AN ANALYTICAL SURVEY
OF THE
MINERAL STATUS OF TRINIDAD COCOA TREES
USING QUICK CHEMICAL TESTS

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D.T.A. Report

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TRINIDAD, B.W.I.
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CORRIGENDA

Pp. 17 (Table 1), 26 (Table 5), 27 (Table 6) & 30 (Table 7b).

The figures for p.p.m. of copper in the above tables should be divided by 100, i.e. the decimal point should be moved two places to the left in each case.
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#### References
A. Previous Work.

The use of rapid chemical tissue tests in determining the mineral status of plants was originated in the United States of America by Hoffer in 1926 (1) working with maize and was later used by Pettinger also on the maize crop (2) in which visual methods had proved not entirely satisfactory.

The effect of soil types and the application of fertilisers on the sap of plants was studied by McCool and Weldon in 1928 (3). Techniques suitable for use on both plants and soils were described by Thornton, Conner and Fraser (4) and, for certain micro-nutrients, by Morgan (5).

From 1943 onwards considerable work on these methods was carried out in England, chiefly by Nicholas, Plant and Jones at Long Ashton (6 - 16) and also, in conjunction with visual methods, by Wallace (21 - 23). Pioneer American workers include Emmert, Carolus and Hester (17 - 20).

The methods had been applied mainly to temperate crops, e.g. potato, cauliflower, tomato, sugar beet, etc. and, with the exception of the apple, had not been used for tree crops. The tests had shown their value in determining deficiencies in the nutrition of these crops, however, and good correlation between visual data, chemical analysis and the tissue tests was obtained.

Actual quantitative values were not set to the results obtained, the quantities present being recorded as high (H+, H,H-), medium (M+,M,M-) or low (L+,L,L-). Methods were evolved for testing for nitrate-nitrogen, potassium, calcium, magnesium, manganese, ferro iron, zinc, phosphorus and chlorine.

Tissue tests, in spite of certain limitations, have some advantages over the usual methods of complete chemical
analysis particularly with respect to economy in time and material, relative simplicity of operation, less apparatus required and the fact that, for some elements, it is possible to carry out the tests in the field. They serve as useful adjuncts to other diagnostic methods such as visual diagnosis and leaf injection tests.

Recently much, as yet unpublished, work has been undertaken by H. Evans at the Imperial College of Tropical Agriculture, Trinidad in adapting these methods for use on cacao and in extending the tests to include certain additional micro-nutrients - notably copper, zinc, boron and molybdenum. This work is still in progress.

The method used by Nicholas (24, 25) was to soak chopped samples of plant tissue (leaf lamina or petioles) for a certain time in Morgan's reagent, or, for the determination of certain micro-elements, in hydrochloric acid and to carry out on the filtered (and if necessary decolourised) extract colorimetric or turbidimetric tests.

B. Scope of Present Work.

Preliminary work consisted of analysing material from I.C.T.A. experimental plots - principally the Shade Experiment - under the supervision of Dr. H. Evans, mainly to gain experience in the use of these methods. The methods used were those originated by certain American workers and developed extensively by Nicholas at Long Ashton, England, as mentioned in the previous section.

This preliminary work took longer than was anticipated owing to various difficulties encountered including, during the early stages, shortage of some equipment and chemicals. Collection and preparation of the material, preparation of reagents and thorough cleaning of the glassware was found to take a considerable proportion of the limited amount of
time available for this work.

After completion of the preliminary investigations work was commenced on the main part of the project - the survey of the nutritional status of Trinidad cacao. This consisted of taking samples from as many different cocoa growing areas of Trinidad and on as many different soil types as possible, in the time available, and determining their relative composition. The following elements were tested for: nitrate-nitrogen, phosphorus, potassium, magnesium, calcium, chlorine, manganese, iron, copper and zinc.

It was originally intended that samples should be taken at two monthly intervals, from the same localities, throughout the year, to determine seasonal trends but this had to be abandoned owing to the excessive amount of travelling it would have occasioned and one sample only was taken from each estate.

It also proved impossible to do tests on samples of both I.C.S. clonal material and Forestero seedling material from each estate and tests on samples from clonal material only were carried out.

C. Aims and Objects.

The objects of the investigation may be summarized as follows:-

(1) To provide experience in the use of rapid tissue tests.

(2) To determine the range of values for the content of the most important mineral elements in cacao leaves in the different localities visited which included different soil types, in order to obtain broad indications of the localities in which deficiency and/or excesses of the various elements might be expected.
To correlate indications provided by the tissue tests with results of more detailed chemical analysis where these were available.

To determine whether there was any correlation between the results of tissue tests and the known fertility status of the soil types on which the trees were grown.

Some preliminary experiments were carried out to determine the relative merits of leaf lamina and petiole samples.
SAMPLING AND PREPARATION OF EXTRACTS.

A. SAMPLING.

Leaf and/or petiole samples were used - they were taken from recently matured flushes but where a new flush had not begun to develop. The first and second leaves on the terminal shoots were taken. Care was exercised always to obtain material of the same age.

Leaves were taken from terminal shoots of each tree at random and from as many trees as conveniently possible, also selected at random, within a block of cacao trees of the same type. The trees themselves, from each locality, were as near the same age as possible, 4 - 5 years, and all trees sampled during the survey of estate cacao were in bearing.

Three methods of sampling the leaf lamina were tried during the preliminary work: firstly picking the whole leaf and cutting it up in the laboratory; secondly picking the whole leaf, punching out discs of lamina at random in the laboratory and then cutting the discs up and thirdly punching out discs of lamina at random in the field and bringing them to the laboratory for cutting up. Similar results were obtained from each method and as the first is the simplest it was adopted for this project.

Samples consisted usually of 25 leaves - this providing ample material to make sufficient extract to carry out all the tests. Approximately 0.5 gms. material is needed to provide extract for each test. In the case of discs of lamina (¾" diam.) about 80 were required to carry out all the tests.

If petioles are used they are cut from the leaf lamina in the laboratory. On the average 16 - 18 leaves give 1 gm. petiole material.
B. PREPARATION OF EXTRACTS.

1. Preparation of material: As soon as conveniently possible (in any case not more than 12 hours after sampling) petioles were cut into slices approximately 2 mm. in thickness with a clean, sharp scalpel or knife on a clean board while leaf laminae were cut into small portions (3-4 mm. square) with scissors, (the use of a scalpel was also tried but did not simplify the process.)

The material was then weighed (while fresh) and divided into two portions - one of 8 gms. and one of 4 gms.

Samples were always cut up to the same degree of fineness.

2. Extraction: (a) With Morgans reagent: The 8 gm. portion of fresh chopped material was put into a 100 cc. beaker and 5 cc. of Morgans reagent added for each 0.5 gms. material (i.e. 80 cc. solution). It was then left to stand for exactly 15 minutes after which time the extract was quickly separated from the tissues by pouring through a fine cotton wool plug in a filter funnel into another 100 cc. beaker.

(b) With hydrochloric acid: The 4 gm. portion of fresh chopped material was put into a 100 cc. beaker and 1 cc. of AR. grade acid added for each 0.5 gms. material (i.e. 8 cc. acid). It was then allowed to stand for exactly 15 minutes and then 5 cc. distilled water was added for each 0.5 gms. material (i.e. 40 cc. water). The mixture was then quickly stirred and the extract separated from the tissues by pouring through a cotton wool plug into another beaker as with Morgans extract.

(c) Preparation of Morgans reagent:
Add 48.8 gms. sodium hydroxide, AR. slowly to 73.2 gms. glacial acetic acid, AR. in a large vessel and stir until dissolved. (This makes 100 gms. sodium acetate). Allow to cool and then add 30 cc. glacial acetic acid, AR. and
mix well. Make up to 1 litre with glass distilled water. The pH should be 4.8.

It was found to be preferable to make up the Morgans reagent in this manner, rather than to use sodium acetate directly, as the sodium acetate available was less pure.

3. Decolourisation: Petiole extracts are generally colourless but extracts of leaf lamina are usually pale yellow in colour, the yellow colour increasing with age of the leaf. These latter extracts were decolourised by adding 'Darco 60' adsorbent carbon to the extract in the beaker at the rate of 0.2 gms. carbon for each 25 cc. extract; (it was unnecessary to weigh out the carbon each time - a measure being used.)

The extract was then stirred for 30 seconds with a glass rod and then filtered through a 'Whatman No. 40' filter paper into a conical flask which was closed with a plug of cotton wool.

If 'Darco 60' carbon is not available, other brands of adsorbent carbon may be used but these may require purification by boiling with dilute hydrochloric acid and washing with hot distilled water until the leachings are free from chloride.
The following are the tests finally decided on and used for the survey of estate cacao. Full details of the procedure and preparation of the reagents are given.

I. TESTS ON MORGANS EXTRACT
A. MACRO-ELEMENTS.

1. Nitrate-nitrogen.

Reagents: a) Phenol-disulphonic acid, AR.
   b) Ammonia soln., AR. (50%)
   c) Hydrogen peroxide soln., AR. (20 vol.)

Procedure: Place 5 cc. of extract in a 50 cc. 'Pyrex' beaker and evaporate to dryness on a water bath. Cool and add 3-5 drops of hydrogen peroxide and again evaporate to dryness. Cool and add 2 cc. phenol-disulphonic acid reagent, allow to stand for 5 minutes, then add 5 cc. distilled water. When cool transfer to a specimen tube marked at 25 cc. and add 8 cc. ammonia soln. Yellow colour appears. Allow to cool and dilute to 25 cc. with distilled water. Measure light transmittance in the spectro-photometer at a wavelength of μ 490 and determine nitrate-nitrogen content from a standard curve.

2. Phosphate.

   b) Reagent B. (Hydroquinone) - this must be freshly prepared every three weeks.
   c) Reagent C. (Sodium carbonate & sodium sulphite).

Procedure: Place 5 cc. of extract in a specimen tube and add 2 cc. of Reagent A (Ammonium molybdate) and 1 cc. Reagent B (Hydroquinone). Allow to stand for 5 minutes for the green colour to develop and then add 2 cc. of Reagent C (Sodium carbonate & sodium sulphite) and mix thoroughly - colour changes to blue and is measured in a Lovibond comparator for approximate values, or in a spectro-photometer for more accurate determination.
Preparation of reagents: (i) Add 65 cc. conc. sulphuric acid, AR. to 200 cc. distilled water and dilute to 500 cc.
(ii) Dissolve 8.8 gms. ammonium molybdate, AR. in 100 cc. distilled water.
(iii) Add 5.3 cc. sulphuric acid, AR. to 100 cc. distilled water.
Mix (ii) with (iii) and make up to 250 cc. with distilled water, then mix this 250 cc. with 250 cc. of soln. (i) - making altogether 500 cc. of reagent A.
Reagent B is made by dissolving 1.0 gm. hydroquinone, AR. in 100 cc. distilled water and then adding 0.5 cc. of soln. (i). Dissolve 100 gms. anhydrous sodium carbonate, AR. and 24 gms. sodium sulphite, AR. in 500 cc. distilled water - this is reagent C.

(3) Potassium.

Reagents: a) Potassium Reagent I.
       b) Potassium Reagent II. (ethyl alcohol, 95%.)

Procedure: Place 2.5 cc. of extract and 2.5 cc. distilled water in a specimen tube and add 5 cc. Reagent I. Shake and add 5 cc. Reagent II (ethyl alcohol). Shake again and allow to stand for 3 minutes - turbidity develops. Measure light transmittance in the spectro-photometer at a wavelength of 630 m\u and determine potassium content by comparison with known potassium standards prepared at the same time and under the same conditions as the extract.

Preparation of reagents: Stock solution of sodium cobaltinitrite - dissolve 5 gms. sodium cobaltinitrite, AR. and 30 gms. sodium nitrite, AR. in approx. 50 cc. distilled water; add 5 cc. glacial acetic acid, AR. and make up to 100 cc. with distilled water. Allow to stand for several days and store in a refrigerator.

Potassium Reagent I - dissolve 15 gms. sodium nitrite, AR. in 100 cc. distilled water, add 5 cc. stock solution of sodium cobaltinitrite and adjust to a pH of 5.0 with acetic acid, AR. This soln. should not be used for a period longer than three days.

(4) Magnesium.

Reagents: a) Titan yellow, AR. (Dissolve 0.15 gms. in 75 cc. of 95% ethyl alcohol, AR. & 25 cc. distilled water.)
       b) Hydroxylamine hydrochloride, AR. (Dissolve 2.0 gms. in 100 cc. dist. water.)
       c) Sucrose, AR. (5% soln. in dist. water.)
       d) Sodium hydroxide, AR. (10% soln. in distilled water.)

Procedure: Put 1 cc. extract in a specimen tube and add 4 cc. distilled water. Add 0.5 cc. hydroxylamine solution and 0.5 cc. sucrose solution and stir. Add exactly
3 drops of *titan* yellow solution, mix and add 2 cc. sodium hydroxide solution - pink or red colour. Compare colour with prepared standards and multiply result by 5 to obtain magnesium content.

(5) **Calcium**.

**Reagents:** a) Ammonium oxalate, AR. soln. (saturated in distilled water).

**Procedure:** Place 5 cc. extract in a specimen tube and add 2 cc. ammonium oxalate solution and shake - white turbidity develops. Measure light transmittance in the spectro-photometer at a wavelength of \(\mu 600\) and determine calcium content from a standard curve.

B. **MICRO-ELEMENTS.**

(1) **Chloride**.

**Reagents:** a) Silver nitrate, AR. (N/50 soln. in distilled water.)

b) Nitric acid, AR. (conc.)

**Procedure:** Place 5 cc. extract in a specimen tube and add 2-3 drops nitric acid and then add 2 cc. of the silver nitrate solution - white turbidity develops. Measure light transmittance in the spectro-photometer at a wavelength of \(\mu 600\) and determine chloride content from a standard curve. Light transmittance is measured after 3 minutes, the tubes being kept in the dark until the actual measurement is made.

(2) **Manganese**.

**Reagents:** a) Sodium acetate soln. (Dissolve 15 gms. sodium hydroxide, AR. in 180 cc. dist. water and add 58 cc. glacial acetic acid, AR. Cool and dilute to 250 cc.)

b) Potassium hypophosphate, AR. soln. (Dissolve 0.48 gms. in 250 cc. dist. water.)

c) Potassium periodate, AR. soln. (Dissolve 0.2 gms. in 100 cc. dist. water. N.B. Prepare fresh reagent every 2 days)

d) Tetrabase reagent. (Dissolve 0.5 gms. tetramethylidiaminodicphenylmethane, AR. in 6 cc. of 2N hydrochloric acid, (AR. redistilled), and dilute to 100 cc. with dist. water. N.B. Prepare fresh reagent every two days.)
Procedure: Place 1 cc. extract and 4 cc. distilled water in a specimen tube and add 2 cc. of the sodium acetate solution and 1 cc. phosphate solution. Dilute mixture to 21 cc. with distilled water and place in a water bath at 20°C. for 15 minutes. Add 3 cc. periodate solution, mix and add 1 cc. tetra-base reagent - blue colour appears. Measure light transmittance in the spectro-photometer at a wavelength of μ 640 after exactly 10 minutes and determine the manganese content by multiplying the result obtained from a standard curve by five.

II. TESTS ON HYDROCHLORIC ACID EXTRACT.

A. MICRO-ELEMENTS.

(1) Iron.

Reagents: a) Citric acid, AR. (20% soln. in dist. water.)
       b) Thioglycollic acid, AR.
       c) Ammonia soln., AR. (50%).

Procedure: Place 5 cc. extract in a specimen tube and add 1 cc. citric acid solution and then 1 drop thioglycollic acid. Mix and then neutralise with ammonia solution (about 4 cc.) - red colour is measured in a Lovibond comparator using the appropriate disc.

(2) Copper.

Reagents: a) Citric acid, AR. (20% soln. in dist. water.)
       b) Ammonia soln., AR. (50%.)
       c) Sodium diethyldithiocarbamate, AR. (0.5% soln. in dist. water.)
       d) Amyl acetate, AR. & amyl alcohol, AR. (50:50 mixture.)
       e) Amyl alcohol, AR.

Procedure: Put 10 cc. extract in a specimen tube and add 1 cc. citric acid solution and then neutralise with approximately 4 cc. ammonia solution. Put the mixture in a separating funnel, shake and then extract twice with 5 cc. of the amyl acetate and amyl alcohol mixture. Filter alcohol portion (yellow colour) and make up to 25 cc. with the amyl alcohol (alone). Measure light transmittance in the
spectro-photometer at a wavelength of μ 440 and determine copper content from a standard curve.

(3) Zinc.

Reagents:

a) Di-beta-naphthyl-thiocarbazone I reagent.
   (Dissolve 20 mgs. SR. in 1 litre of redistilled AR. chloroform containing 10 cc. of absolute alcohol, AR. redist.) - for quantities up to 0.005 mgs. zinc.

b) Di-beta-naphthyl-thiocarbazone II reagent.
   (Dissolve 200 mgs. SR. in 1 litre of redistilled AR. chloroform containing 10 cc. of absolute alcohol, AR. redist.) - for quantities up to 0.5 mgs. zinc.

N.B. Both of the above reagents must be kept in brown bottles and stored in a refrigerator.

c) Sodium diethyldithiocarbamate, AR.
   (1.25% soln. in distilled water.)

d) Thymol blue, AR. soln. (0.1% in distilled water.)

e) Ammonia soln. (redistilled AR.)

Procedure:

Place 5 cc. of extract in a scrupulously clean separating funnel. Add 4 drops thymol blue solution (red colour) and then add the ammonia solution drop by drop to pH 9.5 (blue colour). Mix and add 4 cc. sodium diethyldithiocarbamate solution and shake well. Then add 5 cc. D.B.N.T.C. I (di-beta-naphthyl-thiocarbazone I) reagent and shake for one minute. Faint violet colour of chloroform layer indicates less than 0.005 mgs. zinc while a deeper red colour indicates more than 0.005 mgs. zinc.

In the latter case the test must be started again with a fresh 5 cc. of extract and this time using the D.B.N.T.C. II reagent throughout the test.

If there is only a faint violet colour the chloroform layer (containing the zinc) is separated off into a clean tube and a second 5 cc. of D.B.N.T.C. I reagent added. Shake for one minute and separate off. Then repeat this process a third time and finally measure the light transmittance of the 15 cc. reagent in the spectro-photometer at a wavelength of μ 650. Determine the zinc content from a standard curve.
III. GENERAL NOTES ON THE TESTS.

'Analytical grade' (AR.) chemicals are used throughout except in the case of reagents for zinc determination when even AR. grade is not pure enough and it is essential to use specially purified (SR. grade) and redistilled chemicals. Distilled water used for reagents and in the micro-element tests should be thrice glass distilled.

All glassware must be scrupulously clean - it is cleaned first with acid and finally rinsed with glass distilled water. Separate pipettes are kept for each reagent (or reagent bottles with graduated dropper stoppers can be used).

Standard curves are prepared by carrying out the tests on aqueous solutions containing known quantities of the particular element in the range of concentrations expected; measuring light transmittance of these standards in the spectro-photometer and then plotting the readings on a graph with the extinction coefficient on the horizontal axis and parts per million on the vertical axis. This is repeated several times before a curve is drawn - to avoid error. (See appendix iv.)

Particular care must be taken with zinc and manganese determinations as minute quantities of the elements are involved and it is difficult to avoid impurities.

A 'blank', i.e. a test on glass distilled water, should be carried out along with each test on extracts. This blank is used to set the spectro-photometer to 'zero'.

Phenol-disulphonic acid sets solid and must be liquified by heating on a water bath and then allowing it to cool before use.

The tests detailed were not used throughout the work but only for the survey of estate cacao. Modifications were made by H. Evans, after the preliminary work had been
carried out, in the tests for nitrate-nitrogen and potassium and the test given for zinc is a new one.

The tests used during the preliminary work and then abandoned differed as follows:

**Nitrate-nitrogen** - the 2 cc. of phenol-disulphonic acid was added directly to the 5 cc. of extract in a specimen tube. The extract was not evaporated nor was hydrogen peroxide used. Results from this test were satisfactory only when over 5 p.p.m. of nitrate were present but it was insensitive to contents below 5 p.p.m.

**Potassium** - the test used previously was that used by Nicholas and his co-workers (6 - 13). Its drawback appeared to be failure completely to precipitate potash when the amount was low. The alternative method appeared to be more sensitive within the lower ranges of potash content.

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EQUIPMENT

Minimum quantities of apparatus and equipment required to carry out the tests detailed in the previous section are as follows:

Winchester bottles, dark glass (for stock solns.) ... 2 doz.
Reagent bottles, dark glass, graduated dropper stoppers
Pipettes, graduated, 5 & 10 cc. ............................. 2 1/2 doz
Measuring cylinders, 25, 50, 100 & 500 cc. .......... 1 ea.
Specimen tubes (some marked at 20 & 25 cc.) .......... 3 doz.
Beakers, 50 & 100 cc. ................................. 8 ea.
Flasks, conical, 100 cc. ................................. 8
Glass stirring rods ........................................ 3
Filter funnels, glass, 1 1/2" & 3" .......................... 8 ea.
Spatulas .................................................... 2
Crucible tongs, 8", pairs ................................. 1
Stands for specimen tubes ................................ 1
Stands for filter funnels ................................. 2
Water bath .................................................... 1
Wash bottle .................................................. 1
Beakers, 500 & 1,000 cc. ............................... 2 ea.
Flasks, flat bottom .......... 1 litre ...................... 4
Measuring flask ...... 1 litre ............................. 1
Bunsen burner & tripod .................................. 1 ea.
Separating funnels, 150 & 250 cc. ....................... 2 ea.
Scissors, 6" .............................................. 1 pr.
Chain balance ............................................. 1
Thermometer, 0-100°C. .................................... 1

N.B. If reagent bottles without graduated dropper stoppers are used more pipettes will be required.

In addition to reagents (detailed in the section describing the tests) the following expendable material is also needed:

Filter papers, "Whatman No. 40," 8 cm. & 14 cm.
Adsorbent cotton wool.
"Daxco 60" adsorbent carbon.
Blotting paper.

A Lovibond comparator is useful for reading directly the concentration in parts per million of an element in an extract and with appropriate discs can be used for phosphate, iron, nitrate-nitrogen and magnesium - it is not very satisfactory for the latter, however.

A spectro-photometer is valuable as it can be used for all the determinations - provided the necessary standard curves are prepared - and it speeds up the work and increases accuracy. Special 18 and 24 mm. tubes (together with stands) are required for use with it.

Neither a comparator nor the spectro-photometer are essential as comparison can be made with freshly prepared standards for each element.

The quantities of tubes, funnels, beakers, conical flasks, etc. required depend on the number of extracts it is wished to prepare and test at the same time. The above quantities are based on eight at a time which was found to be a convenient number to deal with.

A vasculum is useful to transport samples from the field to the laboratory but if one is not available the samples can be wrapped in damp blotting paper and then in waxed brown paper or plastic cloth. Even when a vasculum is used the samples should first be wrapped in damp blotting paper.

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PART III

PRELIMINARY INVESTIGATIONS

A. SUITABILITY OF PETIOLES & LEAF LAMINA.

Tests for nitrate-nitrogen, phosphate, potassium, calcium, magnesium, chloride, iron and copper on samples of cacao from the guard rows (no treatment except shade) growing under varying light intensities in the Cacao Shade Experiment at I.C.T.A., St. Augustine were carried out.

Identical tests were carried out at the same time on extracts prepared from the petioles and lamina of the same leaves. The results obtained from these tests are detailed in table 1.

Note: The symbols N, P, K, etc. are used as abbreviations in the tables in this report and do not always refer to the element. Exceptions are: P.p.m. N = p.p.m. NO₃-nitrogen; p.p.m. P = p.p.m. P₀₄; % in DM (dry matter) of K = % in DM of K₂O; % in DM of P = % in DM of P₂O₅.

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P = Petioles  L = Lamina.

Results are given in parts per million concentration in 5 cc. of extract. Samples of about 5 gms. of material taken from 80 leaves sampled at random from several trees of I.C.S. 1 clonal cacao were used. The tests for iron and copper were carried out on hydrochloric acid extract and the...
remainder on Morgans extract. Measurement of nitrate-nitrogen, phosphate and iron was done with a Lovibond comparator; of potassium, copper and chloride by means of a spectro-photometer and standard curves and of calcium and magnesium by comparison with prepared standards.

The results obtained show a slightly higher content of nitrate-nitrogen and iron and a considerably higher content of magnesium in the lamina than in the petioles while the content of phosphate and calcium in the lamina is lower than in the petioles. The results for copper, chloride and potassium show some variation.

In view of the fact that the quantities of nitrate-nitrogen and iron in the tissues are small and, within reason, it is an advantage to use material from which the maximum amount of these nutrients can be extracted, providing the material is also suitable for the determination of the other nutrients as in the case of leaf lamina, it was decided to use lamina exclusively for the remainder of the project.

The use of lamina also has an advantage over petioles in that fewer leaves are required (an important point when sampling from young cacao with few leaves of the right age.)

B. CORRELATION BETWEEN RAPID TESTS & CHEMICAL ANALYSIS.

To carry out this part of the investigation trees in the Cacao Shade Experiment at I.C.T.A., St.Augustine were used. This shade experiment consists of five blocks over each of which is constructed artificial shade which allows the following proportions of full sunlight to reach the cacao plants: 15%, 25%, 50%, 75% and 100%. Each block is divided into two sub-blocks one of which is mulched (with bagasse) and the other unmulched.

Superimposed on the shade treatments is an NPK ferti-
liser experiment with the usual eight treatments, i.e. Control (i), NPK, NP, NK, N, MK, K, P. Three clones are tested in this shade experiment: I.C.S. Nos. 1, 60 and 95. There are two trees of each clone under each combination of treatments.

For the purpose of this project samples from I.C.S. No. 1 trees in the unmulched sub-block only were taken. Determinations were therefore carried out on 40 samples.

Tests were carried out for the content of nitrate-nitrogen, phosphate, potassium, calcium and magnesium. The tests used were those detailed in Part II, section I of this report - "Methods of Analysis" - except for nitrate-nitrogen and potassium (see Part II, section III.)

Phosphate concentration in 5 cc. extract was measured directly in a Lovibond comparator; calcium and magnesium concentration by comparison with prepared standards and nitrate-nitrogen and potassium by means of a spectro-photometer and standard curves.

Samples consisted of 12 leaves from which 3 gms. of prepared material (lamina) was taken. The leaves (young mature flushes) were all of the same age and the samples were taken at random from the two trees under each treatment.

Results are given in table 2, (a)-(h) together with figures for the content of nutrients in the same trees as determined by full chemical analytical methods by the Cocoa Research Department, I.C.T.A. The figures for rapid chemical tests represent parts per million concentration in 5 cc. of the Morgans extract of the fresh plant tissue while the figures for full chemical analysis represent percentage in the dry matter.

Practically no correlation was obtained, by the writer
between the data from the rapid tests and that from full analytical methods in this part of the investigation as will be apparent from a glance at the correlation curve for phosphate (Fig. 1.) There are two probable reasons for this: in the case of potassium the rapid test used was undoubtedly inaccurate for use on cacao and secondly and most important, the analysis by each method was carried out on samples taken at different times of the year. There may have been as much as six months difference between the time when samples were taken for ashing and samples were taken for rapid tests. The trees were therefore at a different state of growth and climatological conditions were not the same.

N.B. Blank spaces in the following table indicate that the data in question was not available for those samples.

TABLE 2. Comparison between results from rapid tests and full analysis.

(a) Treatment: Nil (control).

<table>
<thead>
<tr>
<th>Element</th>
<th>15% light</th>
<th>25% light</th>
<th>50% light</th>
<th>75% light</th>
<th>100% light</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>A B</td>
<td>A B</td>
<td>A B</td>
<td>A B</td>
<td>A B</td>
</tr>
<tr>
<td>P</td>
<td>25 0.42</td>
<td>28 0.34</td>
<td>14 0.33</td>
<td>23 0.42</td>
<td>20 0.32</td>
</tr>
<tr>
<td>K</td>
<td>328 192</td>
<td>244 2.41</td>
<td>256 2.01</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>5 8</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>60 45</td>
<td>25</td>
<td>25</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

(b) Treatment: Nitrogen (N) applied.

<table>
<thead>
<tr>
<th>Element</th>
<th>15% light</th>
<th>25% light</th>
<th>50% light</th>
<th>75% light</th>
<th>100% light</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>- 3.25</td>
<td>- 2.21</td>
<td>- 2.42</td>
<td>- 11</td>
<td>- 2.24</td>
</tr>
<tr>
<td>P</td>
<td>20 0.34</td>
<td>28 0.33</td>
<td>10 0.32</td>
<td>23 0.47</td>
<td>20 0.28</td>
</tr>
<tr>
<td>K</td>
<td>236 280</td>
<td>148 1.27</td>
<td>276 0.69</td>
<td>176</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>7 14</td>
<td>8</td>
<td>20</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>50 35</td>
<td>20</td>
<td>50</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

(c) Treatment: Nitrogen & phosphate (NP) applied.

<table>
<thead>
<tr>
<th>Element</th>
<th>15% light</th>
<th>25% light</th>
<th>50% light</th>
<th>75% light</th>
<th>100% light</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>- 2.70</td>
<td>0.5 2.09</td>
<td>- 2.73</td>
<td>3 2.15</td>
<td>0.25 3.64</td>
</tr>
<tr>
<td>P</td>
<td>25 0.36</td>
<td>29 0.36</td>
<td>15 0.35</td>
<td>27 0.44</td>
<td>20 0.42</td>
</tr>
<tr>
<td>K</td>
<td>208 1.70</td>
<td>244 ?</td>
<td>168 2.26</td>
<td>184 96</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>-----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Ca</td>
<td>50</td>
<td>35</td>
<td>20</td>
<td>45</td>
<td>55</td>
</tr>
</tbody>
</table>

(d) Treatment: Potassium (K) applied.

<table>
<thead>
<tr>
<th>Element</th>
<th>15% Light</th>
<th>25% Light</th>
<th>50% Light</th>
<th>75% Light</th>
<th>100% Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2.62</td>
<td>0.5</td>
<td>1.96</td>
<td>1.96</td>
<td>2.82</td>
</tr>
<tr>
<td>P</td>
<td>25</td>
<td>0.32</td>
<td>0.35</td>
<td>0.37</td>
<td>0.37</td>
</tr>
<tr>
<td>K</td>
<td>286</td>
<td>2.41</td>
<td>0.35</td>
<td>272</td>
<td>3.36</td>
</tr>
<tr>
<td>Ca</td>
<td>6</td>
<td>10</td>
<td>8</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Mg</td>
<td>35</td>
<td>30</td>
<td>25</td>
<td>35</td>
<td>50</td>
</tr>
</tbody>
</table>

(e) Treatment: Phosphate (P) applied.

<table>
<thead>
<tr>
<th>Element</th>
<th>15% Light</th>
<th>25% Light</th>
<th>50% Light</th>
<th>75% Light</th>
<th>100% Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>1.95</td>
<td>0.25</td>
<td>2.02</td>
<td>29</td>
<td>2.62</td>
</tr>
<tr>
<td>P</td>
<td>28</td>
<td>0.35</td>
<td>0.32</td>
<td>15</td>
<td>0.37</td>
</tr>
<tr>
<td>K</td>
<td>280</td>
<td>?</td>
<td>180</td>
<td>?</td>
<td>172</td>
</tr>
<tr>
<td>Ca</td>
<td>5</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Mg</td>
<td>50</td>
<td>30</td>
<td>25</td>
<td>30</td>
<td>35</td>
</tr>
</tbody>
</table>

(f) Treatment: Nitrogen, phosphate & potassium (NPK) applied.

<table>
<thead>
<tr>
<th>Element</th>
<th>15% Light</th>
<th>25% Light</th>
<th>50% Light</th>
<th>75% Light</th>
<th>100% Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2.50</td>
<td>2.45</td>
<td>2.30</td>
<td>3.5</td>
<td>2.13</td>
</tr>
<tr>
<td>P</td>
<td>28</td>
<td>0.33</td>
<td>0.32</td>
<td>10</td>
<td>0.47</td>
</tr>
<tr>
<td>K</td>
<td>288</td>
<td>2.04</td>
<td>240</td>
<td>?</td>
<td>248</td>
</tr>
<tr>
<td>Ca</td>
<td>9</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Mg</td>
<td>50</td>
<td>30</td>
<td>25</td>
<td>30</td>
<td>35</td>
</tr>
</tbody>
</table>

(g) Treatment: Nitrogen & potassium (NK) applied.

<table>
<thead>
<tr>
<th>Element</th>
<th>15% Light</th>
<th>25% Light</th>
<th>50% Light</th>
<th>75% Light</th>
<th>100% Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2.65</td>
<td>2.12</td>
<td>9</td>
<td>3.19</td>
<td>4.5</td>
</tr>
<tr>
<td>P</td>
<td>28</td>
<td>0.41</td>
<td>27</td>
<td>0.29</td>
<td>14</td>
</tr>
<tr>
<td>K</td>
<td>284</td>
<td>2.25</td>
<td>202</td>
<td>?</td>
<td>300</td>
</tr>
<tr>
<td>Ca</td>
<td>4</td>
<td>6</td>
<td>10</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Mg</td>
<td>50</td>
<td>20</td>
<td>20</td>
<td>30</td>
<td>35</td>
</tr>
</tbody>
</table>

(h) Treatment: Phosphate & potassium (PK) applied.

<table>
<thead>
<tr>
<th>Element</th>
<th>15% Light</th>
<th>25% Light</th>
<th>50% Light</th>
<th>75% Light</th>
<th>100% Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2.29</td>
<td>1</td>
<td>2.61</td>
<td>0.5</td>
<td>2.02</td>
</tr>
<tr>
<td>P</td>
<td>22</td>
<td>0.37</td>
<td>30</td>
<td>0.56</td>
<td>20</td>
</tr>
<tr>
<td>K</td>
<td>285</td>
<td>2.04</td>
<td>260</td>
<td>?</td>
<td>196</td>
</tr>
<tr>
<td>Ca</td>
<td>10</td>
<td>6</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Mg</td>
<td>55</td>
<td>40</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

N.B. A = P.p.m. (Rapid tests). B = % in DM. (Full analysis).
The rapid method used for the determination of nitrate-nitrogen proved to be unsatisfactory as an index of nitrogen content. The method used for determining potassium is also somewhat unreliable and was superseded before the survey was commenced - this should be borne in mind when the results obtained for this element are examined. Lack of time precluded repetition of these tests.

Results for full chemical analysis for calcium and magnesium were not available.

There may be considerable differences in the mineral content of leaf samples taken from the same trees at different times. This is demonstrated in table 3: the results shown in the third column were obtained from samples of leaves taken from the same trees as were tested previously (giving the results in the second column) but about 3-4 months later. The analysis was done by full chemical methods by the Cocoa Research Department, I.C.T.A.

**TABLE 3. Difference in mineral content of cacao leaves from the Shade Expt. sampled at different times.**

<table>
<thead>
<tr>
<th>Sample: (treatment)</th>
<th>Phosphate content of lvs.</th>
<th>Potash content of the leaves.</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% in EM.</td>
<td>Ditto, 3-4 months later</td>
<td>% in EM.</td>
</tr>
<tr>
<td>N.50% light</td>
<td>0.32</td>
<td>0.45</td>
<td>0.13</td>
</tr>
<tr>
<td>P.50% &quot;</td>
<td>0.37</td>
<td>0.49</td>
<td>0.12</td>
</tr>
<tr>
<td>N.15% &quot;</td>
<td>0.34</td>
<td>0.35</td>
<td>0.01</td>
</tr>
<tr>
<td>P.25% &quot;</td>
<td>0.32</td>
<td>0.45</td>
<td>0.13</td>
</tr>
<tr>
<td>P.75% &quot;</td>
<td>0.48</td>
<td>0.52</td>
<td>0.04</td>
</tr>
<tr>
<td>P.100% &quot;</td>
<td>0.43</td>
<td>0.48</td>
<td>0.05</td>
</tr>
<tr>
<td>WP.100% &quot;</td>
<td>0.31</td>
<td>1.16</td>
<td>0.85</td>
</tr>
<tr>
<td>HK.75% &quot;</td>
<td>?</td>
<td>2.30</td>
<td></td>
</tr>
<tr>
<td>HK.25% &quot;</td>
<td>2.08</td>
<td>2.90</td>
<td>0.82</td>
</tr>
<tr>
<td>(1)75% &quot;</td>
<td>2.01</td>
<td>3.07</td>
<td>1.06</td>
</tr>
<tr>
<td>K.75% &quot;</td>
<td>1.96</td>
<td>2.58</td>
<td>0.62</td>
</tr>
<tr>
<td>PK.100% &quot;</td>
<td>2.24</td>
<td>2.79</td>
<td>0.55</td>
</tr>
</tbody>
</table>

N.B. % in EM = Percentage in the dry matter.
Further tests for phosphate and potassium were then carried out on a number of samples consisting of 12 leaves from trees in the shade experiment. Discs of lamina were taken from these with a leaf punch, at random, and Morgans extracts prepared from the discs. The remainder of the lamina was ashed.

Rapid chemical tests were done on the extracts and phosphate and potash determined by full chemical analytical methods on the ash. The material used for both methods was therefore as nearly identical as possible and a greater degree of correlation between the results obtained would be expected. This correlation was obtained as shown in table 4 and the correlation curves (Figs. 2 and 3.)

Unfortunately the number of samples taken was hardly sufficient to prove conclusively that there is good corre-
lation between results obtained by rapid chemical tests and full analytical methods but the necessity of commencing work on the survey prevented more time being spent on further tests of this type.

Work by Dr. H. Evans showed that very satisfactory correlation could be obtained and it was therefore decided to start with the survey of cacao on estates in spite of the insignificant information obtained from this part of the preliminary investigations.

**TABLE 4. Results of rapid chemical tests and full analysis of samples from the Shade Experiment, I.C.T.A.**

<table>
<thead>
<tr>
<th>Sample: (treatment)</th>
<th>Phosphate P.p.m. % in DM</th>
<th>Sample: (treatment)</th>
<th>Potassium P.p.m. % in DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. 50% light</td>
<td>35 0.45</td>
<td>NP. 100% 1t.</td>
<td>195 1.16</td>
</tr>
<tr>
<td>P. 50% &quot;</td>
<td>40 0.49</td>
<td>MK. 75% &quot;</td>
<td>510 2.30</td>
</tr>
<tr>
<td>N. 15% &quot;</td>
<td>30 0.35</td>
<td>MK. 25% &quot;</td>
<td>670 2.90</td>
</tr>
<tr>
<td>P. 25% &quot;</td>
<td>35 0.45</td>
<td>(1) 75% &quot;</td>
<td>690 3.07</td>
</tr>
<tr>
<td>P. 75% &quot;</td>
<td>50 0.52</td>
<td>K. 75% &quot;</td>
<td>600 2.58</td>
</tr>
<tr>
<td>P. 100% &quot;</td>
<td>38 0.48</td>
<td>PK. 100% &quot;</td>
<td>650 2.79</td>
</tr>
<tr>
<td>NP. 75% &quot;</td>
<td>46 0.44</td>
<td>N. 50% &quot;</td>
<td>204 1.25</td>
</tr>
<tr>
<td>(1) 25% &quot;</td>
<td>41 0.34</td>
<td>(1) 100% &quot;</td>
<td>350 1.98</td>
</tr>
<tr>
<td>N. 75% &quot;</td>
<td>48 0.47</td>
<td>MK. 15% &quot;</td>
<td>384 2.04</td>
</tr>
<tr>
<td>NP.100% &quot;</td>
<td>44 0.42</td>
<td>PK. 15% &quot;</td>
<td>400 2.10</td>
</tr>
<tr>
<td>P. 75% &quot;</td>
<td>51 0.56</td>
<td>P. 50% &quot;</td>
<td>448 2.24</td>
</tr>
<tr>
<td>K. 50% &quot;</td>
<td>36 0.26</td>
<td>NK. 50% &quot;</td>
<td>300 1.78</td>
</tr>
</tbody>
</table>
FIGURE 2. Correlation between phosphate content of leaf samples as determined by rapid tests and normal analysis.

FIGURE 3. Correlation between potassium content of leaf samples as determined by rapid tests and normal analysis.
C. GRADIENTS IN MINERAL CONTENTS OF PLANTS.

Table 5 shows the range covered in the content of the various minerals, of which determinations have been carried out during the preliminary work and the survey, in cacao plants growing in the field. These include plants subjected to normal manurial treatments but not plants grown in pots, etc. and subjected to special treatments to induce deficiency or toxicity symptoms.

TABLE 5. Range of mineral contents in cacao leaves (p.p.m.)

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Minimum</th>
<th>Average Levels</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate N.</td>
<td>3</td>
<td>5 - 25</td>
<td>63</td>
</tr>
<tr>
<td>Phosphate</td>
<td>10</td>
<td>20 - 30</td>
<td>50</td>
</tr>
<tr>
<td>Potassium</td>
<td>30</td>
<td>200 - 300</td>
<td>690</td>
</tr>
<tr>
<td>Calcium</td>
<td>4</td>
<td>5 - 10</td>
<td>35</td>
</tr>
<tr>
<td>Magnesium</td>
<td>15</td>
<td>25 - 45</td>
<td>70</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.05</td>
<td>0.2 - 0.5</td>
<td>1.15</td>
</tr>
<tr>
<td>Chlorine</td>
<td>2.8</td>
<td>4.0 - 6.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Iron</td>
<td>Nil</td>
<td>0.5 - 1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Copper</td>
<td>0.20</td>
<td>0.5 - 1.0</td>
<td>1.40</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.10</td>
<td>0.5 - 1.5</td>
<td>2.30</td>
</tr>
</tbody>
</table>

Tests were carried out on a large number of apparently healthy cacao leaves, i.e. leaves showing no deficiency or toxicity symptoms, and also - where these were available - on leaves showing visual symptoms indicating deficiencies or toxicities.

In table 6 tentative critical values have been set out, from results obtained, for deficiency symptoms and in two cases toxicity symptoms. The values have been based on the visual appearance of the leaves only.

N.B. Blank spaces in the table indicate that no data is available.
TABLE 6. Critical values for healthy and nutrient deficient leaves - p.p.m. concentration of the minerals in leaf extract as determined by rapid chemical tests.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Healthy Leaves</th>
<th>Deficiency Values</th>
<th>Toxicity Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate N.</td>
<td>M 10</td>
<td>L 5</td>
<td>-</td>
</tr>
<tr>
<td>Phosphate</td>
<td>10 - 50</td>
<td>L 10</td>
<td>-</td>
</tr>
<tr>
<td>Potassium</td>
<td>150 - 400</td>
<td>L 100</td>
<td>-</td>
</tr>
<tr>
<td>Calcium</td>
<td>5 - 25</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Magnesium</td>
<td>30 - 60</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.4 - 1.0</td>
<td>L 0.3</td>
<td>M 2.0</td>
</tr>
<tr>
<td>Chlorine</td>
<td>3 - 10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Iron</td>
<td>1.0 - 2.0</td>
<td>L 0.5</td>
<td>-</td>
</tr>
<tr>
<td>Copper</td>
<td>0.3 - 1.5</td>
<td>L 0.2</td>
<td>-</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.2 - 1.5</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

L = Less than. M = More than.
SURVEY OF ESTATE CACAO ON VARYING SOIL TYPES

A. AREA COVERED BY THE SURVEY.

It was intended, as stated in the introduction to this report, to carry out determinations on cacao samples from as many cacao growing areas and on as many different soil types as possible throughout Trinidad. Owing to the time necessarily spent on preliminary work and other factors however, it has only proved possible to take samples from the following areas:

(a) Northern Range valleys - including the Diego Martin, Santa Cruz, Maracas and Lopinot valleys and the Toco area.

(b) The Montserrat district.

(c) The Tumpuna valley.

(d) The Sangre Grande - Biche area.

Samples from fifteen different estates or stations, including twelve different soil types, were taken. Samples were taken from blocks of cacao which had received no manurial treatment with the exception of that at La Pastora where annual dressings of complete fertiliser had been given.

The estates, etc. are listed below:

1. La Pastora Cocoa Propagating Station. (Cocoa Board) Santa Cruz.
2. Non Valmont Estate.
3. Ortinola Estate.
4. San Jose de Caura Estate.
5. La Nourice Estate.
7. El Reposo Demonstration Station. (Dept. of Agriculture) Sangre Grande.
8. Providence Estate.
9. San Juan Estate.
10. Santa Rita Estate.
11. Forres Park Estate.
12. Santa Maria Estate.
13. Los Amigos Estate.

14. The Imperial College of Tropical Agriculture.

15. Esperanzo Estate.

The following soil types are represented: St. Augustine Loam, Sangre Grande Silty-clay, Talparo Clay, Ecclesville Clay, Brasso Clay, River Estate Fine Sand and four un-named types (A, B, C & D).

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B. RESULTS OBTAINED.

Samples were obtained from the estates as described in Part I of this report ("Sampling and Preparation of Extracts") and determinations for nitrate-nitrogen, phosphate, calcium, potassium, magnesium, chloride, manganese, iron, copper and zinc carried out on each sample by the methods detailed in Part II, sections I and II. The results obtained from this survey are given in Table 7 below.

TABLE 7. (a) Mineral content of cacao on various estates - macronutrients.

<table>
<thead>
<tr>
<th>Estate</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>La Pastora</td>
<td>63</td>
<td>22</td>
<td>176</td>
<td>5.0</td>
<td>20</td>
</tr>
<tr>
<td>Non Valmont</td>
<td>16</td>
<td>18</td>
<td>196</td>
<td>5.0</td>
<td>25</td>
</tr>
<tr>
<td>Ortinola</td>
<td>26</td>
<td>20</td>
<td>270</td>
<td>8.0</td>
<td>40</td>
</tr>
<tr>
<td>San Jose</td>
<td>5</td>
<td>22</td>
<td>205</td>
<td>6.2</td>
<td>70</td>
</tr>
<tr>
<td>La Nourice</td>
<td>10</td>
<td>28</td>
<td>295</td>
<td>5.8</td>
<td>35</td>
</tr>
<tr>
<td>River Estate</td>
<td>5</td>
<td>30</td>
<td>365</td>
<td>6.2</td>
<td>70</td>
</tr>
<tr>
<td>El Reposo</td>
<td>7.5</td>
<td>25</td>
<td>204</td>
<td>5.6</td>
<td>60</td>
</tr>
<tr>
<td>Providence</td>
<td>7.5</td>
<td>22</td>
<td>275</td>
<td>5.0</td>
<td>45</td>
</tr>
<tr>
<td>San Juan</td>
<td>31</td>
<td>40</td>
<td>285</td>
<td>5.2</td>
<td>30</td>
</tr>
<tr>
<td>Santa Rita</td>
<td>2.7</td>
<td>32</td>
<td>150</td>
<td>9.1</td>
<td>40</td>
</tr>
<tr>
<td>Forres Park</td>
<td>7</td>
<td>38</td>
<td>275</td>
<td>11.5</td>
<td>40</td>
</tr>
<tr>
<td>Santa Maria</td>
<td>7.5</td>
<td>28</td>
<td>135</td>
<td>9.7</td>
<td>30</td>
</tr>
<tr>
<td>Los Amigos</td>
<td>15</td>
<td>35</td>
<td>240</td>
<td>6.5</td>
<td>40</td>
</tr>
<tr>
<td>I.C.T.A.</td>
<td>8</td>
<td>30</td>
<td>200</td>
<td>6.0</td>
<td>40</td>
</tr>
<tr>
<td>Esperanzo</td>
<td>3</td>
<td>12</td>
<td>365</td>
<td>8.6</td>
<td>40</td>
</tr>
</tbody>
</table>
TABLE 7. (b) Mineral content of cacao on various estates - micronutrients.

<table>
<thead>
<tr>
<th>Estate</th>
<th>CI</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
<th>Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>La Pastora</td>
<td>3.8</td>
<td>0.76</td>
<td>0.5</td>
<td>0.36</td>
<td>0.25</td>
<td>Un-named - A</td>
</tr>
<tr>
<td>Non Valmont</td>
<td>4.6</td>
<td>1.10</td>
<td>0.5</td>
<td>0.25</td>
<td>2.30</td>
<td>&quot; - B</td>
</tr>
<tr>
<td>Ortinola</td>
<td>5.0</td>
<td>1.15</td>
<td>0.5</td>
<td>0.66</td>
<td>1.15</td>
<td>&quot; - C</td>
</tr>
<tr>
<td>San Jose</td>
<td>12.0</td>
<td>0.45</td>
<td>0.5</td>
<td>0.68</td>
<td>0.50</td>
<td>&quot; - D</td>
</tr>
<tr>
<td>La Nourice</td>
<td>8.5</td>
<td>0.42</td>
<td>0.5</td>
<td>0.75</td>
<td>0.10</td>
<td>Toco Loam</td>
</tr>
<tr>
<td>River Est.</td>
<td>10.5</td>
<td>0.52</td>
<td>1.0</td>
<td>1.40</td>
<td>0.80</td>
<td>River Est. Fine Sand</td>
</tr>
<tr>
<td>El Reposo</td>
<td>12.5</td>
<td>0.60</td>
<td>0.5</td>
<td>0.65</td>
<td>0.63</td>
<td>Sangre Gr. Silty-clay</td>
</tr>
<tr>
<td>Providence</td>
<td>3.5</td>
<td>0.16</td>
<td>0.5</td>
<td>1.00</td>
<td>0.14</td>
<td>Talpero Clay</td>
</tr>
<tr>
<td>San Juan</td>
<td>4.0</td>
<td>0.10</td>
<td>1.0</td>
<td>0.70</td>
<td>1.20</td>
<td>Montserrat Clay</td>
</tr>
<tr>
<td>Santa Rita</td>
<td>4.7</td>
<td>0.90</td>
<td>1.0</td>
<td>0.95</td>
<td>2.11</td>
<td>Talpero Clay</td>
</tr>
<tr>
<td>Torres Ek.</td>
<td>5.0</td>
<td>0.11</td>
<td>2.0</td>
<td>1.00</td>
<td>1.66</td>
<td>Brasso Clay (bad)</td>
</tr>
<tr>
<td>Santa Maria</td>
<td>6.7</td>
<td>0.05</td>
<td>0.5</td>
<td>1.30</td>
<td>0.63</td>
<td>Ecclesville Clay</td>
</tr>
<tr>
<td>Los Amigos</td>
<td>4.5</td>
<td>0.25</td>
<td>1.0</td>
<td>1.00</td>
<td>1.00</td>
<td>Brasso Clay (good)</td>
</tr>
<tr>
<td>I.C.T.A.</td>
<td>4.0</td>
<td>0.40</td>
<td>0.5</td>
<td>1.10</td>
<td>0.75</td>
<td>St. Augustine Loam</td>
</tr>
<tr>
<td>Esperenzo</td>
<td>2.8</td>
<td>0.10</td>
<td>1.0</td>
<td>0.95</td>
<td>0.00</td>
<td>Montserrat Clay</td>
</tr>
</tbody>
</table>

N.B. Montserrat Clay is the so-called "Chocolate Soil" of Trinidad - recognised as one of the best cocoa growing soils.

A study of Table 7 and the section "Notes on the Soil Types" shows that some relationship between the content of nutrients in the leaves and the available nutrients in the soil exists.

For instance Montserrat Clay contains the most nitrogen and the leaf sample from San Juan estate on this soil type also contains the most nitrate - except for the sample from La Pastora, which was much higher in nitrate content but there applications of nitrogenous fertilisers have been given.

Good Brasso Clay is also high in nitrogen and this is borne out by a high figure for nitrate in the leaf sample from this soil. River Estate Fine Sand is low in nitrogen
and the leaf sample from River Estate is also low in nitrogen.

A similar correlation is evident with phosphate. Again Montserrat Clay contains the most available phosphate and the leaf sample from San Juan also gave the most. (The figures for nitrate and phosphate for samples from Esperanzo estate are much lower but in this case the Montserrat Clay is probably a mixture with Brasso Clay.)

Brasso Clay at Los Amigos and Forres Park estates contains the next highest content of phosphate and leaf samples from these two estates also gave a high figure for phosphate. The soils with the lowest phosphate content - Ecclesville Clay and River Estate Fine Sand - did not show the lowest figures for this nutrient on leaf analysis however.

With regard to potash the relationship is not so clear. Montserrat Clay contains the most potash and leaf samples from both San Juan and Esperanzo estates gave a high figure for this nutrient but a high figure was also obtained for the leaf sample from River Estate Fine Sand which is very low in potash.

Iron deficiency is generally associated with a soil which is not sufficiently acid (pH 6.0 or over) and one would therefore expect to find the most iron in leaf samples from the most acid soils. This was not always the case however - Montserrat Clay has an average pH of 7.2 in the upper horizon and yet leaf samples showed no iron deficiency - this may be explained by the fact that the soil becomes acid below a depth of 6" however.

Leaf samples from Brasso Clays with pH figures of 6.5 and 6.9 gave iron contents of 1.0 and 2.0 p.p.m. In no case however was an iron content of over 0.5 p.p.m. obtained where visual symptoms of iron deficiency were present and
visual symptoms were seen on trees in all areas from which samples were taken which gave values for iron content of 0.5 ppm. or less.

It would appear from the figures for leaf analysis that bad Brasso Clay and Ecclesville Clay contain the most calcium while the un-named soil type - D - at San Jose, Sangre Grande Silty-clay and River Estate Fine Sand contain the most chloride. Montserrat Clay, Talparo Clay and St. Augustine Loam are low in chloride.

The soil at San Jose (un-named - D), Sangre Grande Silty-clay and River Estate Fine Sand have a very high content of magnesium while un-named types A and B appear to be deficient in this element - according to leaf tests. The soils with a low magnesium content also show a low copper content.

Ecclesville Clay, Montserrat Clay and Brasso Clay may be deficient in manganese.

Toco Loam appears to be deficient in zinc. Montserrat Clay at Esperanze estate and Talparo Clay at Providence estate contain very small amounts of zinc yet samples from these same soil types at San Juan and Santa Rita respectively contained a high zinc content.

With regard to the macro-nutrients in the un-named soil types, A and C have a low content of available phosphate and potassium. Leaf determinations on samples from these soils gave fairly low phosphate contents; the sample from soil type A also gave a low potassium content but that from soil type C was fairly high in potassium.

Soil type D is medium to high in phosphate and potassium and similar results were obtained from the tests of the leaf sample from that soil. Figures for the un-named soil type B are not available.
C. NOTES ON THE SOIL TYPES.

**Brasso (Heavy) Clay** - tawny yellow colour in the upper zone. Structure less open than Montserrat Clay. Fairly high concentration of organic matter in the top two feet. Can be divided into two main sub-types; good Brasso Clay (C/N ratio 7.3) as at Los Amigos estate and bad Brasso Clay (C/N ratio 5.8) as at Cedar Hill (Forres Park estate). The bad type has a lower lime content but both types are somewhat acidic in the upper zone.

**Montserrat Clay** - upper zone very deep - average about 3 feet, friable, chocolate brown. High organic matter content in the top 6 inches and penetration may extend throughout the zone. Surface layer of decomposing vegetable matter. Usually no calcium carbonate in the surface soil owing to extensive leaching but may show an alkaline reaction rapidly becoming acidic below 6 inches depth. Naturally well drained but does not dry out in dry season. The most fertile cacao soil in Trinidad.


**Ecolesville Clay or Heavy Loam** - yellow-brown, mottled below 12 inches. A highly acid loamy-silt containing medium to low amounts of organic matter and nitrogen with a fairly high C/N ratio in the top 3 inches but rapidly decreasing below. Available phosphate is very low and available potash medium in amount.

**St. Augustine Loam** - free draining, yellow-reddish-brown loam to 3 inches; then moderate brown loam with nutty structure. Below 15 inches the soil becomes reddish and contains numerous quartz and schist particles.
River Estate Fine Sand - free draining dark yellow-brown sandy loam. Prone to suffer from drought. Top horizon only 2 inches thick - nitrogen rapidly decreases below this. Second horizon (2-20") is uniform light yellowish-olive sandy loam with increasing acidity (pH 4.8). This overlies a less acidic layer speckled with orange-brown.


Toco Lom - shallow, dark brown loam overlying dull yellow-brown and grey-brown clay loam. Acid soil, low in available potash; fairly rich in available phosphate.

Un-named - type A - dark brown loamy sand or loam overlying yellowish-brown speckled orange loam. Low in available phosphate and potash.

Un-named type B - moderate to dark brown sandy loam, overlying moderate to light yellow brown loam or sandy loam.

Un-named type C - dark brown sandy loam overlying orange and yellow brown loam. Shallow soil. Low in available phosphate and potash.

Un-named type D - a small area of very fertile soil at San Jose estate.

Average values of laboratory data for the topsoil (top 6") and subsoil (second 6") of these soil is tabulated in Table 8. Where blanks occur in this table figures were not available.
TABLE 8. Average laboratory data for soil types described.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>T/S</th>
<th>N%</th>
<th>CEC</th>
<th>P&lt;sub&gt;2O5&lt;/sub&gt; ppm</th>
<th>K&lt;sub&gt;2&lt;/sub&gt;O ppm</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Brasso Clay</td>
<td>T</td>
<td>0.28</td>
<td>3.3</td>
<td>71</td>
<td>145</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>0.17</td>
<td>1.1</td>
<td>160</td>
<td>-</td>
<td>6.5</td>
</tr>
<tr>
<td>Bad Brasso Clay</td>
<td>T</td>
<td>0.28</td>
<td>2.9</td>
<td>71</td>
<td>151</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>0.14</td>
<td>1.0</td>
<td>123</td>
<td>-</td>
<td>6.4</td>
</tr>
<tr>
<td>Montserrat C.</td>
<td>T</td>
<td>0.54</td>
<td>4.5</td>
<td>343</td>
<td>309</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>0.15</td>
<td>1.6</td>
<td>223</td>
<td>-</td>
<td>7.0</td>
</tr>
<tr>
<td>Talparo Clay</td>
<td>T</td>
<td>0.22</td>
<td>2.6</td>
<td>16</td>
<td>74</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>0.10</td>
<td>1.1</td>
<td>8</td>
<td>-</td>
<td>4.7</td>
</tr>
<tr>
<td>Ecclesville C.</td>
<td>T</td>
<td>0.13</td>
<td>1.8</td>
<td>6</td>
<td>179</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>0.08</td>
<td>0.9</td>
<td>5</td>
<td>-</td>
<td>4.0</td>
</tr>
<tr>
<td>St. Augustine</td>
<td>T</td>
<td>0.13</td>
<td>1.7</td>
<td>65</td>
<td>106</td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>0.16</td>
<td>2.5</td>
<td>9</td>
<td>43</td>
<td>5.6</td>
</tr>
<tr>
<td>Gunupia Clay</td>
<td>T</td>
<td>0.21</td>
<td>3.0</td>
<td>27</td>
<td>82</td>
<td>5.0</td>
</tr>
<tr>
<td>Type D.</td>
<td>T</td>
<td>0.21</td>
<td>-</td>
<td>19</td>
<td>151</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>0.16</td>
<td>-</td>
<td>16</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

T - topsoil.  S - subsoil.

No figures are available for Toco Loam or un-named soil types A, B, and C.
DISCUSSION.

It is regrettable that the results obtained from the work described in this report should have been so variable that no really definite conclusions can be drawn with regard to the nutritional status of the soil types from which samples were taken.

The intention of the writer was to establish correlation between results from rapid chemical tests and normal full analysis of cacao leaf material before proceeding to the survey of estate cacao; this relationship was not obtained for reasons outlined in the text. No further time could be spent on this preliminary investigation and as other workers had proved this method to be satisfactory it was decided to commence the survey.

The results of the survey were to determine whether there was any relationship between the content of minerals in the leaves and the available minerals in the soil. The results of this survey have already been discussed.

It is suggested for future work that rapid tests and full chemical analysis by ashing be carried out at the same time and on samples from the same material collected on the same day.

It is also recommended that a survey be carried out on the same lines as the one described in this report but that soil samples be taken at the same time and from the same area or field as the cacao leaf samples. These samples of soil should then be analysed for available macro and micro-nutrients.
SUMMARY.

(1) Methods of sampling and preparing Morgan's and hydrochloric acid extracts from fresh cacao leaf material are described.

(2) Full details of colorimetric or turbidimetric rapid chemical tests for determining the relative mineral content of cacao leaves are given for the following nutrients: nitrate-nitrogen, phosphate, potash, magnesium, calcium, chloride, manganese, iron, copper and zinc.

(3) Tests establishing that leaf lamina are the most suitable parts of cacao trees from which to prepare extracts are detailed.

(4) A description of tests done to demonstrate correlation between results from rapid chemical tests on fresh cacao material and results from normal full analysis of ash from similar material. Good correlation was not obtained and possible reasons for this are given.

(5) Gradients in the mineral content of healthy and nutrient deficient cacao leaves (as determined by rapid tests) are tabulated.

(6) A survey of the mineral status of cacao trees in various parts of Trinidad as determined by the rapid tests mentioned previously, undertaken with a view to ascertaining the differences to be found in cacao growing on varying soil types, is described.

(7) The results obtained from this survey are discussed in relation to the available nutrient content of the soil types.

(8) Short descriptive notes of the soil types encountered during the survey are given.
ACKNOWLEDGEMENTS.

The writer wishes to record his thanks for the guidance and assistance given by his supervisor, Dr. H. Evans, Senior Plant Physiologist, Cocoa Research Scheme, I.C.T.A. Also to Mr. D. Murray, Junior Plant Physiologist, for much advice.

He is also indebted to various members of the staff of the Trinidad Department of Agriculture for assistance freely given; to the owners and managers of the estates visited for permission to take samples and for information and to student car owners who, on numerous occasions, transported him to estates to collect samples.

----------------------------------
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THE COCOA AREAS OF TRINIDAD

(Showing situation of estates from which samples were taken)

Based on a map included in a paper by Dr. B.A. Montezin presented at the 1950 Cocoa Conference in London.
~SHADE EXPERIMENT~

**Rapid Tests**

(No Mulch Block, I.C.1 Clone)

**Key**
- Green = Phosphate
- Blue = Potash

Nitrate-Nitrogen results are not included as they were unsatisfactory.

**Treatments**
- 15% Light
- 25% Light
- 50% Light
- 75% Light
- 100% Light
- Shade Experiment -

- Key -
  Red = Nitrogen
  Green = Phosphate
  Blue = Potash

Full Analysis

(No Mulch Block, I.C.S. Clone)

Appendix (iii.)
EXAMPLE OF A 'STANDARD CURVE' -

P.p.m. (Concentration in Sec. extract)

Extinction Coefficient

Cl.

WL 600 mµ.
Appendix (v)

RAPID CHEMICAL TESTS ON CACAO LEAF MATERIAL FROM GRENADA.

Although not actually within the scope of this project the results of rapid tests for nitrate, potash, phosphate, chloride, calcium, iron, magnesium and manganese on samples of cacao leaves from the five main soil types of Grenada, B.W.I. are given here as being of some interest.

The tests used were the same as those used for the survey of Trinidad cacao and they were carried out on samples of lamina material taken from 12 leaves of seedling cacao collected in the manner described previously. The age of the trees was 30 - 40 years.

<table>
<thead>
<tr>
<th>Element</th>
<th>I (ppm)</th>
<th>II (ppm)</th>
<th>III (ppm)</th>
<th>IV (ppm)</th>
<th>V (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>7.0</td>
<td>5.0</td>
<td>3.5</td>
<td>14.0</td>
<td>4.5</td>
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<tr>
<td>P</td>
<td>35</td>
<td>30</td>
<td>25</td>
<td>25</td>
<td>35</td>
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<tr>
<td>K</td>
<td>49</td>
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<td>69</td>
<td>110</td>
<td>51</td>
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<tr>
<td>Mg</td>
<td>40</td>
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<td>45</td>
<td>45</td>
<td>45</td>
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<tr>
<td>Cl</td>
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<td>14.0</td>
<td>3.75</td>
<td>4.5</td>
<td>3.75</td>
</tr>
<tr>
<td>Ca</td>
<td>8.2</td>
<td>13.5 ap.</td>
<td>7.0</td>
<td>11.0 ap.</td>
<td>11.5 ap.</td>
</tr>
<tr>
<td>Fe</td>
<td>0.75</td>
<td>1.0</td>
<td>1.0</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Mn</td>
<td>0.09</td>
<td>0.28</td>
<td>0.13</td>
<td>0.21</td>
<td>0.22</td>
</tr>
</tbody>
</table>

TABLE 9. Mineral Content of Cacao Leaf Samples from Grenada.

Results are given as parts per million concentration in 5 cc. of Morgans extract (hydrochloric acid extract in the case of iron) of the fresh leaf material.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Estate</th>
<th>Situation</th>
<th>Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Brothers</td>
<td>Cenis Rd.</td>
<td>Grey soil (ash &amp; tuff)</td>
</tr>
<tr>
<td>II</td>
<td>Tufton Hall</td>
<td>Cenis Rd.</td>
<td>Grey soil (agglomerate)</td>
</tr>
<tr>
<td>III</td>
<td>Fraze</td>
<td>Belvidere Rd.</td>
<td>Red soil (basalt)</td>
</tr>
<tr>
<td>IV</td>
<td>Mt. Pleasant</td>
<td>Grenville Rd.</td>
<td>Yellow-brown soil</td>
</tr>
<tr>
<td>V</td>
<td>Grand Bacolet</td>
<td>St. Andrews Main Rd.</td>
<td>Red soil (augite-andesite)</td>
</tr>
</tbody>
</table>

TABLE 10. Situations and Soil Types from which Samples were obtained.
Notes on the Soil Types.

**Grey Soil (Agglomerate)** - alkaline, rich in bases except at high elevations.

**Grey Soil (Ash and Tuff)** - similar to that formed from agglomerate with a very high content of exchangeable bases.

**Red Soil (Basalt)** - acidic, generally deficient in bases (especially lime and potash) at the higher elevations.

**Red Soil (Augite-Andesite)** - alkaline at low elevations and fairly high in exchangeable bases. Acidic at higher elevations and exchangeable base content lower.

**Yellow-brown Soil (Hornblende-Andesite)** - somewhat acidic, relatively low content of exchangeable bases.

Notes on the results obtained.

Nutrient content and acidity or alkalinity of Grenadian soils depends on altitude and rainfall to a greater degree than on soil type or parent material. For this reason it is of little value to compare results of rapid tests on cacao leaf material with the soil analytical data available.

It would be essential to take soil samples for analysis from the same area as the cacao samples were taken in each case.

The sample from the Grey (agglomerate) soil shows a very high chloride content - probably toxic amounts - and this result has been borne out by attempts to produce rooted cacao cuttings at Maran on this soil type.