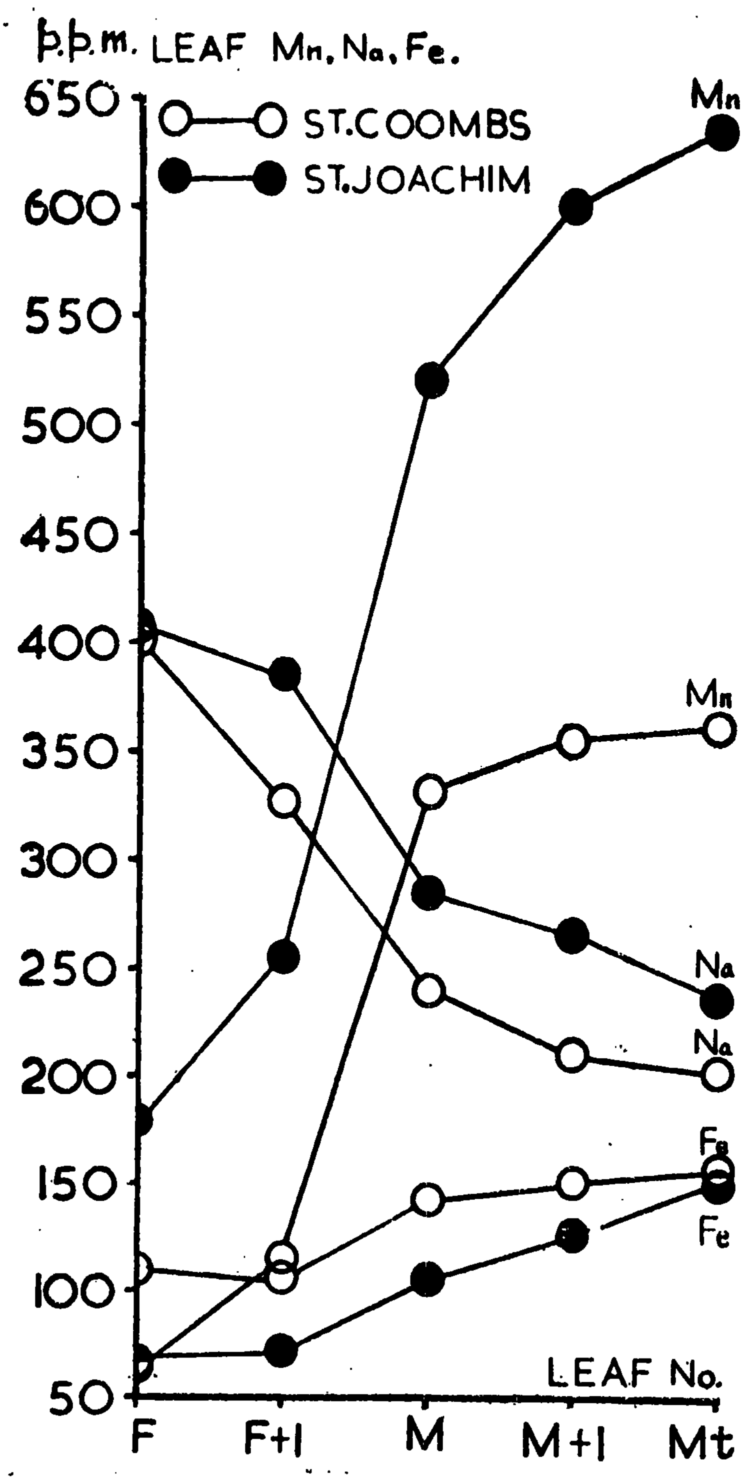

FIGURE 3 — *The relation between leaf position (F = youngest; Mt = oldest leaf) and leaf Mn, Na and Fe (ppm on dry matter)*

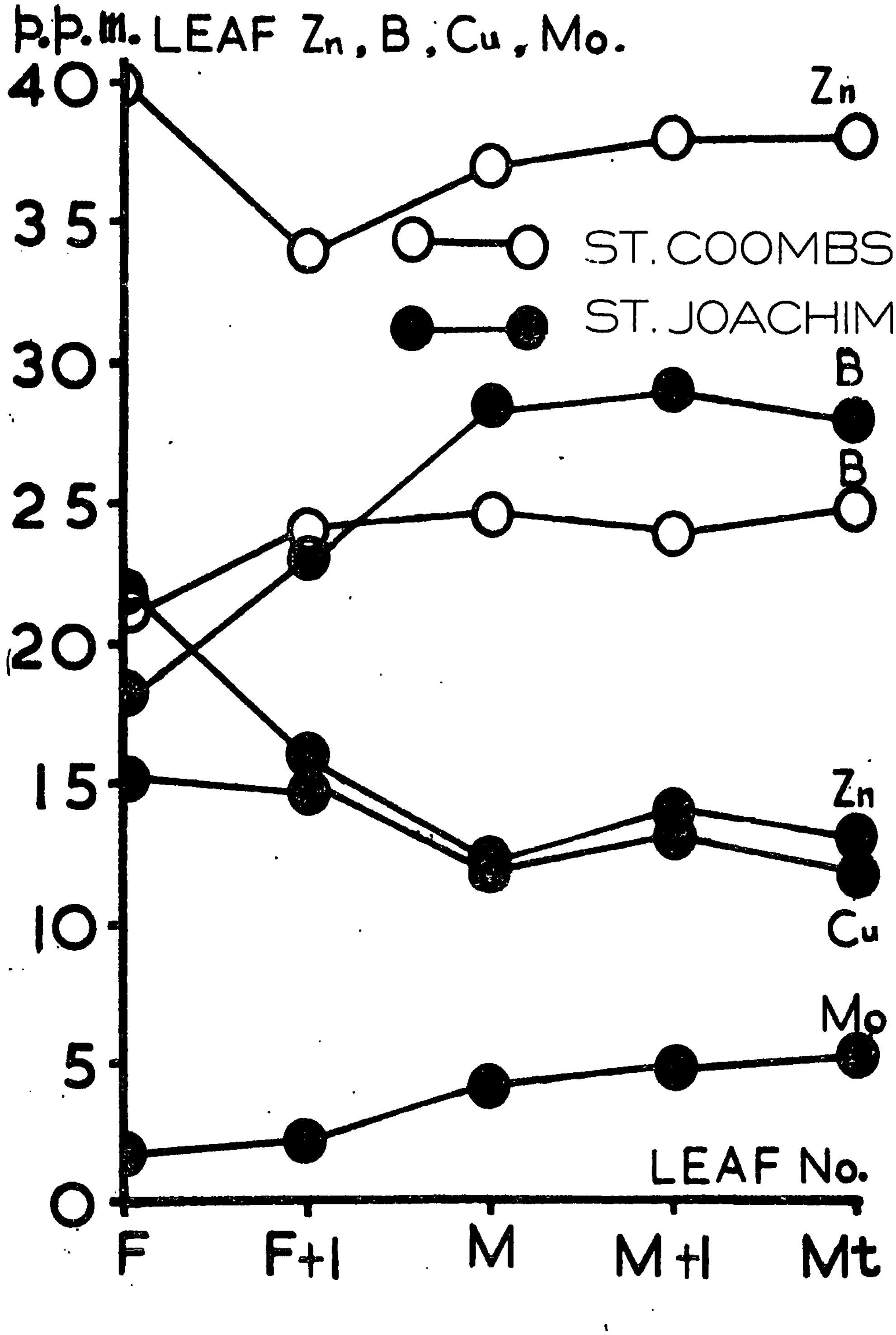

FIGURE 4.— *The relation between leaf position (F = youngest; Mt = oldest leaf) and leaf Zn, B, Cu and Mo (ppm on dry matter)*

Comparing the low and up-country analyses, the former plants contained, on average, higher amounts of N, K, P, Mg, Na, Mn and B, but less Ca, Al, Fe and Zn. No comparison could be made in respect of Mo as it was not determined in the low-country samples and of Cu as the up-country samples were contaminated by copper sprays. On the average, higher N, P and B and lower Ca leaf contents in the low-country were due to the higher N, P, and B and the lower Ca contents of the B-leaves (*ie* the leaves below the plucking table), the A-leaves (*ie* those above the plucking table) showing a reversed trend (Table 1). The changes in nutrient contents during maturation of the leaves were larger in the up-country, as compared with the low-country, for N, Ca, P and Na, but smaller in respect of K, Mg, Mn, Fe, Zn and B.

TABLE 1—*Nutrient content of leaves above plucking table (A= mean of leaves F and F+1) and below plucking table (B=mean of leaves M, M+1 and Mt) and the irratios A/B in % – Each figure represents mean of 160 (St Joachim) of 192 leaf samples (St Coombs) of clones TRI 2023 and 2025 respectively*

	St Joachim			St Coombs		
% dry matter	A	B	$\frac{A}{B}$%	A	B	$\frac{A}{B}$%
N	3.60	2.88	125	3.58	2.60	138
K	1.92	0.99	194	1.64	0.87	189
P	0.325	0.201	162	0.346	0.167	207
Ca	0.45	1.17	38	0.45	1.82	25
Mg*	0.22±0.012	0.28±0.013	79	0.21±0.011	0.26±0.011	85
ppm dry matter						
Na	396	263	151	365	217	168
Mn	218	586	37	91	350	26
Fe	70	128	55	109	150	73
Cu	15.0	18.5	81	—	—	—
B	20.8	28.5	73	22.6	24.6	92
Zn*	19 ±1.2	14 ±0.8	68	37 ±2.0	38 ±1.6	97
Mo	2.1	4.7	45	—	—	—
Al	916	—	—	1322	—	—

NOTE — *Standard errors have been computed only when there was some doubt as to whether the nutrients between A & B leaves differed significantly

Changes in nutrient contents (Figures 1-4) of leaves of increasing age are relatively much less for the B-leaves than for A-leaves. From the viewpoint of standardizing the leaf sampling technique and the fact that there is no standard method of plucking, this would be one reason in favour of sampling leaves below rather than above the plucking table. On the other hand, analysis of the A-leaves in general, and the pluckable flush in particular, would furnish a more direct comparison in studies on a possible relationship between mineral constituents and quality of the crop. This would be particularly so, if the relationship between the nutrient contents of A and B leaves would appear to be dependent upon environmental conditions.

In order to determine this, the consistency of the $\frac{A}{B}$ ratios of both up and low-country plants in different months of the year was tested by plotting the mean nutrient contents of the A-leaves against those of the B-leaves (Figures 5-8). Differences in environmental conditions between up and low-country and between different

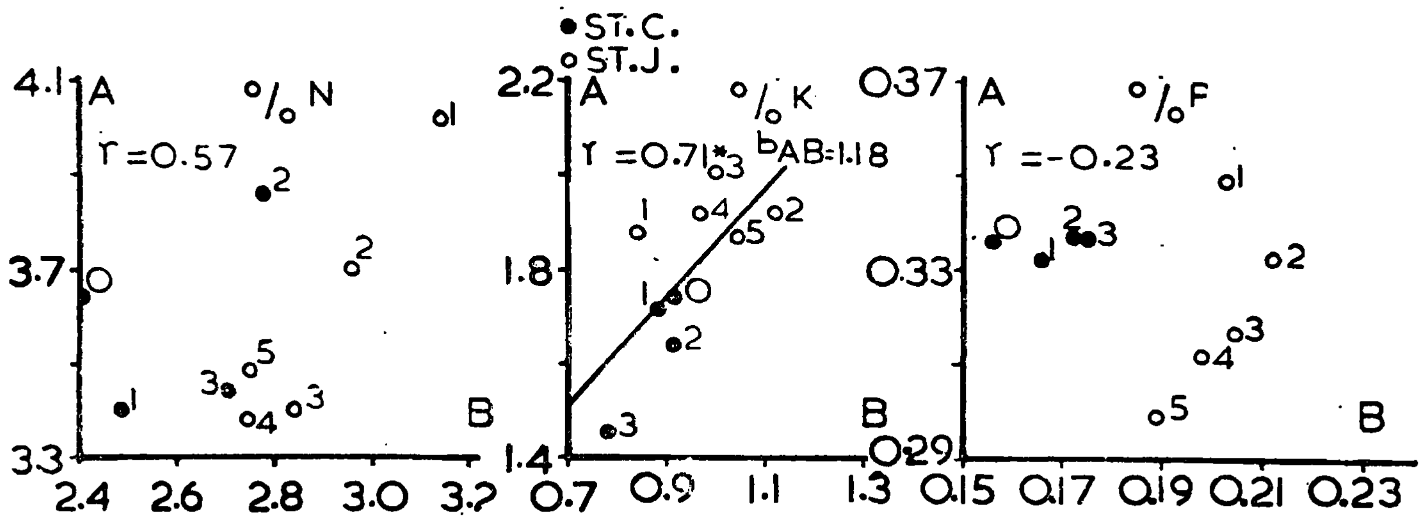

FIGURE 5 — *The relation (r = correlation coefficient; *P = 5%; **P = 1%; ***P = 0.1%;* b_{AB} *= regression coefficient (between the mean N, K and P contents (% dry matter) of leaves above (A) and below (B) the plucking table sampled in up-country (St Coombs) and low-country (St Joachim) in months 0 to 5 of 1962 — (Month) = June; 1 = July; 2 = August; 3 = September; 4 = October; 5 = November 1962*

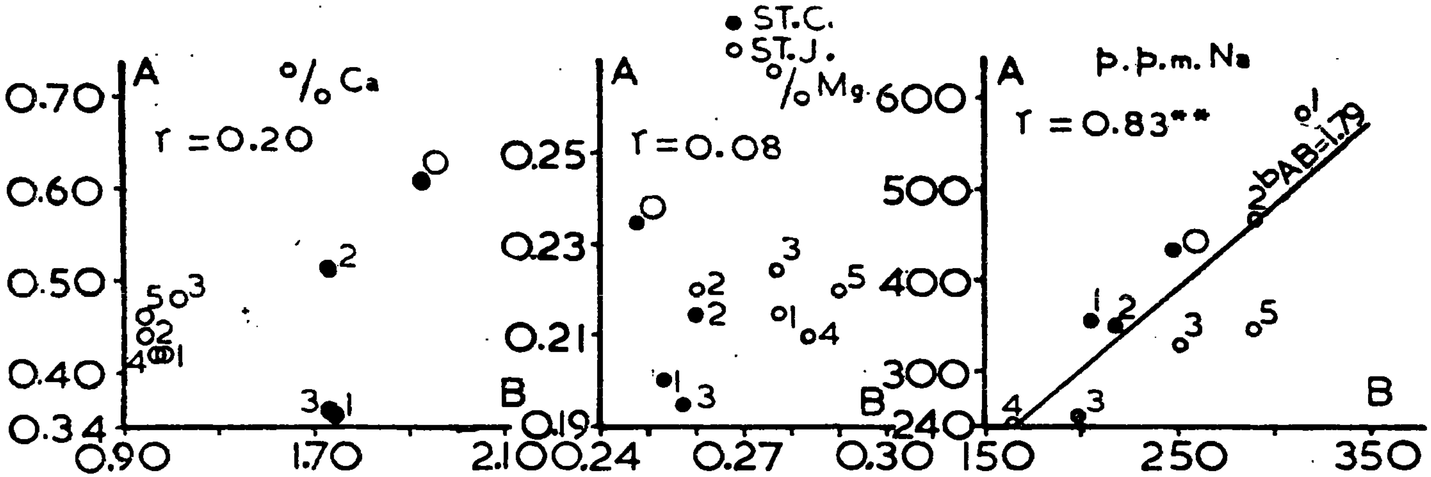

FIGURE 6 — *The relation between A and B leaves for % Ca, % Mg and ppm Na* – (*See Figure 5*)

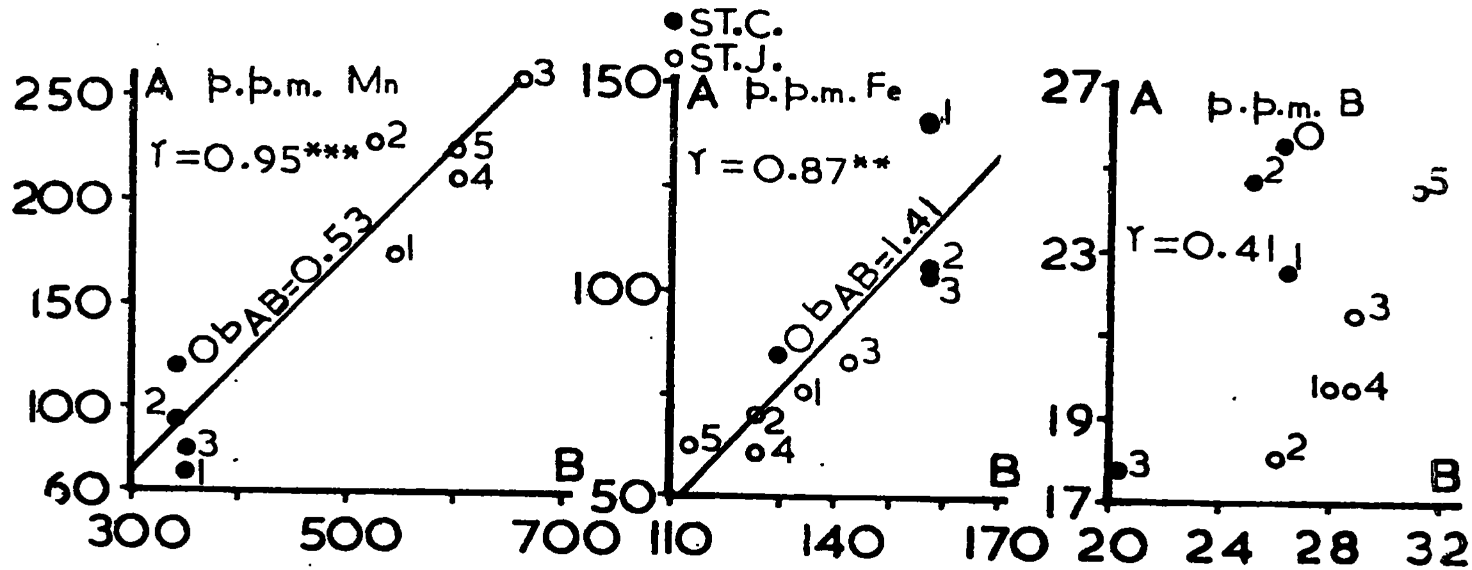

FIGURE 7 — *The relation between A and B leaves for Mn, Fe and B (ppm) – (See Figure 5)*

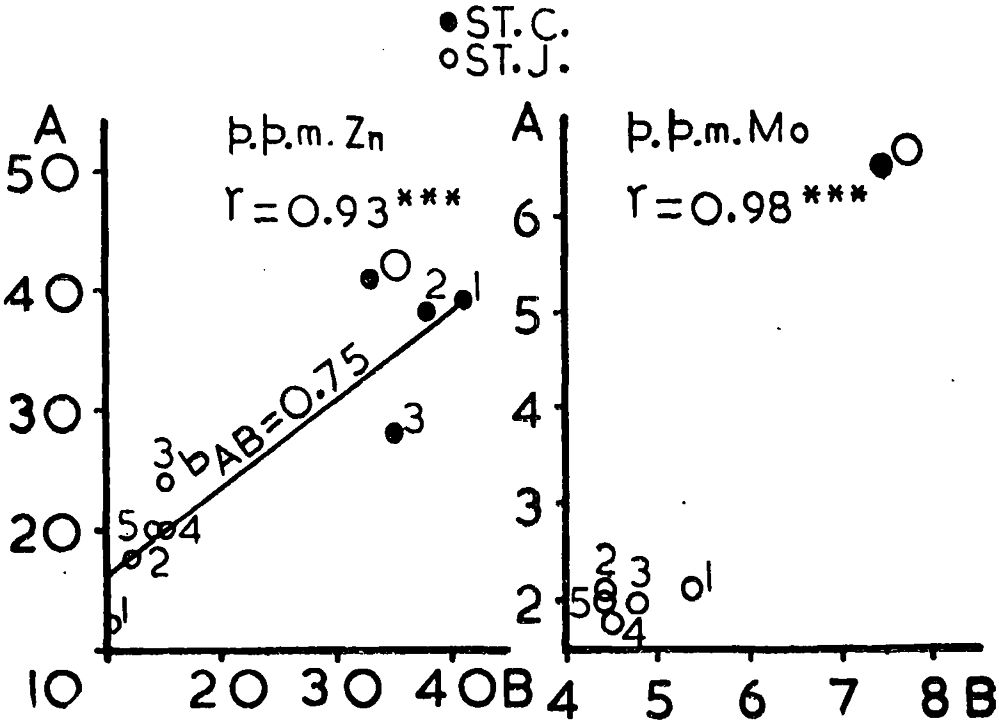

FIGURE 8 — *The relation between A and B leaves for Zn and Mo (ppm) – (See Figure 5)*

seasons in the up-country are well established for their effect on quality of the crop. They were, therefore, segregated for this test rather than those between fertilizers, light intensity and soils (*ie* the other variables in the trials), whose relationship, if any, with quality remains rather speculative (Keegel 1963; Anon. 1964).

It will be seen from Figures 5-8 that the mean Mo, Mn, Zn, Fe, Na and K contents of the A-leaves was significantly related to those of the B-leaves under a wide variety of conditions. Thus, an increase in the nutrient concentration of B-leaves was accompanied by an increase of that of the A-leaves, in such a way that the A-leaf concentration of Mn, Fe and Na increased relatively more than that of the B-leaves. Consequently, the $\frac{A}{B}$ ratios for Mn, Fe and Na increased with increasing leaf concentrations of these elements. The $\frac{A}{B}$ ratios for K and Zn, however, decreased.

The N, P, Ca, Mg and B concentrations in the A-leaves were not significantly associated with those of the B-leaves, so that analysis of the N, P, Ca, Mg and B nutrients in the B-leaves would not necessarily or always provide an index of their contents in the A-leaves and *vice versa*. It would appear from Figures 5-8 that the variations in the $\frac{A}{B}$ ratios of the latter nutrients were influenced by the effect of elevation in particular. In other words, N, P, Ca, Mg and B contents of A and B-leaves were more closely associated within a region (or elevation group) than between different elevations or regions. In these circumstances, standardization of leaf choice on a regional basis could be useful, more particularly in respect of N, P, Ca, Mg and B than with regard to K, Mn, Fe, Na, Zn and Mo.

Considering the question of leaf choice in standardizing the leaf sampling technique a mature leaf from below the plucking table would seem to be preferable for nutritional studies. An easily recognizable B-leaf is the mother (M) leaf, *ie* the leaf from the axil of which the present pluckable shoot has emerged. However, if quality relations is one of the objectives of foliar anaylsis, analysis of an A-leaf or of the flush itself would provide additional information, particularly in respect of possible relations between leaf, N, P, Ca, Mg and B and quality of the crop. This follows also from the ensuing observations.

A closer study of Figures 5-8 shows that the large variations in the $\frac{A}{B}$ ratios for N were mainly due to the up-country (St Coombs) samples, the $\frac{A}{B}$ ratios being higher and subject to larger monthly variations than in the low-country (St Joachim). In the low-country the N concentrations of A and B-leaves appeared to be closely associated notwithstanding the appreciable effects due to changes in the weather in the period July to November 1962. Weather conditions in month 1 (July sampling) were sunny and dry in both up and low-country, as distinct from the other months which were wetter and more cloudy. The effect of weather in month 1 on leaf N of both A and B-leaves was pronounced (Figure 5) both in up and low-country. If for reasons of simplification the difference between up and low-country is considered as one of temperature and that between months as one of rainfall, then the magnitude of the $\frac{A}{B}$ - ratio for N would seem to be more dependent on temperature (rainfall being the same) than on rainfall (temperature being the same). The effect of more rainfall (compare month 1, dry, with month 2, wet) was that it reduced N of both A and B leaves at high temperatures (St Joachim), but increased it at low temperatures (St Coombs). These opposite trends may however, also be explained on the basis of temperature differences, the effect of dry and bright weather being mainly one of causing low night temperatures in the up-country but one of high day temperatures in the low-country.

In respect of P, higher temperatures (St Joachim) had a lowering effect on the $\frac{A}{B}$ ratio. Rainfall did seem to have a decreasing effect on P content of A-leaves but not of B-leaves at high temperatures.

Looking at K and Mn, neither temperature nor rainfall disturbed the association between A and B-leaf contents, though the effect of temperature on both A and B-leaves was striking (see also Figure 1). Because low temperatures had a depressing effect on K and Mn contents of the leaves irrespective of their age. Rainfall, irrespective of temperature, had a marked effect on leaf Mn dry weather decreasing leaf, Mn, particularly of the A-leaves at low temperatures. Temperature and rainfall trends for Fe were the opposite of those of Mn. As regards Ca, dry weather irrespective of temperature decreased the Ca content of A-leaves markedly. Trends in respect of Mg were irregular. Mg-content of B-leaves at high temperatures and of A-leaves at low temperatures varied appreciably irrespective of rainfall. $\frac{A}{B}$ ratios for Na did not show variations corresponding with those in temperature or rainfall, except perhaps an increase in A-leaf Na in dry weather at high temperatures. As regards Zn and B, the nutrient concentrations of the A and B-leaves were related to each other in respect of Zn, but not of Boron. Zn and B contents at high temperatures decreased steeply with decreasing rainfall, particularly the Zn content of the A-leaves. The available data in respect of Mo indicated a very large reduction in both A and B-leaves at high temperatures and in the B-leaves due to rainfall.

In order to see whether the calculated $\frac{A}{B}$ values (Figures 5 to 8) for different nutrients were related to each other, correlation co-efficients for pairs of nutrients were computed. In this way, significant coefficients were found for: N & P (r= +0.87), N & Mg (+0.73), Mn & Ca (+0.91), Fe & P (+0.72), Mn and Fe (-0.76) Ca & Fe (-0.82), P & Zn (-0.76) and Ca & B (-0.66). Apparently, rising $\frac{A}{B}$ values for Mn were accompanied by an increase of the $\frac{A}{B}$ value for Ca but by a decrease of that for Fe and *vice versa*. The relations which did not reach significance were K & Ca, K & Mg, N & K, P & K, K & Mn, K & Na and N & Zn. These findings are mentioned here to indicate that there are numerous interactions between leaf nutrients and that the direction of these interactions may differ and be influenced by leaf age (Hasselo & Brzesowsky 1964).

Approaching the results of Figures 5 to 8 from a different angle, it was not surprising to find that the A & B leaf nutrient contents were related to each other in respect of K, Mn and Na, because these elements are known to be easily translocated within the plant. Neither was it unexpected that there was no such dependence for P, Ca and B, because these nutrients are generally not easily translocated from older to younger leaves. On the other hand, it is, for the same reasons, not so obvious why there was no close association for N and Mg, which are easily translocated, whereas there happened to be a close relation in respect of Fe and Zn, which are not easily translocated.

Taking N as an example, it would mean that the N-content of leaves above the plucking table is not necessarily or always representative of the N-content of the B-leaves which cover the major part of the tea bush, the older leaves contained adequate amounts of N. In these circumstances, flush-N content would not (or not yet) be representative of the N-status of the bush, but rather of the availability of N during the formation of the flush.

The large monthly fluctuations in $\frac{A}{B}$ ratios (Figure 5) suggest some kind of a relationship with the monthly variations in the weather. It will be seen from Figure 5 that the N content of the A-leaves in the up-country fluctuated with the rainfall (or/and sunshine), it being 3.6% in June (very wet), 3.4% in July (very dry), 3.9% in August (wet) and 3.0% in September (wet and dry).

The leaf N fluctuations may have been caused by factors located in the bush itself and/or in the soil. If the cause is to be sought in the plant itself then it is possible that insufficient N was translocated from older leaves to the flush. If the soil were the cause, it must have been due to shortage of available N or total N. Availability of soil N has been found to be larger by Birch (1960) and Hasselo (1961), working in East and West Africa respectively, in conditions of alternate wet and dry weather, particularly after a prolonged dry spell. This, and the observation that N-deficiency is more apparent in certain periods of the year than in others and that such low-N periods may be followed by high-N periods, irrespective of fertilizer-N supply, suggest that the absence of a relation for N between A and B-leaves was weather-induced. Changes in the weather might, therefore, have affected the translocation of N from B to A-leaves and/or the availability of N in the soil. Similar or other explanations may be valid for other nutrients.

General considerations, which will not be elaborated here, led to the following suggestions as regards sampling time and size. The large monthly fluctuations in leaf nutrient contents indicated the necessity to take several samples during a number of consecutive months, preferably during the transition from dry to wet weather. If one particular period had to be chosen, the best sampling time is considered to be just after the main flush season(s). Hence June/July or November/December for the conditions prevailing at St Coombs.

Unpublished results suggest that samples taken from minimally 10 to 20 plants of a vigorously growing clone would form an adequate sample size on a uniform soil. If there are, however, large productivity gradients (Hasselo 1964, 1964a) in the area or field to be investigated and if their magnitude and direction is not known, many more plants will have to be sampled, whilst the actual number of plants to be sampled will also depend on the element to be analysed.

Sample size is no problem if the flush is to be analysed as it would then be a matter of taking a representative sample from the total crop harvested from the field to be investigated. Soil productivity gradients, however, result in different growth rates. There would then be different contributions of different parts of different parts of the area to the total crop harvested. Soil productivity gradients would still have to be accounted for, and more accurately so for some elements than for others.

Summary

Trends in the N, K, P, Ca, Mg, Na, Mn, Fe, Cu, B, Zn, Mo and Al contents of tea leaves of increasing age grown in two shade *cum* fertilizer trials, one at St Coombs and the other at St Joachim were discussed. Leaf N, K, P, Na, Zn, and Cu decreased with increasing age of the leaves, but leaf Ca, Mg, Al, Mn, Fe, B and Mo increased. The changes with age were relatively larger for K, P, Ca, Al and Mn than for N, Mg, Zn, B and Cu.

Leaves below the plucking table were considered to provide a better index for the nutrient status of tea bushes grown in a wide range of environmental conditions than those above the plucking table. The mother leaf, *ie* the leaf from the axil of which the present pluckable shoot has emerged, was considered to be the better choice for standardization of the leaf sampling technique.

The K, Na, Mn, Fe, Zn and Mo contents of the mother leaf will give a fair indication of their contents in leaves situated above the plucking table under widely differing growing conditions. However, in respect of N, P, Ca, Mg and B this will only be so, if at all, for plants growing in the same region, a region being determined by its elevation.

Nutrient contents of leaves above the plucking table reflect with little delay the effects of climatic changes. These leaves are, therefore, the more obvious choice for studies of climatic effects on nutrient uptake by the tea bush and/or changes in nutrient availability in the soil, as well as for investigations on the relation between nutrition and weather-induced quality of the crop. This is particularly so in respect of the elements N, P, Ca, Mg and B and in the up-country.

The presence or absence of N-deficiency symptoms in the flush at any one time is not necessarily an indication of the inadequacy or otherwise of the N-supply of the plant. This is probably particularly so in the up-country. The presence of such symptoms in the flush may merely indicate a temporary and weather-induced shortage. This phenomenon has been discussed in relation to translocation of nutrients within the bush and to weather-induced changes in the availability of soil N. Suggestions for minimal sample size and best sampling time were given on the basis of general considerations and of, as yet, unpublished results.

Acknowledgments

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