Wageningen 1955

THE APPLICATION OF FOLIAR ANALYSIS IN OIL PALM CULTIVATION

H. BROESHART

NN080201,193

Dit proefschrift met stellingen van
HANS BROESHART
landbouwkundig ingenieur, geboren te Amsterdam, 28 November 1924, is goedgekeurd door de promotor
Dr A. C. SCHUFFELEN,
hoogleraar in de landbouwscheikunde.

De Rector Magnificus der
Landbouwhogeschool
W. F. EYSVOOGEL

Wageningen, 23 Februari 1955.

THE APPLICATION OF FOLIAR ANALYSIS IN OIL PALM CULTIVATION

PROEFSCHRIFT
TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE LANDBOUWKUNDE, OP GEZAG VAN DE RECTOR MAGNIFICUS IR W.F. EYSVOOGEL, HOOGLERAAR IN DE HYDRAULICA, DE BEVLOEIING, DE WEG- EN WATERBOUWKUNDE EN DE BOSBOUW-ARCHITECTUUR, TE VERDEDIGEN TEGEN DE BEDENKINGEN VAN EEN COMMISSIE UIT DE SENAAT VAN DE LANDBOUW-HOGESCHOOL TE WAGENINGEN OP VRIJDAG 1 APRIL 1955 TE 16 UUR

DOOR

HANS BROESHART

UITGEVERIJ EXCELSIOR — Oranjeplein 96 — 's-GRAVENHAGE

PREFACE (voorwoord)

Bij het beeindigen van dit proefschrift, gaat allereerst mijn oprechte dank uit naar U, Hooggeleerde SCHUFFELEN, Hooggeachte promotor. Uw candidaats- en ingenieurs colleges hebben de basis gelegd voor mijn latere werk in de Belgische Congo. Ook na mijn ingenieurs examen, als Uw assistent, heb ik veel van U mogen leren; de prettige sfeer op Uw laboratorium zal ik nooit vergeten. Onze gedachtenwisselingen in Leopoldville op het Internationaal Bodemkundig Congres en in Yaligimba op het proefstation van Huilever S.A., hebben tot verbetering van dit proefschrift bijgedragen.

Hooggeleerde KUIPER, U dank ik voor Uw welwillendheid om de statistische verwerkingen in dit proefschrift met mij te hebben willen doornemen.

To the Direction of HUILEVER S.A., I wish to express my gratitude for permission to publish on work which was carried out by the Research Department in the Belgian Congo. Not many companies allow their young scientists to publish data of private research.

Mr. de BLANK, Director of the Research Department, I am indebted for great help, encouragement and criticism, as well as for the correction of the English text.

Professor WARDLAW, I want to thank for encouragement and advice, in the preparation of this thesis.

Mesrs. KOVACHICH and FERWERDA, in the years we worked closely together in the Research Department, you have proved to be good friends and good scientists. Mr. KOVACHICH I thank particularly for his valuable criticism and advice, as well as for his aid in the description of leaf deficiency symptoms.

Jan FERWERDA, in vele opzichten beschouw ik je als een van mijn leermeesters. Ook in de toekomst hoop ik nog veel te kunnen leren van je grote ervaring als landbouwkundige en je scherpe critische geest. Ik dank je dat ik gegevens van je proefvelden in Bolembo, Kanangai en Yaligimba, heb mogen verwerken in dit proefschrift.

Mr. EVANS, I am indebted for the way he introduced me to the particular difficulties of laboratory work in the tropics. I will never forget his friendship during and after working hours.

Chèr Monsieur VREVEN, je vous remercie pour votre aide avec l'échantillonage des expériences à Brabanta.

Mes assistants Africains, je vous remercie pour les milliers d'analyses que vous avez fait dans notre laboratoire.

VADER en MOEDER, jullie dank ik voor de wijze, waarop jullie mij altijd hebben gestimuleerd in mijn studie, ondanks de vaak moeilijke omstandigheden.

BEP, het is zo onnoemelijk veel waarvoor ik je danken moet; aan jou draag ik dit proefschrift op.

CONTENTS

I. INTRODUCTION

In the general economy of the Belgian Congo, the production of palm oil has come to play an important rôle. Palm oil for export is produced by organised plantations and from natural palmeries, exploited by the local population.

Despite early optimistic prognostications in respect of production from natural palmery fruit of oil of satisfactory quality for industrial purposes, it quickly became evident that these expectations would not be realised and that in order to obtain the required quantities of good quality palm oil, other methods for its production would have to be instituted. The solution of this problem was considered to lie in the creation of organised plantations. In these circumstances it was natural that the early oil palm plantations should be started in those regions, where natural palmeries represented a feature of the existing vegetation.

It was inevitable that some of these early ventures should result in comparative failure, owing to lack of fundamental knowledge on the succesful establishment of oil palm plantations. An investigation of the factors responsible for these failures revealed that wrong appreciation of soil quality, incorrect cultural methods and use of unsuitable seeds were mainly involved. It had not been sufficiently realised that the majority of the soils in the Belgian Congo consisted of highly weathered formations of inherently low fertility and that forest density was not a satisfactory measure of the soil nutritional status. After the creation of the plantations it quickly became apparent, in some areas, that general growth and development were unsatisfactory, as manifested by a high disease incidence and low production. During the war years it was not possible to investigate these conditions owing to lack of staff, and the problem only received serious attention in the years, following the termination of hostilities. Investigations carried out immediately after the war, suggested that the problems affecting these areas couldbe devided into two main groups:

(i) diseases due to fungal attack;
(ii) diseases of physiological origin.

Later it was shown that, under certain conditions, these two groups may be closely related and that the incidence of fungal diseases is partly governed by soil nutritional status. Based on the above considerations, it was evident that the use of appropriate mineral fertilisers represented a valuable aid in resolving some, if not all, of these difficulties. Owing however, to lack of adequate satisfactory experimentation, no knowledge was available in respect of the type and quality of fertiliser, that might be required, nor were data available on the general economics of such treatments. Classical methods of soil analysis were unlike to be of much value in this respect, due to inadequate knowledge of the soils of these regions, and the only satisfactory method of approach at that time appeared to be by means of suitable field experiments, which have the great disadvantage of being both combersome and long term in character. The application of new techniques to this problem, such as by means of leaf injection, tissue tests etc., were tried out but proved generally unsatisfactory when dealing with a monocotyledonus treeculture.

The application of foliar analysis to oil palm, as first suggested by Chapman and Gray in Malaya, was, therefore, investigated as a promising approach to provide a rapid means of diagnosis. Further experience has shown that a combination of soil analysis, field fertiliser experiments and foliar analysis represents the only satisfactory solution at this stage to determine the qualitative and quantitative fertiliser requirements of oil palms. Each of these methods will be examined in more detail.

A. Fertiliser experiments

To date, these represent the only satisfactory method for determining the means of correcting deficiency symptoms and for increasing the overall production of existing oil palm plantations. It must be recognised, however, that fertiliser experiments suffer from the great inconvenience that they must be, of necessity, complex and long term in character before data, from which reliable conclusions may be drawn, are obtained, However, they still represent the only satisfactory method for the accurate determination of optimal levels of fertiliser applications. Thus, although in our present state of knowledge, fertiliser experiments remain indispensable, it should be recognised that:

1. Contrary to general opinion, Congo soils do not show that high degree of homogeniety, generally attributed to them. Thus, a fertiliser experiment, covering only a smal part of the actual plantation provides data, applicable only to the soil type, on which it has actually been established and not necessarily to the plantation as a whole. In large plantation complexes, various soil types or fertility gradients may occur, which may only be determined by means of detailed soil studies but on the results of which it is not possible to extrapolate the results obtained from the actual experiment.
2. In these circumstances, it would be necessary to lay down fertiliser experiments on each soil type, obtaining in the plantation, representing a very costly procedure:
3. Owing, to the changes, which inevitably occur in the nutritional status of plantation soils, due to the exportation of mineral elements with the final products and general degradation by leaching of the soluble elements, it would be necessary to maintain the field experiments throughout the life of the plantations.
4. In young plantations, established on virigin forest land, the changes in the nutritional status, due to the rapid release of nutrients from the decomposition of forest cover, increased micro-biological activity and a high rate of weathering in the early years, are so rapid that these can not be detected by means of fertiliser experiments.

It should be stressed, however, that, in the present stage of knowledge, the use of fertiliser experiments is indispensable as an aid in the quantitative correction of deficiencies and as playing an important part in the interpretation of the results of leaf and soil analysis.

B. Soil Analysis

In temperate regions, advice on fertiliser policy may now be based on the data obtained from soil analysis. These are obtained by the use of neutral salts, buffered solutions and dilute acids to extract the "Readily available" nutrients, which, for the major part, are adsorbed by the adsorbtion complex of the soil. From the analytical data accumulated over a long period, plus the information obtained from fertiliser experiments and the correlations between crop yields and analytical data for a wide range of soil types, it is now possible for soil chemists in these areas to determine the critical nutrient levels in such soils. In cases where an element falls below this critical level, its application in appropriate form will result in an increase in production.

It should be stressed however, that these critical levels in the soil are valid only for one particular soil type, for the same combination of colloidal and physical properties of the soil and for any particular crop. There are considerable difficulties in the interpretation of soil analytical data, which reduces considerably the value of the soil analysis as a basis for a sound fertiliser policy. In point of fact, it is not possible to translate the chemical composition of a soil extract, obtained by conventional means, in terms of availability of nutrients to plant roots. This depends on a series of factors mainly physical and colloidal, amongst which should be mentioned oxygen content, porosity, water relationships, soil temperature, all of which play their part in the uptake of elements by plant roots. Thus, two soils with the same contents of citric acid soluble phosphorus may show a widely varying availability of this element, due to differences in structure, oxygen content or other factor(s), mentioned above. Another difficulty is introduced by the fact that the reaction of plant roots depends not on the concentration of the various nutrients in the soil, but on their activity, which, in turn, depends for the major part on the nature and amount of the clay minerals present, the organic matter content, the ratio between cations and anions and their actual concentrations. It has not yet proved possible to determine, in a simple direct way, the activities of the various elements in the soil.

An added difficulty in the interpretation of soil analytical data results from the nature of the plant in general and from its root system in particular. The amount of nutrients extracted by different plants species, growing under the same nutritional conditions, will vary in relation to their requirements and further depends on the extent and depth of the rooting systems.

Under tropical conditions, the difficulties, mentioned above, are of even greater importance for the following reasons:

1) Insufficient data obtained from areas of known productivity are

available to enable the necessary regressions to be determined:

2) The number of fertiliser experiments on oil palms, which have resulted in positive responses, are still too limited to enable definite conclusions of general applicability to be drawn.

3) The characteristics of tropical African soils differ materially from those of temperate regions. The former contain such low concentrations of readily available nutrients, due to their low adsorbtion capacity, their low organic matter content, and as a result of excessive leaching, that considerable difficulties are encountered in their determination in a neutral salt solution or dilute acid.

4) The high content of iron and aluminium compounds results in the fixation of phosphorus in a form, unavailable to plants, despite the fact that dilute acid extraction figures may be relatively high.

5) It has not sufficiently been realised that the constant weathering of the mineral reserves and subsequent release of elements provides a steady supply of plant nutrients, so that it is important to determine not the availability but the total mineral reserves in these soils.

C. Foliar Analysis

The interpretation of the changes in the chemical composition of leaves is based on the conception that growth and production are directly related to the concentration of nutrients in the leaf tissue, irrespective of the character of the nutrient medium. An important advantage of this method is the fact that the nutrient status of the palm is directly and not indirectly determined.

Having ascertained the relationships between the chemical leaf composition and growth and/or production, and knowing that fertiliser applications result in corresponding changes in leaf composition, growth and production responses, the method of foliar analysis as a diagnostic tool offers considerable advantages over fertiliser experiments and soil analysis for the following reasons:

1) The reasons for bad growth conditions or low production levels are known immediately on completion of the foliar analysis, representing a very material saving on time;

2) The anticipated effect of a response to fertilisers may be identified some considerable time, before the actual response is obtained, constituting a valuable advantage in those cases, where early information is required on the effect of fertiliser applications in plantations;

3) Maps of plantations, based on the results of foliar analysis, may be prepared at regular intervals, showing the nutrient status of the palms of each block.

4) The rapid changes in soil nutrient conditions in young plantations may be followed up, enabling recommendations to be made for appropriate fertiliser applications, to ensure optimal growth of the young palms.

The above points suggest that the method of foliar analysis constitutes a rapid diagnostic tool, on the results of which appropriate fertiliser policies may be based.

Aim of the thesis

The aim of the present work is to investigate to what extent foliar analysis of oil palms is able to provide information on the qualitative and quantitative application of fertilisers to oil palm plantations.

After examination of the literature on this subject and the choice of a sampling and an analytical technique, the influence of various factors, such as the morphological position of the leaflets, age of the palms, effect of climate and errors in the sampling and analytical techniques on the chemical composition of the palm leaves require investigation. The relation between growth and production of palms as related to leaf nutrient concentrations should be determined. The recognition of major element deficiencies, Nitrogen, Phosphorus, Potassium, Calcium and Magnesium, their cure and corresponding changes in leaf composition, induced by fertilisers, forms one of the main sections of this work.

After showing that the method may be applied qualitatively, i. e. the diagnosis of deficiencies, the quantitative relationship between leaf composition on the one hand, and growth and/or production on the other hand, as a function of fertiliser application, will be examined.

II. LITERATURE

The literature on the subject of Foliar Analysis is enormous. An excellent review of the investigations, carried out on a great number of crops, is given by GOODALL and GREGORY (1947). In Sweden, LUNDEGÅRDH applied the principles of foliar analysis to cereals (1951), one of the rare examples, where the method has been used to advice on fertiliser policy on a large scale. In the U. S. A., tissues tests are frequently being applied for practical purposes.

CHAPMAN and GRAY, working in Malaya, were the pioneers in applying the principles of foliar analysis to oil palms (1949). More recently, OLLAGNIER, PREVOT and other workers of the "Institut de Recherches pour les Huiles et Oleagineux" in French Equatorial Africa (1952-1954) and BROESHART in the Belgian Congo (1950-1954) have continued these investigations.

A review of the literature, with special reference to the application of foliar analysis to oil palms as a diagnostic method for determining fertiliser requirements, follows.

(i) Extraction Procedure

Two main extraction techniques are used by workers on foliar analysis:
(a) The determination of the readily soluble fractions of the various elements in the leaves;
(b) The analysis of the total quantities of elements present in the leaves.

(a) This determination is based on the concept that these elements have recently been taken up by the plant and, thus, indicate the present nutrient status. (THORNTON-1934, ULRICH-1941, EMMERT-1942, MORGAN-1935 and CAROLUS-1938). The method deals particularly with the elements Nitrogen. Phosphorus and Sulphur, which have been shown to play an important part in the formation of proteins in the protoplasm. The following extractants have been used:
water (PAGE, BURKHART - 1941),
2% acetic acid (EMMERT, CAROLUS)
sodium acetate buffer solution (MORGAN-1937).
In all these techniques, it is essential that the extractions are made on fresh material, as important changes in the proportions between the readily and non readily soluble fractions may take place, dependent upon the time elapsed between sampling and analysis.

(b) Determination of the total quantity of elements in the leaves. This involves the wet or dry ashing of the plant material. LUNDEGÅRDH uses dilute hydrochloric acid as extractant and found that a N/1 solution dissolves the total quantities of all metals present.

With reference to foliar analysis of the oil palm, wet and dry ashing techniques were used by CHAPMAN and GRAY in Malaya and by the French workers (PREVOT, OLLAGNIER and SCHEIDECKER). As leaf samples from oil palm plantations have frequently to be sent to a central laboratory by mail, the material should be oven dried, prior to despatch, precluding the possibility of determining the readily soluble nutrient fractions by one of the extractants, mentioned above.

(ii) Expression of Analytical Results

Analytical data may be expressed on a leaf, a unit leaf area (LINDNER, HARLEY - 1942-1944), on a fresh weight (van GINNIKEN and BRUINSMA - 1938), on dry weight or on an ash basis. CHAPMAN and GRAY expressed their results for rubber and oil palms, as a % of leaf ash, whereas PREVOT, OLLAGNIER and SCHEIDECKER (1954) prefer to present their figures as a % of dry matter. The latter method of expression is most commonly used by other investigators, although is has never been shown that any method has particular advantages. CHAPMAN and GRAY suggested that expressing data as a % of ash, saves a considerable amount of analytical work. This is not quite clear, as the ashing of plant tissues is a time consuming procedure. Moreover, they express their results as ratios between the several elements, implying that expressing leaf composition as a % of dry matter or as a % of leaf ash is not of primary importance.

NICOLAS and JONES (1944) using the tissue test technique, have expressed their results on a semi-quantitative basis, i.e. high, medium and low. These simple analytical methods have the advantage that a great number of analyses may be carried out in a limited period of time.

(iii) Location of the Samples

The chemical composition of the leaves depends very largely on their age and morphological position. Some elements, such as Potassium, and to a lesser extent, Nitrogen and Phosphorus, are translocated from the older to the younger leaves when the latter become deficient in one of these elements. Taking these facts into consideration, REMY (1903) and NIGHTINGALE (1952) preferred to sample older leaves. On the other hand, certain elements, such as Calcium or Boron, are not translocated from the older to the younger leaves, and, consequently, Calcium and Boron deficiency always occur first in the younger leaves. ROACH (1945) pointed out that younger leaves are freer from contamination and that the influence of differences in physiological age are more easily eliminated.

The necessity to compare the chemical composition of leaves of the same physiological age has been demonstrated by a great number of investigators: LARSON (1933), WALLACE (1940), CHAPMAN (1941) and GOODALL (1943), In respect of oil palms, CHAPMAN and GRAY also showed that the chemical composition of the leaf tissue was dependent on the position of the leaflet on the frond and the part taken for analysis. The choice of the middle sections of the leaflets of the 17th leaf for routine analysis was based on the constatation that, under Malayan conditions, their contents of Potassium and Phosphorus were significantly correlated with production of the palms. This procedure was not followed by the French workers, nor by BROESHART in the Belgian Congo; they found that the chemical composition of the younger leaves gave a relatively better indication of the nutrient status of the oil palms.

Moreover, under African conditions, the 17th leaf is generally useless for routine sampling, as it is frequently dessicated or seriously affected by deficiency symptoms.

In this connection, the question may be posed whether leaves, which are necrosed or show deficiency symptoms, may be utilised for sampling and analysis. GOODALL (1945), REUTHER and BOYNTON (1940) and DROSDOFF and PAINTER (1942) showed that, in such cases, the contents of other non deficient elements may have changed considerable, thereby increasing the difficulties in the interpretation of analytical data. This suggests that only healthy leaves should be taken for analysis.

(iv) Influence of various Factors on Leaf Composition

Independent of the nature of the nutrient medium, the chemical composition of leaves is influenced by other factors, such as climate, time of sampling, age of plants and light intensity. (LUNDEGÅRDH, MITCHELL, 1936, ULRICH 1943). A suitable sampling technique should be chosen so that, either a correction for these factors may be made or that their influence on the chemical composition of the sample is negligible (PFEIFFER - 1912, LAGATU and MAUME, and LUNDEGÅRDH).

With regard to oil palms, no systematic investigation on this particular subject has yet been published.

(v) Interpretation of Foliar Analysis Data

Most investigators, mentioned above, and those listed by GOODALL and GREGORY, base their conclusions on the magnitude of the percentage of the several elements, found in the leaves. The principle underlying this method of interpretation (ULRICH - 1948), is based on the assumption that plants will respond to applications of fertilisers when the concentrations of nutrients in the plant tissue fall below a certain critical level. With a decreasing nutrient concentration in the plant, growth response, as a result of fertiliser applications of the nutrient in question, will increase. When the critical levels for the various elements are known for a standard sampling and analytical procedure, recommendations for practical fertiliser advice may be made.

LUNDEGÅRDH, using index values to express the quantities of elements in the leaves of oats and rye, adopts more or less the same principle, but he also takes into consideration the index values of elements, not present in limiting quantities in the leaf tissue, when estimating the probable response to a particular fertiliser (index value = mgm. atom/100 gm dry matter).

In the opinion of LUNDEGÅRDH, yield increases, due to fertiliser application as a function of the index values, may be represented as concave hyperbolic curves, of the following nature:

$Y + a = b/x^c . K_i$, in which

x = index value;

γ = increase in yield after fertilising with a standard quantity of the appropriate factor;

a, b and c, constants;

K_i = interference factor representing the effect of a second index value

Another method of expressing leaf analytical data is by means of ratios between two or more elements. The foliar diagnosis school of Montpeiller (LAGATU, MAUME 1924-1943) express N. P and K as a % of the sum of these elements. In Malaya CHAPMAN and GRAY used the K/P ratio in the leaves as an indication of the nutritional status of oil palms. The leading idea is the hypothesis that growth and production of crops is rather a function of the balance between the various elements in the leaves, than a question of the absolute levels.

Van GINNEKEN (1943), expressed the elements in the leaves of sugerbeets as a % of the average normal content of a certain area. By means of vertical diagrams, he was able to compare deviations from this average ("100 % lines") for each particular case.

STEENBJERG (1951) showed that yield, as a function of the percentage of a certain element, e. g. P and Cu, in the leaf tissue, may be represented by a curve with a minimum. This means that, in cases of extreme deficiency of a particular element, its concentration in the leaf may be medium or even high. Applications of this element as fertilisers will, in such a case, decrease the concentration in the leaf, due to rapid growth of the plant and "dilution" of the leaf components. STEENBJERG points out that the curve representing yield increase as a function of one element, applied as a fertiliser, may be sigmoidal instead of parabolic, logarithmic or hyperbolic, as is generally assumed by many investigators.

III. CHOICE OF METHODS OF ANALYSIS

(i) Preparation of Samples and Extracts

The determination of the readily soluble fractions in leaf tissues will, under the conditions of the present investigations, encounter many technical difficulties, It is essential that the leaf tissue be examined immediately after sampling, as important changes in the readily soluble fractions rapidly take place. Analysis of the total content of the elements in the leaves, expressed as a % of ash or of dry matter, remains the only possibility. As regards the method of expression of analytical data, it is not possible to make a definite choice, before it has been shown that one is preferable to the other; expression both as a % of ash and of dry matter must be compared before a final choice is possible. It should be pointed out, however, that unless the samples are properly dried and packed, prior to despatch, the determination of various constituents as a % of dry matter, may result in erroneous results, owing to the fact that fungae and bacteria may have attacked the samples during transport.

(ii) Chemical Analysis

The following determinations were carried out on each sample:

1) Potassium as K.
2) Phosphorus as P.
3) Calcium as Ca.
4) Magnesium as Mg.
5) The ash content as a % of dry matter.

It has not been possible to carry out Nitrogen determinations, involving a considerable amount of analytical work on a separate sub-sample as opposed to K, P, Ca and Mg, which are easily determined in the same extract.

The choice of the analytical methods were a compromise between accuracy and rapidity. It is regrettable that greater rapidity is generally accompanied by reduced accuracy, but the former is essential, where a large number of samples have to be analysed in a limited period of time. On the other hand, until such time as the errors involved in sampling and the magnitude of the changes in leaf composition, due to external factors such as climatic and soil conditions, have been determined, the greatest possible accuracy is desirable.

Spectographic analysis has proved very satisfactory in Sweden, where LUNDEGÅRDH devised a special flame spectograph.

Flame photometry and micro titrimetric methods have been used for this kind of work by many investigators. The advantages of the latter, as compared with spectographic methods, are that the equipment is much less costly and does not require highly specialised laboratory staff and conditions.

Colorimetric methods, although commonly used, have the disadvantage in the tropics that the colour intensity of the solutions is influenced by temperature changes. The intensity of the colour solutions has always to be compared with standard solutions, containing known quantities of the element to be determined, the comparison being made by means of a photo-electric colorimeter.

The analytical procedure, adopted for this work may be sumarised as follows: (for full details, see appendix).

1) Preparation of Extracts.

The leaf samples are cleaned with a cloth or, if necessary washed with distilled water. After rejection of the midribs, the middle sections of the leaflets are dried at 105° C and ashed.

Ashing takes place in a muffle furnace at a temperature, which does not exceed 550° C. The ash content as a % of dry matter is determined.

A known quantity of ash is digested in a mixture of concentrated sulphuric and nitric acids, for oxydation of possible C content. The digest is made up to standard volume with 3% acetic acid after neutralisation with caustic soda (phenolphthalein as indicator).

Silica is removed by filtering the extracts, and from this filtrate aliquots are taken for the analysis of K, P, Ca and Mg.

2) Potassium Determination.

K is precipitated with a solution of sodium cobaltinitrite, to which silver nitrate has previously been added.

The intensity of the stable blue colour, which develops when ammonium thiocyanate in alcoholic solution is added to this precipitate, is measured by means of a Hilger Spekker Absorbtiometer.

The actual percentage of K is read off a graph prepared from the readings obtained from a range of known standard K solutions.

3) Phosphorus determination.

The intensity of the blue colour, which develops when ammonium phosphomolybdate is reduced by stannous chloride, is measured with the Hilger Spekker Absorbtiometer and the P content read off a graph, prepared for P.

4) Magnesium Determination.

To an aliquot of the extract, titan yellow is added. Caustic soda forms a red lake with the Magnesium titan yellow complex. Precipitation of this red complex is prevented by means of the addition of a glucose solution. The intensity of the colour is determined by means of the Hilger Spekker Absorbtiometer, and compared with a range of known standard solutions.

5) Calcium Determination.

The Ca content is determined by the precipitation of Ca as oxalate and subsequent titration with potassium permanganate in the presence of sulphuric acid. As the quantity of oxalate is very small and only N/100 potassium permanganate is used, a series of know standards is always included and the Ca content of the aliquot determined graphically.

General.

Under tropical conditions, rapid fluctuations in temperature often introduce considerable variation in the speed of developing and fading of the coloured solutions. It was found to be essential to include a complete set of standard solutions with each series of determinations.

Cooling of washing solutions, such as acetone for the K determination to remove the excess of reagent, proves to be advantageous, as the quantity of precipitate lost with washing was reduced to a minimum.

IV. SAMPLING TECHNIQUE

The choice of a standard sampling technique, depends on two factors, influencing the chemical composition of a sample:

1) The variation of the leaf composition as a function of other factors than soil conditions, such as age of leaves, age of palms, and climate;
2) The sensitivity of the leaf to changes in soil nutrient conditions, as reflected by alterations in the chemical composition of the leaf.

The ideal sample for routine analysis, would be one, sensitive in its reaction to varying soil nutritional conditions, but whose chemical composition is not or very little influenced by other factors, such as age of the palms and changes in climatological conditions.

As the aim of leaf analysis is to obtain information on soil nutrient conditions, the influence of all other factors must be determined to enable corrections or eliminations to be made. As causes of variation in the chemical composition of leaf samples, other than varying soil nutritional conditions may be mentioned:

1) Location of the sample; the chemical composition will be different for leaflets taken from the tip, middle part or base of the leaves.

   Also the physiologival age of the leaves may be of importance.

2) Influence of the age of the palm on leaf composition. There may be a difference in the chemical composition of comparable samples taken from palms of different ages.

3) The influence of climate, dry and wet seasons, rainfall, relative humidity and insolation etc. Investigations should be made to determine whether systematic differences exist in the chemical composition of samples, taken at interfalls during the year, to study the influence of dry and wet periods and other climatological factors.

4) Sampling errors due to daily variations in the chemical composition of the samples, small differences in age and exposure to sun etc.

5) Errors in the analytical technique.

Each of the above points will be examined in more detail.

(i) Location of the Sample

Table 1 shows the chemical composition of the middle parts of leaflets, sampled at distal ends, between this and the centre, between the centre and the base, and at the base of the leaves of differing physiological age.

The phylotaxis of the oil palm is 5/8, and consequently leaf 9

TABLE 1

EXAMPLE OF DISTRIBUTION OF K, P, Ca and Mg IN THE LEAVES OF AN OIL PALM
(Data as a % of ash)

Leaf number	Part of leaf	% K	% P	% Ca	% Mg	Ash as a % of dry matter
Leaf 1	Tip	19, 4	3, 58	7, 6	3, 12	6, 62
	Half way Tip	22, 1	3, 26	6, 1	2, 64	6, 22
	Centre	24, 6	4, 25	6, 3	2, 68	6, 50
	Half way Centre	23, 9	3, 97	6, 0	2, 47	7, 14
	Base	24, 4	4, 28	6, 0	2, 32	7, 90
Leaf 5	Tip	16, 8	2, 74	8, 5	3, 08	5, 74
	Half way Tip	16, 7	3, 14	8, 2	3, 06	5, 88
	Centre	19, 2	3, 12	7, 3	2, 64	5, 65
	Half way Centre	22, 1	3, 31	7, 7	2, 12	6, 08
	Base	25, 0	4, 50	7, 1	1, 86	6, 27
Leaf 9	Tip	19, 8	2, 60	11, 0	3, 75	6, 44
	Half way Tip	20, 8	2, 85	11, 1	3, 89	6, 04
	Centre	18, 0	2, 84	10, 4	3, 29	5, 84
	Half way centre	22, 1	2, 94	10, 5	3, 59	6, 26
	Base	22, 1	2, 92	7, 2	2, 81	6, 31
Leaf 13	Tip	15, 9	2, 65	10, 0	3, 50	6, 06
	Half way Tip	15, 0	2, 90	9, 2	3, 12	5, 53
	Centre	18, 6	3, 24	10, 7	3, 15	6, 03
	Half way Centre	17, 6	3, 37	10, 7	3, 01	6, 27
	Base	18, 6	3, 42	9, 3	2, 65	6, 58
Leaf 17	Tip	13, 9	2, 12	12, 1	3, 55	6, 50
	Half way Tip	19, 0	2, 23	11, 8	3, 47	6, 04
	Centre	19, 5	2, 70	11, 3	3, 94	5, 96
	Half way centre	16, 8	2, 70	11, 8	3, 94	6, 22
	Base	20, 0	2, 55	11, 1	3, 49	6, 15

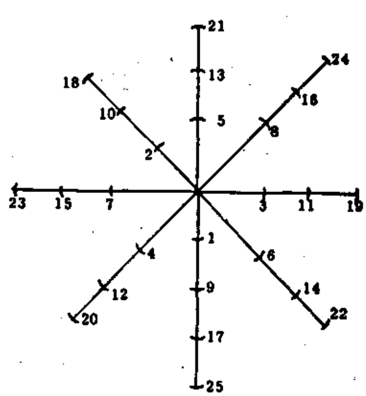


Figure 1. Phylotaxis of the Oil Palm

is found under the base of leaf 1, i. e, ,the youngest fully opened leaf (see fig. 1). Leaf 17 lies immediately under leaf 9, leaf 5 is opposite leaf 1, whereas leaf 13 is found under the base of leaf 5. Under Congo conditions, leaves older than the 17th, are often dessicated, as was mentioned previously, and have not been sampled for analysis.

From table 1 it may be seen that the composition of the leaflets taken from the tip of a leaf, are not comparable with the composition of the leaflets taken from the base. The tips have a lower K and P content, but a higher Ca and to a lesser extent, Mg content. Leaves of different physiological ages show variations in chemical composition; older leaves have a lower K and P content and a higher Ca content than younger leaves. It will be evident that, where the chemical composition of leaves of different palms is compared, samples must be taken from identical parts of leaves of the same physiological age.

In the following investigations a standardised sampling technique has been adopted and consideration given to samples taken from the central parts of leaves. As CHAPMAN and GRAY have shown that also the chemical composition of tips, central parts and bases of the leaflets may be different, only the middle sections of the leaflets have been considered in the present investigations. From the data in table 1 it is not possible to make a definite choice as regards which leaf should be sampled for routine practice. In our preliminary investigations, samples have been taken from the central parts of the youngest fully opened leaf and from the 9th leaf for the purpose of determining sensitivity and variability.

(ii) Age of Palms, Changes in Climatic Conditions and Chemical Leaf Composition

The determination of the influence of the age of the palms on the chemical composition of leaves of differing physiological ages, and its possible interactions with changes in climatic conditions is not an easy procedure, as under plantation conditions, differences in planting technique, in cultural methods, origin of seed and varying soil conditions can not be eliminated. Only in cases, where replacements have been made in a young block, may the chemical composition of palms in limited area be considered as not having been influenced by one of the above factors, and possible differences between palms of different ages be determined at various times of the year.

An experimental area was chosen in a block in which the original palms had reached the productive stage, but in which replacements, which were still in the vegetative stage, had been made later. The light conditions for all the palms were similar, and there was no shading effect of the older oh the younger palms. 20 productive and 20 replacement palms in the same vicinity were selected at random and sampled at monthly interfalls during a period of one year. Samples were taken from the first and the

TABLE 2

FOLIAR ANALYSIS OF INDIVIDUALY, MONTHLY SAMPLED PALMS (average 20 palms)
(data expressed as a % of dry matter)

Sampling time	% Potassium				% Phosphorus				% Calcium				% Magnesium			
	leaf 1		leaf 9		leaf 1		leaf 9		leaf 1		leaf 9		leaf 1		leaf 9	
	young	old	young	old	young	old	young	old	young	old	young	old	young	old	young	old
March '53	1,85	2,06	1,34	1,34	0,147	0,198	0,126	0,163	0,564	0,612	0,742	0,709	0,264	0,380	0,252	0,408
April	2,05	1,88	1,39	1,04	0,195	0,206	0,165	0,175	0,615	0,667	0,802	0,770	0,384	0,405	0,323	0,429
May	1,80	1,70	1,15	1,38	0,185	0,204	0,169	0,170	0,615	0,666	0,725	0,677	0,267	0,357	0,249	0,356
June	1,75	2,00	1,42	1,59	0,189	0,201	0,155	0,190	0,606	0,598	0,644	0,639	0,296	0,370	0,299	0,344
July	1,91	1,72	1,76	1,34	0,209	0,168	0,196	0,161	0,591	0,607	0,601	0,667	0,402	0,414	0,388	0,491
Aug.	1,65	1,78	1,44	1,28	0,206	0,200	0,183	0,188	0,593	0,597	0,751	0,626	0,359	0,398	0,343	0,380
Sept.	1,54	1,90	1,29	1,44	0,210	0,202	0,207	0,190	0,621	0,624	0,612	0,698	0,273	0,325	0,274	0,382
Oct.	1,80	1,42	1,35	2,00	0,215	0,202	0,204	0,221	0,590	0,663	0,649	0,753	0,276	0,338	0,253	0,358
Nov.	1,74	1,57	1,22	1,22	0,223	0,236	0,220	0,219	0,616	0,603	0,691	0,739	0,286	0,338	0,286	0,353
Dec.	1,68	1,82	1,17	1,43	0,211	0,218	0,194	0,198	0,595	0,593	0,728	0,716	0,399	0,298	0,377	0,315
Jan. '54	2,04	2,15	1,63	1,82	0,189	0,213	0,179	0,171	0,520	0,534	0,705	0,607	0,283	0,326	0,298	0,322
Febr.	2,05	1,84	1,68	1,36	0,170	0,196	0,157	0,165	0,582	0,531	0,704	0,712	0,241	0,275	0,280	0,319

TABLE 3

FOLIAR ANALYSIS OF INDIVIDUALY, MONTHLY SAMPLED PALMS (average 20 palms)
(data expressed as a % of ash)

	% Potassium				% Phosphorus				% Calcium				% Magnesium			
Sampling	leaf 1		leaf 9		leaf 1		leaf 9		leaf 1		leaf 9		leaf 1		leaf 9	
time	young	old	young	old	young	old	young	old	young	old	young	old	young	old	young	old
March	24,8	25,6	17,4	18,8	1,97	2,50	1,79	2,30	7,49	7,69	10,04	9,55	3,64	4,60	3,47	5,56
April	26,0	23,3	18,2	16,6	2,45	2,56	2,14	2,74	8,21	8,19	10,40	11,80	4,81	5,00	4,21	6,55
May	25,0	19,5	17,5	17,8	2,60	2,42	2,71	2,71	8,61	7,81	11,56	9,03	3,72	4,18	3,90	4,72
June	23,3	28,0	22,0	23,8	2,50	2,87	2,36	2,89	7,96	8,54	9,72	9,79	3,91	5,30	4,48	5,30
July	30,8	25,4	33,5	22,0	3,59	2,53	3,67	2,86	10,15	9,02	11,52	11,30	6,85	6,08	7,21	8,20
Aug.	25,7	26,1	25,3	20,7	3,23	3,08	3,17	3,03	9,28	9,23	10,20	10,08	5,61	6,28	6,05	6,09
Sept.	29,0	28,9	25,9	24,3	3,95	2,93	4,22	3,22	11,66	9,65	11,66	11,62	5,20	4,95	5,24	6,28
Oct.	26,4	19,5	19,7	18,0	3,17	2,92	2,96	3,33	8,78	9,38	9,36	11,40	4,10	4,79	3,64	5,47
Nov.	25,3	25,7	19,2	20,6	3,28	3,73	3,49	3,71	8,87	9,89	10,82	12,66	4,12	5,78	4,47	6,17
Dec.	22,7	27,5	18,5	22,6	2,88	3,35	3,30	3,06	8,18	8,80	12,91	11,47	5,71	4,47	6,14	4,89
Jan.	32,0	31,3	24,2	28,7	2,94	3,11	2,65	2,71	8,17	7,75	10,48	9,75	4,37	4,78	4,48	5,03
Febr.	29,4	31,8	24,5	23,0	2,44	3,39	2,27	2,80	8,33	9,18	10,74	12,00	3,42	4,72	4,12	5,32

TABLE 4

FOLIAR ANALYSIS OF INDIVIDUALY, MONTHLY SAMPLED PALMS (average 20 palms)

sampling time	Ash as % of dry matter			
	leaf 1		leaf 9	
	young	old	young	old
March '53	7,20	7,90	7,31	7,20
April	7,99	8,18	7,84	6,69
May	7,29	8,77	6,55	7,75
June	7,66	7,21	6,62	6,84
July	6,01	6,86	5,42	6,10
Aug.	6,49	6,44	6,09	6,24
Sept.	5,46	6,60	5,06	6,05
Oct.	7,00	7,29	7,04	6,81
Nov.	6,97	6,52	6,54	6,28
Dec.	7,40	6,86	6,47	6,82
Jan. '54	6,51	6,95	7,00	6,40
Febr.	7,03	6,02	7,08	6,61

9th leaves in the morning between 7 and 10 a. m. This was started at the beginning of the wet season, in March 1953 and ended in February 1954. All samples were analysed individually (80 samples per month).

Table 2 gives the analytical results, with the data expressed as a % of dry matter, while table 3 and 4 show the results as a % of ash. Each figure represents the average of 20 leaf samples, which were analysed individually. The experiment may be considered as a split plot, comprising three errors. The estimation of the error variance for "age of the palms" is based only on 40 palms, as the successive monthly samplings may not be considered as randomised replications. Further, the error variance for the influence of the morphological position of the leaf on chemical composition may, for the same reason, be based only on 40 palms. As, however, the 1st and 9th leaves of each palm have been sampled, the error variance for "age" is not the same as the error variance for "leaf", although both are based on the same number of degrees of freedom (error b). To calculate the influence of sampling time and its interactions with age of the palms and position of the leaf, all the data accumulated over a whole year (960) may be used for the estimation for error variance c.

TABLE 5

ANALYSIS OF VARIANCE, INDIVIDUALY, MONTHLY SAMPLED PALMS
(data as a % of dry matter)

Description	Degrees of Freedom	Potassium x 10^4		Phosphorus x 10^6		Calcium x 10^6		Magnesium x 10^6		Ash as a % of dry matter x 10^4	
		SS	V	SS	V	SS	V	SS	V	SS	V
Total	959	2176791		1626719		20875725		10358207		17042606	
Agregate leaves/age	79	645578		293153		6470733		2994510		1383385	
Agregate leaves	39	134947		173719		4399186		2746714		453318	
Age	1	740	740	13200	13200	44260	44260	850840	850840++	48200	48200+
Error a	38	134207	3532	160519	4224	4354926	114603	1895874	49891	405118	10661
Leaf	1	452400	452400++	85880	8580++	1809600	1809600++	21100	21100+	400160	400160
Age x leaf	1	600	600	60	60	980	980	24200	24200+	13780	13780
Error b	38	57631	1516	33494	828	260967	6867	202496	5328	516127	13582
Month	11	162680	14789++	290540	26413++	1042460	94769++	1302500	118409++	2958840	268985++
Month x age	11	98240	8931++	77520	7047++	251800	22891	664760	60433++	863400	78491++
Month x leaf	11	38920	3538++	21700	1973	592460	53860++	83280	7571	257940	23449
Month x age x leaf	11	23880	2171	10760	978	287000	26091	59580	5416	264320	24029(+)
Error c	836	1207493	1444	933046	1116	12231272	14631	5253577	6284	11314721	13534

Significance
+ = sign. at P = 0,05
++ = sign. at P = 0,01
SS = sum of squares
V = Variance

pressed as a % of dry matter, have been given, leading to the following observations:

1) Influence of the Age of the Palms.

There appears to be a highly significant difference in Mg content of the leaves between the young, non-productive palms and the older, productive palms. No differences seem to exist for any of the other elements. The ash content as a % of dry matter is similar for young and old palms.

2) Influence of Morphological Position of the Leaf.

The difference in chemical composition of the 1st and 9th leaves appears to be highly significant in respect of K, P, Ca and ash as a % of dry matter. The difference in Mg content just fails to attain significance at $P = 0.05$.

The interaction between leaf and age is only significant for the Mg content of the samples; this would seem to suggest that the change in Mg content of the leaf tissue, as a function of the physiological age of the leaf, is not the same for young non-productive and for palms in production.

The interaction between age and leaf is not significant for the other elements nor for the ash content as a % of dry matter.

3) Influence of Sampling Time.

The sampling time, i.e. the month, in which the leaf sample was taken, has a highly significant effect on the chemical composition of the leaves. The differences in K, P, Ca and Mg contents, as well as the % ash on dry matter, appear to be highly significant, when comparing leaf samples, taken at various periods of the year. The interaction between sampling time and age of the palms is highly significant for K, P and Mg content and ash as a % of dry matter, but not for the Ca content of the samples. This suggests that the changes in leaf composition, induced by changes in climatological conditions (sampling time), are not identical for young and old palms. This was not unexpected, as the rooting system of younger palms is more restricted than that of older palms and, as a consequence, suffer relatively more from dry periods. At such times, the top soil, in which the bulk of the adsorbing roots are situated, is often completely dried out, and, as a consequence, ion uptake is restricted or may even cease altogether.

Another example of a differential reaction of young and old palms, to changes in climatological conditions, is that increases in production after periods of heavy rainfall are first noticed in young palms.

The interaction between time of sampling and age of the leaf, is highly significant for K and Ca. This would suggest that these changes, due to climatic variations, are not identical for the first and 9th leaves.

The second order interactions do not attain significance for any of the leaf components.

To facilitate the comparison between the results of the analysis of variance, the figures 2-5 have been prepared showing the chan-

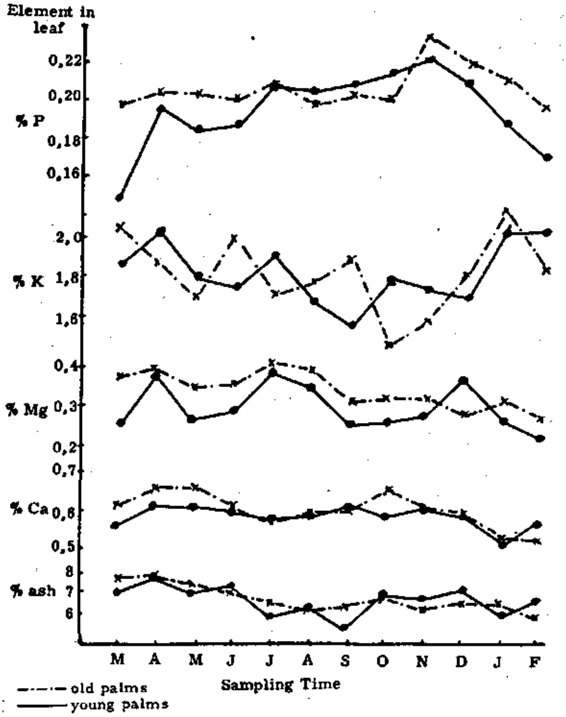


Figure 2. Influence of sampling time on the chemical composition of the 1e leaf (as a % of dry matter)

ges in leaf composition as a function of the sampling time. In figure 6 the observations of the meteorological station are given for the area, in which the experiment was laid down.

It will be seen that the wet season starts in March and finishes towards the end of November, with an interruption of a short dry season of a few weeks in June. Fig. 6 shows the rainfall and insolation during the period, in which the palms were sampled. Comparing the data from the figures 2-5 with those from fig. 6, the following observations may be made:

a) There are significant differences in leaf composition of leaves of different physiological age, a fact previously noted. The K and P contents of the first leaves, expressed on ash or on dry matter, are higher than those of the 9th leaves; the Ca and Mg contents of the first leaves are lower than those of the 9th leaves; ash on dry matter is higher for the first than for the 9th leaf.

b) The difference in age of the palms has an influence on the P and Mg contents of the leaves. During the dry periods, the P content of the leaves of younger palms is significantly lower than that of the leaves of the older palms, particularly when the data are expressed on dry matter. The Mg content of the leaves of the younger palms is lower than that of the older palms, irrespective of the way in which the data are expressed.

c) Sampling time has a very significant effect on leaf composition,

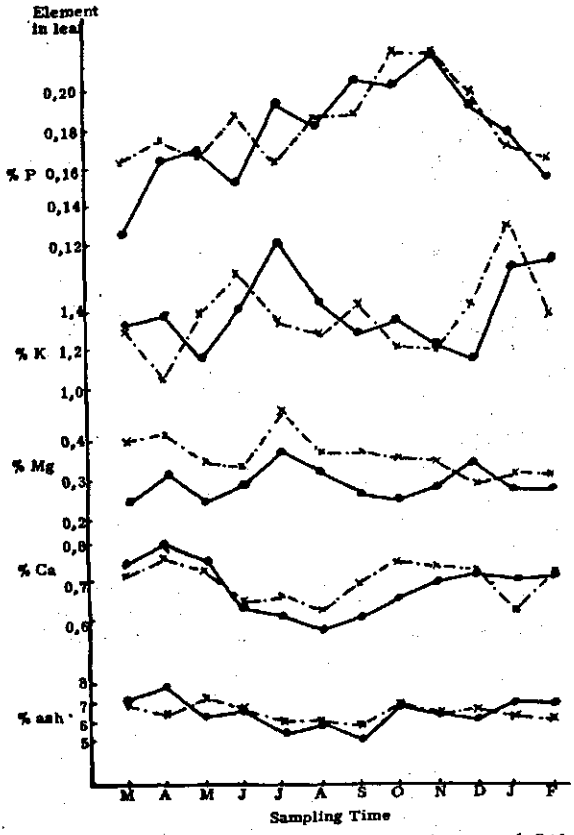


Figure 3. Influence of sampling time on the chemical composition of the 9th leaf (as a % of dry matter)

which is similar for both the 1st and 9th leaves. This suggests that the influence of changes in climatic conditions should be taken into consideration when a definite sampling technique is adopted. It will be seen that:

Potassium on ash or on dry matter, shows high values in the dry seasons and in the small dry season in June/July; Magnesium, is significantly higher in April, July and December, coinciding with the changes from wet to dry seasons. This is irespective the method of expression of the data.

Phosphorus, on ash and on dry matter is lower in the dry than in the wet season and attains its maximum value in November at the end of the wet period.

Calcium on dry matter, has its minimal values in the middle of the wet season. This effect is more pronounced for the 9th than for the 1st leaf. However, on ash, Ca has its highest values in the middle of the wet season, for the 1st but not for the 9th leaf.

Ash on dry matter, decreases during the first part and increases slowly in the second part of the wet season. The lowest values for both the first and the ninth leaves are found in July, August and September.

It should be pointed out that changes in the concentration of the several leaf components, under the influence of variations

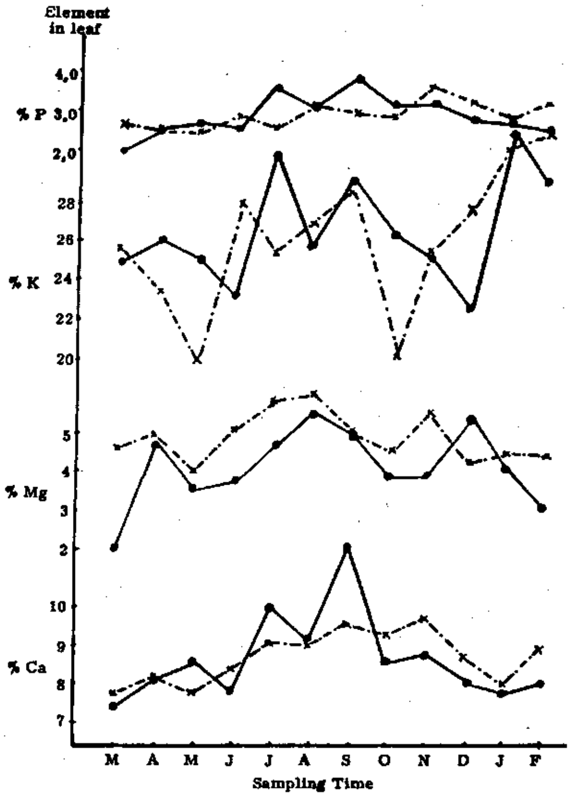


Figure 4. Influence of sampling time on the chemical composition of the 1e leaf (data as a % of ash)

in soil and climatological conditions, need not necessarily be the same for plantations, situated in other parts of the Congo The main conclusion to be drawn from the above considerations, is, that it is essential to compare the chemical composition of leaf samples taken during comparable periods of the year.

d) Variations in climatological conditions do not have the same influence on the leaf composition of young and old palms, as suggested by the significant interactions between month of sampling and age of palms. From fig. 2-5 it may be seen that generally speaking, the characteristic changes in respect of the P, Ca and Mg contents of the leaves, as a function of sampling time, are more pronounced for younger than for older palms.

The P content of the leaves of young palms attain much lower values in the dry season than that of older palms. Further, the increase in Mg content, caused by the changes from wet to dry seasons, are larger for young than for old palms. The same may be said for the Ca content and ash on dry matter. The fluctuations are greater in young than in the old palms. With regard to K, the interaction between month of sampling and age of palms is demonstrated by the fact that increases in leaf K of young palms do not coincide with similar changes in leaf K content of older palms, due to changes in climatolo-

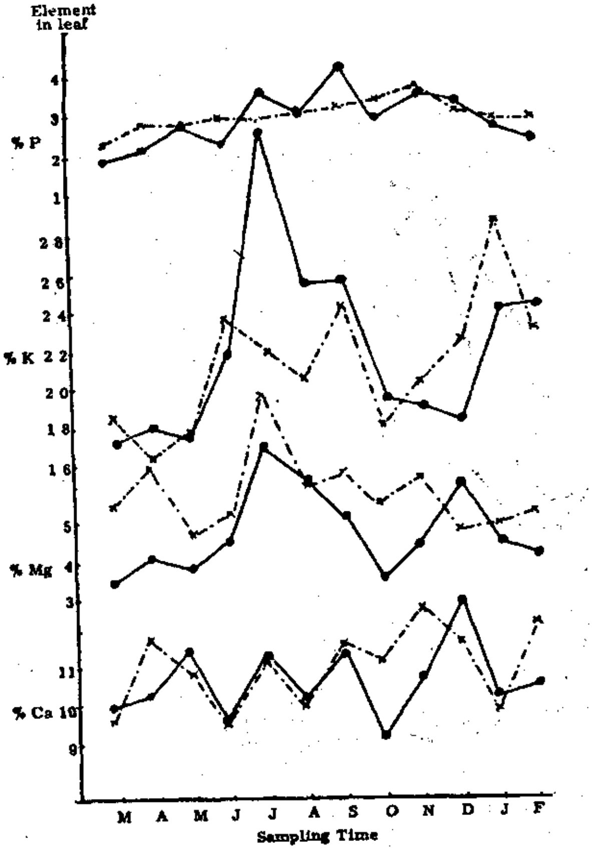


Figure 5. Influence of sampling time on the chemical composition of the 9th leaf (data as a % of ash)

gical conditions. Fig. 2 suggests that the reaction of older palms to increases and decreases of leaf K is retarded by approximately two months.

One further point remains to be considered: In the preceding analysis of variance and subsequent conclusions, the assumption was made that variations in leaf composition due to non systematic errors, follow the law of the normal frequency distribution. The technique of analysis of variance may be applied only to data, with a normal distribution of the errors. It is generally not possible to test data for normal frequency distribution. In this case, however, we are dealing with sufficient analytical data to obtain information on the frequency distribution when a correction is made for the most important systematic influences.

It was shown earlier, that, apart from age of leaves and of palms, the sampling time (climatic influence) is the most important facor, responsible for variations in chemical composition. The K and P contents in the 1st leaves of young palms were corrected for the influence of climate, in the following way:

The Correction Factor is represented by the difference between the average K and P contents for any given month and the average figures for the month, showing the lowest K and P contents.

When all the figures for the same leaf from palms of comparable age, growing under identical soil conditions, have been corrected for the influence of climate, any variation in those figures is due

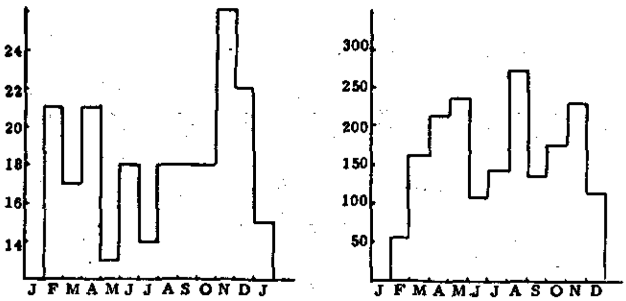


Figure 6. Insolation (1954) Rainfall in mm. (1954)

to the influence of climate, and any variation in those figures is due to non systematic errors; as a consequence, the distribution would be expected to follow the normal frequency curve.

In order to examine this point, all figures have been grouped in classes at intervalls of 0.1 % for K and 0.01 % for P.

From figures 7 and 8, it will be seen that the distribution of the leaf elements (in this case only K and P are considered) follows approximately a normal distribution and, in consequence, the analysis of variance may safely be applied to check the validity of the previous conclusions, suggested by the table and the figures 2-5.

(iii) Sampling and Analytical Errors

The standard deviations of the various leaf constituents of young and old palms in the 1st and 9th leaves, on ash and on dry matter, found during the successive monthly samplings, are given in table 6 and 7. These data have been subjected to analysis of variance and the results are given in table 8 and 9. Some conclusions may be drawn from these.

1) A major part of the variation may be ascribed to the influence of the sampling time, i.e. climate. It will be seen that in the case of leaf K, the smallest standard deviations are found at the beginning of the wet season, irrespective of the way in which the data are expressed.

On the other hand, leaf P, on dry matter, shows the largest standard deviations in March, July and November, coinciding with the change from dry to wet seasons. When, however, the data are expressed on ash, the standard deviations increase towards the end of the wet season.

When Ca is exprssed on dry matter, the variation is larger in the dry than in the wet season but remains constant throughout the year when expressed on leaf ash.

Mg on dry matter tends to show higher variation in the small dry season in July, but on ash the variation is smaller in the dry than in the wet season. Ash on dry matter has a rather constant standard deviation throughout the year.

2) Age of the palms has, generally speaking, no influence on the standard deviations in leaf constituents.

TABLE 6

STANDARD DEVIATIONS OF INDIVIDUALY MONTHLY SAMPLED PALMS
(data as a % of dry matter)

Sampling time	γ Potassium				γ Phosphorus				γ Calcium				γ Magnesium			
	leaf 1		leaf 9		leaf 1		leaf 9		leaf 1		leaf 9		leaf 1		leaf 9	
	young	old	young	old	young	old	young	old	young	old	young	old	young	old	young	old
March	0,24	0,24	0,24	0,26	0,047	0,040	0,030	0,027	0,13	0,19	0,16	0,26	0,018	0,084	0,058	0,098
April	0,23	0,42	0,36	0,37	0,032	0,033	0,029	0,014	0,13	0,16	0,22	0,18	0,094	0,010	0,095	0,110
May	0,39	0,36	0,50	0,56	0,028	0,025	0,026	0,025	0,12	0,10	0,18	0,11	0,037	0,079	0,076	0,110
June	0,27	0,35	0,35	0,47	0,022	0,024	0,026	0,017	0,10	0,097	0,13	0,12	0,089	0,090	0,093	0,099
July	0,33	0,40	0,30	0,34	0,051	0,044	0,035	0,056	0,13	0,12	0,088	0,075	0,170	0,081	0,100	0,090
Aug.	0,29	0,45	0,38	0,50	0,037	0,037	0,026	0,035	0,11	0,11	0,098	0,14	0,079	0,046	0,090	0,110
Sept.	0,41	0,50	0,51	0,33	0,024	0,036	0,024	0,026	0,077	0,083	0,083	0,13	0,050	0,084	0,042	0,110
Oct.	0,52	0,56	0,58	0,48	0,043	0,027	0,039	0,032	0,085	0,12	0,085	0,11	0,075	0,088	0,062	0,110
Nov.	0,19	0,29	0,26	0,30	0,032	0,055	0,020	0,055	0,12	0,087	0,11	0,15	0,079	0,099	0,051	0,078
Dec.	0,53	0,32	0,46	0,53	0,036	0,050	0,032	0,045	0,094	0,071	0,10	0,093	0,083	0,087	0,087	0,103
Jan.	0,20	0,26	0,35	0,28	0,024	0,028	0,022	0,022	0,089	0,11	0,17	0,078	0,055	0,057	0,068	0,075
Febr.	0,59	0,34	0,34	0,46	0,029	0,026	0,025	0,029	0,13	0,11	0,21	0,16	0,063	0,054	0,075	0,068

TABLE 7

STANDARD DEVIATIONS OF INDIVIDUALY MONTHLY SAMPLED PALMS
(data as a % of ash)

Sampling time	Potassium				Phosphorus				Calcium				Magnesium			
	leaf 1		leaf 9		leaf 1		leaf 9		leaf 1		leaf 9		leaf 1		leaf 9	
	young	old	young	old	young	old	young	old	young	old	young	old	young	old	young	old
March	3,2	2,8	4,7	3,5	0,26	0,45	0,43	0,60	1,6	2,0	1,7	3,0	0,40	1,0	1,1	0,80
April	3,2	3,9	5,5	8,3	0,39	0,43	0,41	0,62	1,6	1,7	3,0	2,9	1,0	1,1	1,4	1,6
May	4,7	5,3	6,7	6,9	0,60	0,63	0,70	0,70	2,1	1,9	3,8	2,7	0,90	1,2	1,2	1,8
June	4,1	7,3	8,2	8,2	0,48	0,66	0,40	0,64	1,3	2,4	1,4	2,9	1,1	1,3	1,4	1,8
July	4,2	7,5	7,9	5,8	1,30	0,75	1,50	0,61	1,9	1,4	2,6	2,8	1,9	1,1	1,8	1,8
Aug.	4,4	7,7	8,6	7,8	0,74	0,67	0,72	0,63	1,9	2,2	1,9	2,1	1,3	2,1	2,1	1,5
Sept.	9,5	6,5	10,0	6,7	0,81	0,98	1,10	0,71	2,2	1,9	2,3	2,0	1,5	1,2	1,4	1,6
Oct.	9,4	7,4	9,8	7,1	0,93	0,37	0,76	0,73	2,5	2,4	2,3	3,0	1,4	1,5	0,97	2,2
Nov.	4,2	8,2	5,3	6,7	1,2	0,94	0,77	1,20	1,6	3,1	2,1	4,4	1,1	2,9	1,3	2,7
Dec.	5,0	6,4	5,8	8,2	0,60	0,98	1,27	0,58	1,6	1,7	3,7	2,3	2,2	1,3	2,7	1,4
Jan.	5,1	4,2	6,2	4,8	0,30	0,46	0,55	0,42	1,9	1,5	3,4	1,6	0,85	0,89	1,5	1,1
Febr.	4,9	9,0	6,1	9,0	0,32	0,62	0,43	0,71	1,7	2,6	3,6	4,3	0,78	1,2	1,5	1,5

TABLE 7a

STANDARD DEVIATIONS OF INDIVIDUALY MONTHLY SAMPLED PALMS

ash as a % of dry matter

sampling time	leaf 1 young	leaf 1 old	leaf 9 young	leaf 9 old
March	1, 72	1, 36	0, 93	1, 12
April	0, 92	1, 30	1, 36	1, 48
May	1, 01	1, 35	1, 28	1, 23
June	0, 93	1, 43	0, 92	1, 48
July	0, 94	0, 61	1, 14	0, 96
Aug.	1, 29	0, 90	0, 87	2, 14
Sept.	0, 97	0, 97	0, 95	0, 89
Oct.	1, 22	1, 41	0, 89	1, 17
Nov.	0, 71	1, 61	1, 09	1, 63
Dec.	1, 58	1, 05	1, 92	1, 17
Jan.	1, 11	1, 34	1, 54	0, 87
Febr.	0, 92	1, 16	2, 10	1, 20

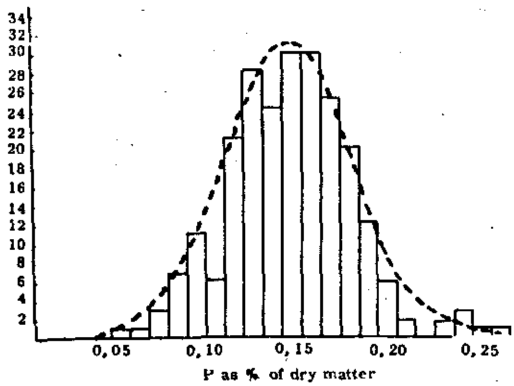


Figure 7. Frequency distribution of Phosphorus content of first leaves of oil palms (as a % of dry matter)

3) The age of the leaf has, in many cases, a marked influence on the variation of the leaf composition. The variation in K content is greater for the 9th than for the 1st leaf and is more pronounced when the figures are expressed on leaf ash. On the other hand, P content on dry matter, varies less in the 9th than in the 1st leaf, whereas there is no difference if the data are expressed on leaf ash. The variation in Ca content is greater for the 9th than for the 1st leaf, irrespective of the way in which the data are expressed. In respect of Mg content, no difference in variation exists for the first and the 9th leaf,

TABLE 8

ANALYSIS OF VARIANCE OF SAMPLING VARIATION
(data as a % of dry matter)

Factor	D. F.	Potassium		Phosphorus		Calcium		Magnesium		Ash as a % of dry matter	
		SS	V	SS	V	SS	V	SS	V		
Total	47	5735		4879		789		29425		53171	
Age	1	64	64	100	100	0	0	2147	2147^{+}	481	481
Leaf	1	144	144	266	266^{+}	72	72^{++}	981	981	1364	1364
Month	11	3583	326^{+}	2604	236^{++}	419	38^{++}	9591	872^{+}	9844	895
Age x leaf	1	0	0	7	7	3	3	893	893	99	99
Leaf x month	11	535	48	227	21	86	8	4592	417	10238	931
Age x month	11	475	43	1268	115^{+}	131	12	8989	817^{+}	17236	1567
Error	11	934	85	407	37	78	7	3125	284	13909	1264

TABLE 9

ANALYSIS OF VARIANCE OF SAMPLING VARIATION
(data as a % of ash)

Factor	D. F.	Potassium		Phosphorus		Calcium		Magnesium	
		SS	V	SS	V	SS	V	SS	V
Total	47	17799		37187		2738		1252	
Age	1	305	305	161	161	54	54	32	32
Leaf	1	1817	1817^{++}	363	363	760	760^{++}	99	99^{+}
Month	11	8138	739^{++}	21707	1973^{+}	508	46	503	45^{+}
Age x leaf	1	561	561^{+}	169	169	1	1	2	2
Leaf x month	11	1231	112	561	51	371	34	29	26
Month x age	11	4518	411^{+}	8157	741	845	77^{+}	444	40^{+}
Error	11	1229	112	6069	552	200	18	143	13

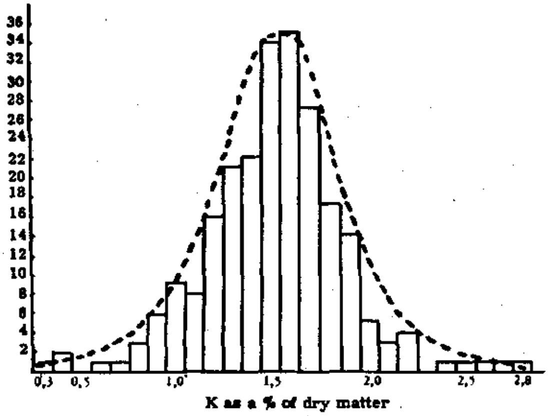


Figure 8. Frequency distribution of Potassium content of 1e leaves of oil palms (data as a % of dry matter)

when the figures are expressed on dry matter but, on ash, the 9th leaf shows the largest variation.

The standard deviation of the ash content as a % of dry matter is similar for the 1st and the 9th leaf.

4) It will be seen that the variations in standard deviations due to other factors, such as small differences in soil conditions, differences in insolation and errors in the preparation and chemical analysis of samples, amounts to only 14-24% of the total variation with the exception of P on ash, where 33% of the total variation should be ascribed to the above mentioned factors.

In table 10, the standard deviations of the several leaf constituents for the 1st and the 9th leaf, averaged over 12 months are given.

From this it will be seen that the standard deviations for the 9th leaf are slightly greater than for the 1st leaf, as indicated previously by the analysis of variance. It also appears that data, expressed on ash, show a slightly larger standard deviation than those, expressed on dry matter. The variation coefficients in the table comprise.

a) Analytical Errors;
b) Sampling variation.

To obtain some information on the magnitude of the analytical errors, a series of 30 sub samples were taken from one leaf sample and individually analysed. The variation coefficients (standard deviations as a % of the mean) were found to be:

For the determination of K, 4.0%
For the determination of P, 4.8%
For the determination of Ca, 12%
For the determination of Mg, 13%
For the determination of ash on dry matter, 9%.

From these, it is clear that the analytical methods in use, are sufficiently accurate for the purpose of the work, as the sampling variation appears to be much bigger than the variation, resulting from the analytical technique adopted.

Further it appears that there is little advantage in sampling

TABLE 10

STANDARD DEVIATIONS OF SEVERAL LEAF CONSTITUENTS FOR THE 1st AND 9th LEAF, AVERAGED OVER A PERIOD OF ONE YEAR

	Average standard deviation of 1st leaf	Standard dev. as a % of mean	Average standard deviation of 9th leaf	Standard dev. as a % of mean
Potassium as % of ash	5,7	21	7,0	32
Potassium as % dry matter	0,36	20	0,39	28
Phosphorus % ash	0,66	22	0,71	24
Phosphorus % dry matter	0,035	17	0,029	15
Calcium % ash	1,9	21	2,7	25
Calcium % dry matter	0,11	18	0,13	19
Magnesium % ash	1,3	27	1,6	30
Magnesium % dry matter	0,077	23	0,085	25
Ash as % dry matter	1,16	16	1,26	19

more than 20-25 palms as, according to table 10, a bulk sample, consisting of 20 palms has a standard deviation of the order of 4-6%, which is of the same magnitude as for the analytical errors.

One observation should be made concerning the accuracy of the analytical data, when expressed on ash. During our investigations, it became evident that relatively large errors may arise, should the preparation of the ash not follow a standard procedure. Differences in the rate of temperature rise, place in the muffle furnace, and initial moisture content may have a marked influence. A good ash is light gray and slightly cintered. It has been observed, however, that, despite all precautions, dark coloured ashes which still contain a considerable quantity of carbon are frequently obtained. As a result, a bad ash, with a high C content, will show comparatively low contents of K, P, Ca and Mg, expressed on ash.

Additional factors, responsible for errors, are the hygroscopicity of the ash and the high relative humidity in the tropics. All weighings for the ash/dry matter determinations should be carried out quickly, to obviate increase during the weighing.

(iv) General Conclusions

1) When adopting a routine sampling system for practical purposes, the morphological position of the leaf sample must be taken into consideration. Leaflets should be taken from corresponding parts of leaves of the same physiological age.

2) The age of palms has an influence on leaf composition. The influence of changes in climatological conditions on leaf composition is not identical for young and old palms. In general, this will fluctuate more in young palms than in older productive palms.

3) Sampling time has a significant influence on leaf composition

and samples taken in the dry season are not comparable with those, taken in the wet season. As far as possible, samples should be taken at the same periods of the year.

4) The errors, involved in the chemical analysis, represent only a small fraction of the total variation. Bulk samples should consist of 20-25 palms.

5) When data are expressed on leaf ash, the ashing should follow a standard procedure to avoid the considerable errors, which may arise, due to incomplete ashing.

V. GROWTH, PRODUCTION AND LEAF COMPOSITION

To obtain direct information on the sensitivity of the 1st and 9th leaves for the purpose of diagnosing possible mineral deficiencies, growth and production records from fertiliser and other experiments are plotted against the leaf composition, irrespective of the nature of the treatments. The leaf, showing the closest correlation between growth and/or production and chemical composition, should be chosen for routine sampling. This has been investigated for a series of experiments on different soils, located in various parts of the Belgian Congo. Figures 9-10 show the results of the foliar analysis of bulk samples, taken from the experimental plots of a replanting experiment in the Kasai region. See also table 33.

Growth was recorded as the increase in the number of leaves during a given period of time.

Attention is drawn to the fact that, in this case, the growth of the young palms is positively correlated with the K content of the leaves, and that, moreover, the correlation is closer in the case of the 1st than that of the 9th leaf.

P and Ca in the 1st leaf are correlated negatively with growth. Those relationships do not seem to hold for the P and Ca contents in the 9th leaf.

As some authors (CHAPMAN and GRAY), have worked with ratios between the elements, we have followed the same procedure to enable comparisons to be made with data, given in literature for oil palms and other crops. The advantage of expressing analytical data as ratios lies in the fact that the errors involved in the ash/dry matter determination have no influence, provided the analysis of all elements concerned is carried out on the same leaf extract.

In how far growth and production are more closely related to the ratio between the various elements in the leaf than to the actual contents, expressed on ash or on dry matter, remains to be investigated.

The K/P and K/Ca ratios of the first leaf show a very close correlation with growth, as a corollary of the changes in K content on the one hand and the P and Ca contents on the other. Those correlations have not been found for the 9th leaf.

Similar evidence was obtained for the chemical composition of leaves from other fertiliser experiments in this area. Figures 11 and 12 show the correlation between the leaf composition of young palms in an experiment, in which height is taken as measure of growth. In this instance, it also appears that the K, K/P and K/Ca figures in the leaves are positively correlated with growth and that the P and Ca contents are negatively correlated with the height of the young palms.

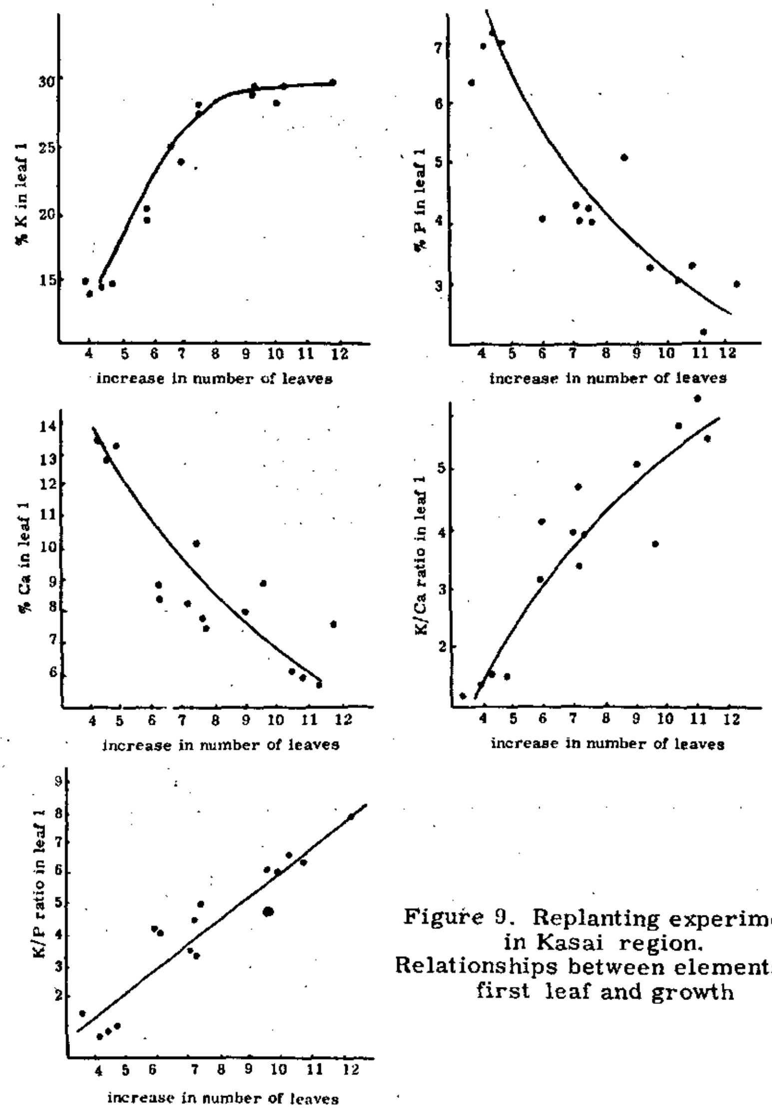


Figure 9. Replanting experiment in Kasai region. Relationships between elements in first leaf and growth

This also holds good for the production from an experiment on old palms in this area, for which precisely the same relationships were found (fig. 13).

In all these figures it is clearly shown that the closest correlations obtain between growth and production and the chemical composition of the first leaf.

The relation between leaf composition and growth and/or production of palms is not necessarily as found above; in a plantation in the central Congo basin the P content of the first leaves of young palms in a fertiliser experiment, shows a positive correlation with the number of female flowers and bunches, used as a

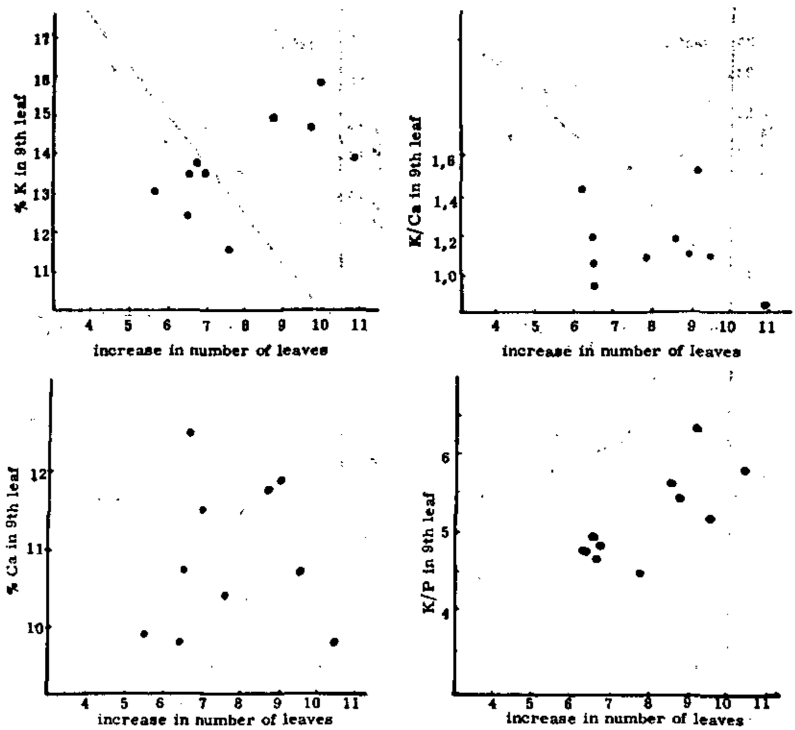


Figure 10. Replanting experiment in Kasai region. Relationships between elements in 9th leaf and growth

measure of the response to the treatments. Fig. 14 shows the growth data as a function of the P content. The K/P ratio was found to be negatively correlated with the number of bunches and female flowers.

Although these preliminary results would seem to suggest that the sampling of the 1st in stead of the 9th leaf as a standard practice has definite advantages, due to the closer relationships, as shown in the graphs, both the 1st and the 9th leaves have been sampled for the purpose of this work to obviate any possibility that other relationships, not yet apparent in any of the above cases, might arise for the 9th leaves.

It was shown that the chemical composition of leaves is definitely related to growth of young palms and production of older palms. The relationships found were, however, different in nature for the different soil types, obtaining in the Central Congo basin and Southern Congo. From a series of fertiliser experiments, in the Kasai region it appeared that leaf K, K/Ca and K/P were positively correlated with growth of young palms and yield of productive palms, whereas a negative correlation with growth and/or production was observed for leaf Ca and P.

The relationship between the various leaf constituents and growth or yield of palms, as established for the Southern Congo, could not be confirmed for plantations in the Central Congo basin. In the latter area, positive correlations between leaf P and growth

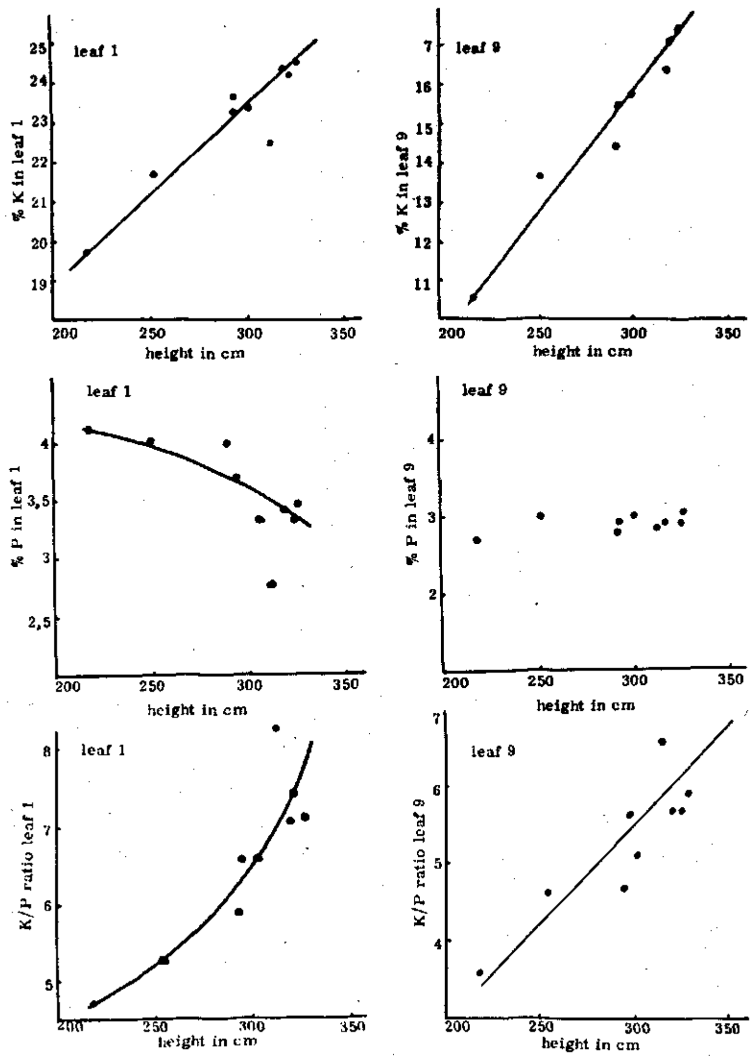


Figure 11. Fertiliser experiment on young palms. Correlations between leafcomposition and growth

of young palms or production of older palms were frequently found, while the K/P ratio was negatively correlated with growth and production.

An attempt was made to compare the chemical leaf composition of palms of widely differing ages, growing on a wide range of soiltypes with growth and/or production. The palms were growing on soils having the following characteristics:

1) Kasai Region (Brabanta).
   (probable Karroo formation)
   Sandy soil containing 6-12% of clay (< 2), 1% of silt (2-20 μ), ± fine sand (20-200 μ) and 30-35% of coarse sand (200-2000 μ).

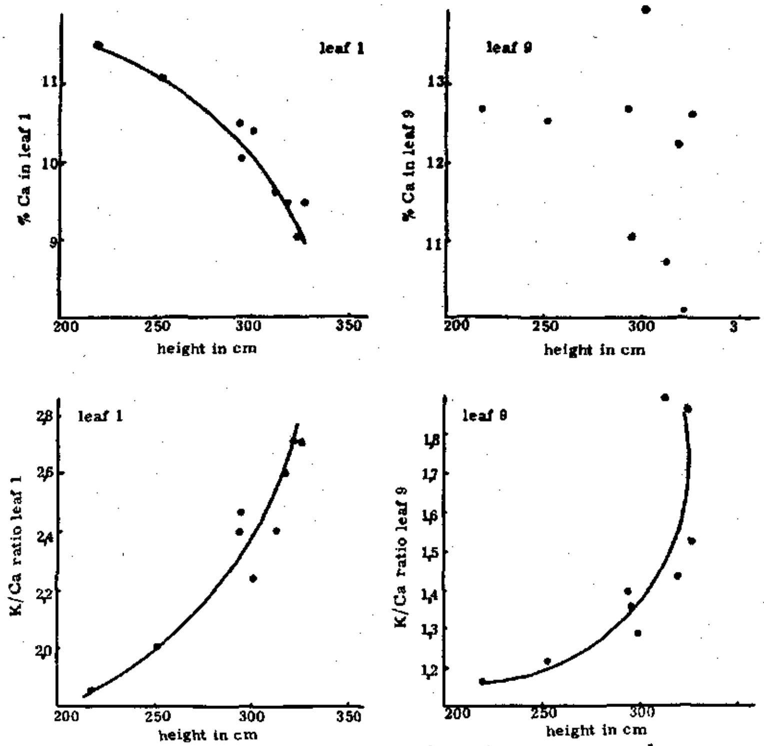


Figure 12. Fertiliser experiment on young palms.
Correlations between leafcomposition and growth

The organic carbon content, as determined by the rapid method of WALKLY and BLACK, is of the order of 0. 7-1. 0%, corresponding to an organic matter content of 1. 2-1. 7%.

Nitrogen, as determined by the Kjeldahl method amounts to 300-700 ppm.

Total Potassium, as extracted by one hour boiling in concentrated. hydrochloric acid, varies from less than 50 ppm-300 ppm. Phosphorus, determined in the same extract, is of the order of 100-200 ppm.

The pH (glass electrode) varies between 4. 3 and 4. 7.

2) Kwilu Region (Lusanga area).

The soils of this region are chiefly comprised of Kalahari sand and only on some steep riverine slopes may the underlying Karroo formation be observed.

The area is extremely sandy, the clay content amounting to 4-12% with a silt content of invariably 1%; fine sand varies from 40-55% and coarse sand accounts for 35-55%.

The organic carbon content amounts to 0. 6-1. 2%, corresponding with 1-1. 5% organic matter.

The Nitrogen content is of the order of 300-800 ppm.

Total Potassium content on the flat, higher plateau soils, is less than 50 ppm, but may be considerable higher on the steep riverine slopes, varying between 100 and 300 ppm.

Phosphorus varies from less than 10 ppm - ± 150 ppm.

The pH range is from 4. 3-5. 5.

3) Red Latosol in the Central Congo Basin (Elisabetha).

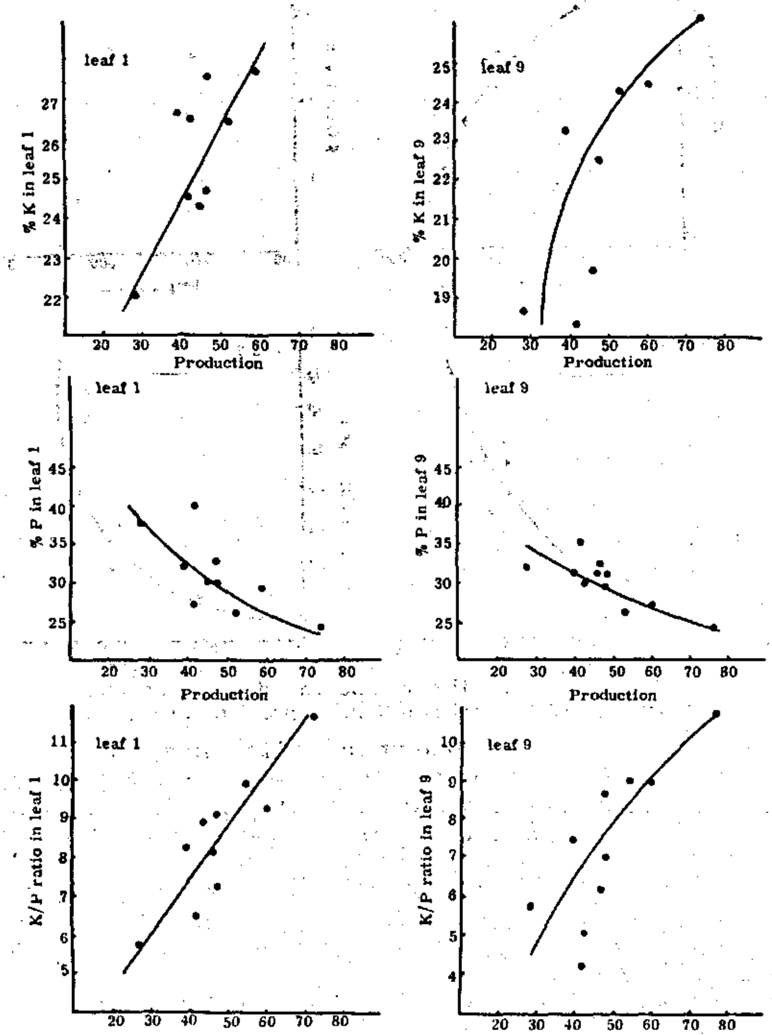


Figure 13. Correlations between leafcomposition and production (as average kg of bunches per palm per annum) of fertiliser experiment on productive palms

The clay content of the area ranges from 10-30%. The fine sand fraction between 40 and 60% and the coarse sand between 20-40%.

The organic C content is of the order of 0.4-0.8% which corresponds with an organic matter content of about 1%.

The N content varies between 300 and 600 ppm.

The total K content of the soils is high, of the order of 400 ppm. to more than 2000 ppm.

The total P content of these soils is very variable and may lie between less than 10 ppm to 200 ppm.

The soils have a high P fixing capacity.

The pH varies between 4.2 and 4.7.

4) Red Yellow Latosol (Yaligimba).

The clay content varies between 12 and 30%, fine sand between 35 and 50% and coarse sand 30-40%.

The organic matter content is of the order of 1%.

Nitrogen varies between 300 and 800 ppm.

The total K content of the soils ranges from 100-200 ppm; total P between 30 and 200 ppm. The soils have a high P fixation capacity.

The pH is 4.3-5.0.

5) Yellow Soil in Swampy Area near Coquilhatville (Flandria).

The top soils have a clay content of 10-15%; coarse sand accounts for 22-28% and fine sand for 50-60%.

The organic C content is very high for tropical conditions and varies from 0.8-1.2%, corresponding with an organic matter content of 1.5-2.0%.

The total N content is also high and is often of the order of 900 ppm.

The K content of the soils is extremely low and almost invariably less than 50 ppm.

The total P content, on the other hand is on the high side and varies between 130 and 300 ppm.

Considerable variations are found in the pH in the limits between 4.5 and 5.6, which may be related to the swampy conditions of the region.

The age of the palms, from which samples were taken for analysis, varied between one year (after planting) and 30 years.

Growth of the young palms has been assessed by the increase in the number of leaves during a certain period or by height increases. In one case the number of fruit bunches and female inflorescenses of the young palms, entering the productive phase, were recorded; the production was recorded as weight of bunches per individual palm.

The records obtained from a series of fertiliser experiments and the block yields from the plantations were used for the determination of growth and production.

As it is the object to compare the chemical composition of leaves with growth and production records of palms of different ages, growing under widely varying conditions of soil and climate, it will be evident that comparisons between areas may only be made in the practical terms of good, medium or poor, the absolute production level being a function of a complex of soil and ecological factors, which are different for the areas under consideration.

All palms have been sampled during the wet seasons, to avoid as much as possible the influence of climate on leaf composition.

In table 11, some of the data have been tabulated for comparison; in addition to the actual percentages of the several elements, the K, Ca and Mg contents have also been expressed as a % of the sum of K + Ca + Mg and the K, P and Ca content as a % of K + P + Ca. This method of expression enables the data to be plotted in trian-

TABLE 11

RELATIONSHIPS BETWEEN GROWTH / PRODUCTION AND LEAFCOMPOSITION
(data as a % of ash)

Description	% K	% Ca	% Mg	% P	Total K+Ca+Mg	K as a % of total	Ca as a % of total	Mg as a % of total	Total K+Ca+P	K as a % of total	Ca as a % of total	P as a % of total
1. Kasai region, fertiliser experiment on young palms; control plots bad growth	20,7	11,3	3,83	4,12	35,8	57	31	12	36,1	57	31	12
2. As 1, but plots with medium growth	23,4	10,3	3,60	3,75	37,3	62	27	11	37,5	62	27	11
3. As 1 and 2, but plots with good growth	24,0	9,41	3,53	3,24	36,9	64	25	11	36,7	65	25	10
4. Kasai region, fertiliser experiment on old palms; plots with highest production	26,2	7,02	3,33	2,22	36,6	71	19	10	35,4	74	19	7
5. As 4, but plots with medium production	28,3	7,00	3,57	2,87	38,9	72	17	11	38,2	74	18	8
6. As 4, but plots with low production	25,4	10,4	3,42	3,75	39,2	64	26	10	39,6	64	26	10
7. Kasai region; replanting experiment; plots with very good growth	28,6	6,45	3,80	3,20	38,8	73	16	11	38,3	74	16	10
8. As 7, but growth medium to good	28,4	9,05	3,50	4,35	40,9	69	22	9	41,8	67	21	12
9. As 7, but bad to medium growth	24,7	8,02	4,90	4,07	37,6	65	21	14	36,8	67	21	12
10. As 7, but very bad growth	13,4	13,9	4,20	6,80	31,5	42	44	14	34,1	39	40	21
11. Kwilu region, blocks with good production	24,9	9,29	3,02	3,00	37,2	66	24	10	37,2	66	24	10
12. As 11	23,6	8,19	2,73	2,91	34,5	68	24	8	34,7	68	23	9

TABLE 11 continued

Description	% K	% Ca	% Mg	% P	Total K+Mg+Ca	K as a % of total	Ca as a % of total	Mg as a % of total	Total K+Ca+P	K as a % of total	Ca as a % of total	P as a % of total
13. As 11, but blocks with low production	23, 2	10, 5	3, 29	3, 72	37, 0	62	28	10	37, 4	62	28	10
14. As 13.	22, 1	10, 7	4, 50	3, 72	37, 3	59	28	13	36, 5	60	29	11
15. As 13.	18, 8	9, 68	4, 17	2, 81	32, 7	57	29	14	31, 3	60	30	10
16. As 13.	21, 2	11, 4	3, 29	3, 34	35, 9	59	31	10	35, 9	59	31	10
17. Northern Congo, Yaligimba, low/medium production	28, 9	4, 88	4, 26	2, 68	38, 0	75	12	13	36, 5	79	13	8
18. As 17	28, 7	5, 15	4, 52	2, 59	38, 4	74	13	13	36, 4	78	14	8
19. As 17	27, 5	5, 59	4, 27	2, 64	37, 4	73	14	13	35, 7	77	15	8
20. Yaligimba; young palms on recently felled forest area	25, 6	7, 69	4, 60	2, 60	37, 9	67	20	13	35, 9	71	21	8
21. Yaligimba; fertiliser experiment, highest producing plots	26, 4	7, 98	3, 57	3, 04	37, 9	69	21	10	37, 5	70	21	9
22. Northern Congo, Elisabetha, fertiliser experiment on young palms; control plots bad growth	32, 1	5, 92	3, 72	2, 42	41, 7	77	14	9	40, 4	79	15	6
23. As 22, but plots with good growth	30, 0	6, 50	3, 25	2, 93	39, 8	75	16	9	39, 4	76	16	8
24. Central Congo Basin, Flandria, medium/good production blocks	24, 0	8, 73	6, 07	3, 33	38, 8	62	22	12	36, 1	66	24	10
25. As 24, but bad producing blocks; much leaf scorch	13, 8	14, 9	3, 45	3, 71	32, 2	43	46	11	32, 4	42	46	12
26. Central Congo Basin, Flandria, chlorosed nurseries	37, 5	5, 03	1, 45	3, 32	44, 0	85	11	4	45, 9	82	11	7

gular diagrams, from which the ratios between the elements may easily be determined (see figures 15 and 16).

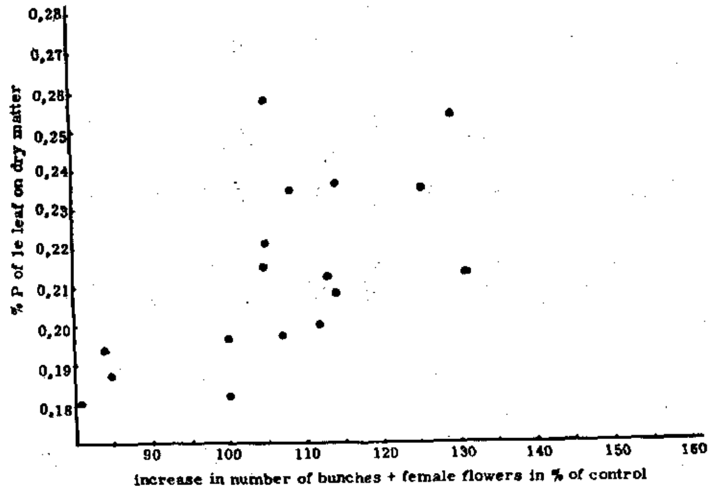
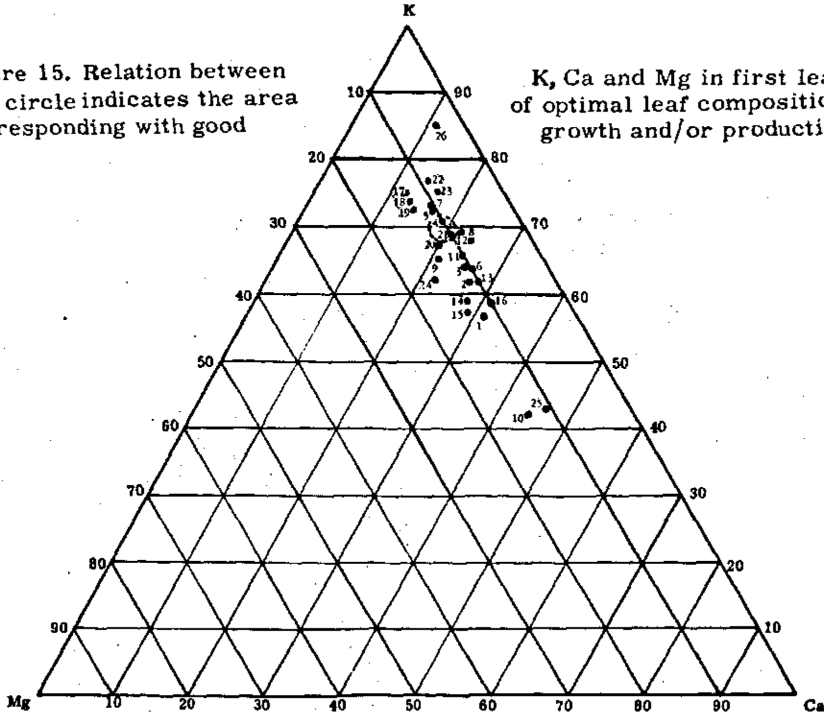


Figure 14. Positive correlation between production and P content (on dry matter) of 1e leaf

Figure 15. Relation between K, Ca and Mg in first leaf. The circle indicates the area of optimal leaf composition, corresponding with good growth and/or production



The following conclusions may be drawn from the tables and the diagrams:

1) All the data fall in a narrow band in the diagrams.

From these it may be observed that the K/Ca ratio seems to play an important part in the nutrition of oil palms. The Mg content expressed as a % of K + Ca + Mg is rather constant for wide-

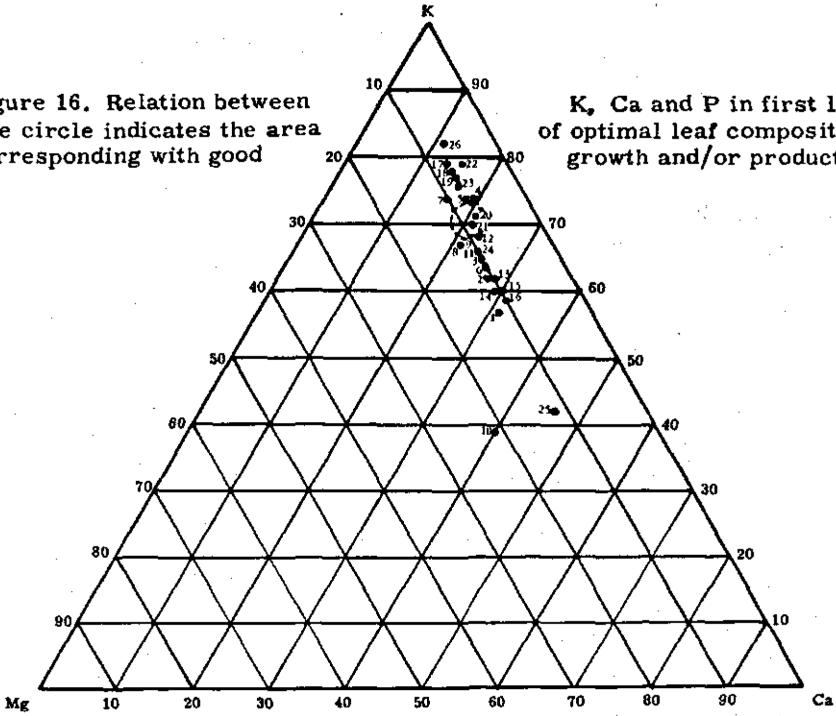


Figure 16. Relation between K, Ca and P in first leaf. The circle indicates the area of optimal leaf composition, corresponding with good growth and/or production

ly different soil and climatic conditions. The same may be said for the P content as a % of K + P + Ca, which seems to be constant. The antagonism between K and Ca has been studied for a lot of other plants and many similar examples may be found in the literature.

2) It will be seen that the points, representing the leaf composition of high producing plantation blocks, wide-spread in the Congo, and of fertiliser experiments, from which the highest growth or production figures were recorded, appear to fall in a very limited area, in each of the triangular diagrams. This area is approximately represented by the following limits:

K. 67 to 70% of the sum of K + Ca + Mg.
Ca. 19 to 24%.
Mg. 10 to 13%.

In general the deviations from the above limits are found in plantation blocks of low productivity, or in the control plots of fertiliser experiments, where poor growth of young palms or low production from mature palms are obtained.

The figures cited above correspond approximately with the following actual percentages, expressed as a % of leaf ash:

K. 25-28% on ash.
Ca. 7-9% on ash.
Mg. 3.7-4.8% on ash.

or expressed on dry matter:

K. 1.7-1.9% of dry matter
Ca. 0.55-0.65% of dry matter
Mg. 0.25-0.35% of dry matter.

Similarly, leaf P varies around 3.0-3.5% of leaf ash or 0.21-0.23% of dry matter.

These findings suggest that there is an "optimal" composition of oil palm leaves [1].

The I. R. H. O. workers in French Equatorial Africa arrived at similar conclusions for ground nuts and oil palms. Although the sampling and analytical methods used are somewhat different from the technique adopted by us, the area of optimal composition in their triangular diagram for K, Ca, Mg, corresponds closely with that in figure 15. However, their further approach to the problem is different from that adopted by us. The I. R. H. O. workers established so-called "critical values" for the various leaf constituents. As soon as an element in the leaf tissue falls below this critical value, it is considered as being deficient and fertilising with that particular element is advised. The "critical" values, as given by the French workers, are:

N. 2.75% on dry matter;
P. 0.15%
K. 1.0%
Mg. 0.24%

This indicates that, with the exception of N, which has not been considered in this work, the other levels fall below the "optimal" range, found for Congo conditions.

Our approach on the contrary, is based on the concept of the "optimal" leaf composition.

Apart from the fact that variations in leaf composition may exist, due to differences in age and climatological factors, there would seem to be an "optimal" range of levels and ratios of various elements in the leaves. Within these, considerable variations in leaf composition may still be due to differences in age of the palms and in climatological conditions. Our problem will,thus consist in the evaluation of qualitative and quantitative deviations from the "optimal" leaf composition, characteristic for various mineral deficiencies in the soil.

1) The expression "optimal" composition is used to indicate the chemical composition of leaves of palms having regional maximal growth and/or production.

VI. LEAF COMPOSITION OF MINERAL DEFICIENT PALMS

To remedy mineral deficiencies in the oil palm may be a long process, if the appropriate fertilisers are applied after the appearence of the deficiency somptoms. The common diagnosis of the deficient element or elements is, however, based on the external symptoms, shown by the palms. It was, therefore, considered important to test whether the diagnosis of mineral deficiencies, before the symptoms were evident, was possible by foliar analysis. For this diagnosis, it is essential that the changes in leaf composition, resulting from the various deficiencies are known. It was therefore, decided to establish a sand culture experiment and to analyse the leaves of palms receiving the various treatments at monthly interfalls to determine the effect on leaf composition. Young palms were employed in this experiment on the assumption that changes in the leaf composition of young and old palms are similar.

The design of the experiment was a 6 X 6 Latin square, including the following treatments:

A.	Palms	watered	daily	with	a complete	nutrient	solution.
B.	"	"	"	"	"	minus	N.
C.	"	"	"	"	"	"	P.
D.	"	"	"	"	"	"	K.
E.	"	"	"	"	"	"	Ca.
F.	"	"	"	"	"	"	Mg.

Each treatment consisted of six palms, each of which was planted in a half 200 liter drum, containing washed river quartz sand. The palms were approximately one year old at the time of planting and their roots were washed clean with tap water before planting. Immediately after planting, the leaves were bound together to prevent excess water loss and were left like this until growth was resumed.

The nutrient solution adopted for use in this experiment was that recommended by HEWITT, i. e.

Elements	Milli. equivalent per litre
NO_3^-	15
PO_4^{---}	4
SO_4^{--}	3
Ca^{++}	10
Mg^{++}	3
K^+	5
Na^+	1.33
H^+	2.67
Fe^{+++}	0.33
Mn^{++}	0.02
Cu^{++}	0.002
Zn^{++}	0.002
B	0.033 milli Mol/liter.
Mo	0.0002 " "

When a cation was omitted, it was replaced by Na; in the case of an anion being omitted, it was replaced by SO4.

The chemicals (analytical pure) used to make up the various nutrient solutions were:

KNO_3; $Ca(NO_3)_2$ $4H_2O$; NaH_2PO_4 $2H_2O$; $MgSO_4 7H_2O$; $NaNO_3$; K_2SO_4; Na_2SO_4. $10H_2O$; $CaSO_4$; $FeC_6H_5O_7$; $MnSO_4$. $4H_2O$; $CuSO_4$. $5H_2O$; $ZnSO_4$. $7H_2O$; H_3BO_3; and $(NH_4)_2Mo\ O_4$.

Stock solutions of the above chemicals were made and aliquots were diluted for the nutrient solutions. Each nutrient solution was adjusted to pH 5 by the addition of caustic soda or sulphuric acid. Each palm received $\pm$ 1.5 liters of the solution per day. Holes were made in the base of the drums to permit free drainage of the sand and this was checked daily. Tap water was used to make up the solutions.

TABLE 12

RESULTS SANDCULTURE EXPERIMENT; FIGURES EXPRESSED AS A % OF DRY MATTER

Treatments	element in leaf	Febr.	March	April	May	June	July	Aug.
Complete	% K	1,90	1,86	2,01	1,91	2,71	2,34	2,62
	% P	0,284	0,291	0,323	0,317	0,338	0,314	0,364
	% Ca	0,625	0,618	0,615	0,657	0,652	0,669	0,595
	% Mg	0,290	0,240	0,261	0,234	0,230	0,356	0,376
Without N.	% K	1,99	1,70	2,18	2,19	2,36	2,35	2,66
	% P	0,266	0,425	0,638	0,665	0,622	0,715	0,448
	% Ca	0,628	0,738	0,800	0,766	1,38	0,970	0,770
	% Mg	0,291	0,348	0,452	0,542	0,424	0,426	0,318
Without P.	% K	2,23	1,83	2,02	1,96	2,68	2,15	2,48
	% P	0,241	0,233	0,245	0,264	0,263	0,197	0,287
	% Ca	0,689	0,693	0,637	0,582	0,560	0,596	0,560
	% Mg	0,270	0,272	0,236	0,297	0,205	0,321	0,300
Without K.	% K	1,78	1,32	1,33	1,43	1,57	1,01	1,81
	% P	0,256	0,292	0,334	0,327	0,354	0,405	0,480
	% Ca	0,732	0,772	0,786	0,703	0,722	0,736	0,795
	% Mg	0,301	0,341	0,352	0,324	0,368	0,396	0,351
Without Ca	% K	2,20	1,85	2,17	2,31	2,95	2,02	2,57
	% P	0,235	0,311	0,323	0,283	0,252	0,269	0,321
	% Ca	0,606	0,576	0,523	0,436	0,390	0,333	0,347
	% Mg	0,289	0,313	0,291	0,297	0,268	0,300	0,278
Without Mg	% K	2,07	1,99	2,34	2,06	3,05	2,30	2,81
	% P	0,234	0,301	0,329	0,310	0,328	0,364	0,402
	% Ca	0,701	0,721	0,750	0,738	0,787	0,846	0,852
	% Mg	0,256	0,227	0,224	0,275	0,196	0,320	0,250

Analysis of this water showed that the amounts of anions and cations present were negligible.

The drums were first placed in a glass roofed shed at a spacing

TABLE 13

RESULTS SANDCULTURE EXPERIMENT, FIGURES EXPRESSED AS A % OF ASH

Treatments	element in leaf	Febr.	March	April	May	June	July	August
	% K	26, 8	28, 1	27, 3	33, 3	39, 2	31, 5	35, 5
	% P	4, 01	4, 44	4, 49	5, 52	4, 92	4, 21	4, 42
Complete	% Ca	9, 24	8, 71	8, 36	11, 22	9, 39	8, 97	7, 33
	% Mg	4, 10	3, 73	3, 99	4, 17	3, 34	4, 77	4, 74
	% ash	7, 09	6, 68	7, 56	5, 84	6, 96	7, 52	8, 22
	% K	29, 7	23, 2	23, 6	25, 1	23, 3	24, 4	24, 9
	% P	3, 69	4, 81	6, 92	7, 37	6, 16	7, 37	4, 10
Without N	% Ca	9, 65	9, 95	8, 79	8, 80	14, 6	10, 09	7, 54
	% Mg	5, 51	4, 70	5, 43	6, 25	4, 25	4, 46	3, 25
	% ash	6, 57	7, 42	9, 28	8, 73	10, 08	9, 70	10, 17
	% K	30, 9	28, 4	26, 7	30, 9	44, 4	32, 2	31, 8
	% P	3, 63	3, 70	3, 06	4, 08	4, 34	2, 99	3, 80
Without P	% Ca	9, 22	10, 79	8, 46	9, 24	8, 99	9, 07	7, 35
	% Mg	4, 02	4, 30	3, 14	4, 41	3, 40	4, 86	3, 95
	% ash	6, 91	6, 53	7, 68	6, 56	6, 27	6, 64	7, 75
	% K	28, 4	21, 2	19, 1	24, 4	30, 2	18, 8	22, 3
	% P	4, 08	4, 82	4, 85	5, 63	6, 79	7, 48	6, 77
Without K	% Ca	11, 29	12, 34	11, 54	11, 89	13, 8	13, 58	11, 07
	% Mg	4, 63	5, 51	5, 14	5, 55	6, 99	7, 39	5, 03
	% ash	6, 54	6, 22	6, 97	5, 91	5, 57	5, 62	7, 61
	% K	31, 2	24, 1	28, 3	33, 5	42, 2	28, 8	34, 3
	% P	3, 23	4, 01	4, 15	3, 97	3, 60	3, 84	4, 34
Without Ca	% Ca	8, 49	5, 76	6, 93	6, 35	5, 60	4, 83	4, 76
	% Mg	4, 02	3, 35	3, 85	4, 01	3, 90	4, 28	3, 95
	% ash	7, 29	7, 82	7, 84	7, 00	7, 09	7, 12	7, 70
	% K	30, 4	26, 8	28, 1	29, 0	38, 4	28, 3	30, 4
	% P	3, 44	3, 96	3, 96	4, 16	4, 22	4, 53	4, 35
Without Mg	% Ca	10, 36	10, 07	8, 97	10, 63	12, 6	10, 50	9, 16
	% Mg	3, 97	3, 26	2, 80	3, 90	2, 51	3, 95	2, 75
	% ash	6, 97	7, 72	8, 50	7, 15	7, 94	8, 15	9, 33

of 50 cms. After 5 months, the rapid growth of the palms resulted in over crowding and half of the palms were moved to a second shed, close to the first and the spacing increased to one meter. The deviding of a latin square over two separate areas although frequently found in practice, still implies that there do not exist interactions between rows and columns. The chance that this last assumption is not absolutely true increases when the above procedure is followed, but could under the given conditions not be avoided.

Leaf samples were taken from the youngest fully opened leaf, each month for the first 7 months of the experiment After this period, leaf sampling was not possible, due to the poor growth, combined with a fungus attack of the palms of some of the treatments

(i) Results of Foliar Analysis

The average leaf composition for each of the treatments for the first 7 months is shown in tables 12 and 13, expressed both on ash and dry matter. For the calculation of the significance of the difference in leaf composition between the various treatments, it should be borne in mind that the error variance for the treatments, rows and columns effects are based in only 20 degrees of freedom, as the monthly samplings of the same palms do not provide true replications. The effect of the time of sampling and the interactions of the sampling time with the treatments, rows and columns, is based on one hundred and twenty degrees of freedom. For the allocation of degrees of freedom and details of the analysis of variance, see tables 14 and 15. From tables 14 and 15 the following conclusions may be drawn:

1) The effect of the treatments on the chemical composition of the leaves has been highly significant.

2) The effect of the arrangement of the palms in the sheds has not been of great importance, as shown by the generally insignificant row and column effects.

3) The effect of the month of sampling was in all cases significant. The cause of this effect may be ascribed to environmental and climatic conditions.

4) The interactions between sampling time and treatments are highly significant, both when expressed on ash and on dry matter, except for K on ash.

   This indicates that the changes in leaf composition, as compared with time of sampling, are not similar for all the treatments.

5) The interaction between the time of sampling and columns is significant for the K and Mg contents on dry matter, and for the P, Ca and Mg contents on ash.

   This means that changes in leaf composition, induced by varying environmental conditions, have not been the same for all the columns.

TABLE 14

ANALYSIS OF VARIANCE SANDCULTURE EXPERIMENT (as a % of dry matter)

Factor	Degrees of freedom	Potassium		Phosphorus		Calcium		Magnesium		Ash as a % of dry matter	
		sum of squ. x 10^4	Variance	Sum of squ. x 10^6	Variance	Sum of squ. x 10^6	Variance	Sum of squ. x 10^6	Variance	Sum of squ. x 10^4	Variance
Total	251	837691		5210295		12790585		2340300		6944813	
Whole unit	35	292301		2758017		5973932		875776		2316195	
Treatments	5	217580	40351^{++}	2124362	424872^{++}	4508123	901625^{++}	665954	133191^{++}	1504187	300837^{++}
Columns	5	15683	3137	64969	12993	347614	69503	29413	5882	79403	15881
Rows	5	4997	999	152440	30488	234442	46888	29710	5942	49129	9825
Error A	20	54041	2702	416246	20812	883753	44187	150699	7535	683476	34174
Month	6	170135	28356^{++}	489837	81639^{++}	449072	74845^{++}	134424	22404^{++}	800003	133334^{++}
Month x treatm.	30	77680	2589^{++}	928234	30941^{++}	2741938	91398^{++}	425371	14179^{++}	881886	29396^{++}
Month x columns	30	103364	3445^{++}	194511	6484	508286	16943	305426	10181^{++}	702652	23422
Month x rows	30	56626	1887^{+}	196115	6537	705553	23518	145221	4841	383363	12779
Error B	120	137585	1146	643581	5363	2411804	20098	454082	3784	1860714	15506

TABLE 15

ANALYSIS OF VARIANCE SANDCULTURE EXPERIMENT (as a % of ash)

Factor	Degrees of freedom	Potassium		Phosphorus		Calcium		Magnesium	
		Sum of squares x 10^2	Variance	Sum of squares x 10^4	Variance	Sum of squares x 10^4	Variance	Sum of squares x 10^4	Variance
Total	251	1585684		6506596		27044946		6137605	
Whole unit	35	395730		2679856		12571154		2904371	
Treatments	5	280299	56059^{++}	1984900	396980^{++}	7891282	1578256^{++}	1435723	287145^{++}
Columns	5	51298	10259^{+}	119411	23882	1066241	213248	37995	7599
Rows	5	6286	1257	299372	59874^{++}	1010598	202119	90725	18145
Error A	20	57847	2892	276173	13808	2603033	130152	1339928	66996
Month	6	296128	49355^{++}	554888	92481^{++}	1877912	312985^{++}	308944	51491^{++}
Month x treatm.	30	151755	5058	1065317	35510^{++}	2602725	86757^{+}	748214	24940^{++}
Month x columns	30	171183	5706	530906	17697^{+}	2644964	88165^{+}	646710	21557^{++}
Month x rows	30	113534	3784	456313	15210	1523894	50796	402946	13431
Error B	120	457354	3811	1219316	10161	5824297	48536	1126427	9387

+ significant at P = 0,05
++ significant at P = 0,01

6) The interaction between time of sampling and rows is not significant.

To obtain information on the changes in leaf composition, resulting from various deficiencies, comparisons have been made between the complete nutrient and the other treatments. These are listed below:

A. Nitrogen Deficiency

Omitting N from the nutrient solutions resulted in the following changes.

Potassium

The average K content expressed as a % of dry matter is the same for both treatments; the K content on ash is lower in the deficient palms. Throughout the 7 months, the K content of the deficient palms on dry matter remained constant, apart from a decrease after the 5th month, followed by an increase to the previous level. The drop in K content on ash, is not significant as compared with the complete treatment, on account of the insignificant interaction between month and treatment.

Phosphorus

The average P content on dry matter is significantly higher in the N deficient palms; if the data are expressed on ash, the difference in P content between the complete and the O N treatments is highly significant.

The actual results of the analyses are tabulated in table 16.

The P content on dry matter increases rapidly but decreases after 5 to 6 months, Similar changes in P content were noticed with time, as compared with the complete treatment, if the data were expressed on ash.

Calcium

The average Ca content on dry matter is significantly higher than in the palms receiving the complete treatment. When expressed on ash, there appears to be no significant difference.

The Ca content on dry matter increases rapidly at first but decreases after the 5th to 6th month.

No consistent changes are to be seen when Ca is expressed on ash.

Magnesium

The average Mg content on dry matter is significantly higher. On ash, there are no, significant differences.

The Mg content expressed both on ash and dry matter, increases in the first 4-5 months but decreases later to a level, much below normal.

Ash as a % of dry matter

The ash content increases during the first 5 months and shows a slight decrease after that period. The changes in leaf composition for deficient palms as compared with those, which received complete nutrient solution, is demonstrated in table 16.

Sumarising, it may be seen, that N deficiency in the leaves may be recognisedby the abnormally high P, Ca and Mg content, provided the data are expressed as a % of dry matter. When the data

TABLE 16

MINERAL DEFICIENCIES AND LEAFCOMPOSITION

NITROGEN DEFICIENCY

Average leafcomposition of complete and without N-treatment

Treatment	Potassium		Phosphorus		Calcium		Magnesium		Ash as a % of dry matter
	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	
Complete	2,19	31,2	0,319	4,57	0,642	9,04	0,284	4,12	7,27
Without. N	2,20	25,1++	0,535++	5,77++	0,863++	9,97	0,401++	4,71	8,82++
Sig. diff. at P=0,05	0,24	2,45	0,066	0,53	0,096	1,64	0,039	1,17	0,84
Sign. diff. at P=0,01	0,32	2,80	0,090	0,73	0,131	2,24	0,045	1,60	1,14

CHANGES IN LEAFCOMPOSITION OF COMPLETE AND WITHOUT N TREATMENT, DURING 7 MONTHS

(data as a % of dry matter)

Element in leaf	Febr.	March	April	May	June	July	Aug.	Sign.interaction at P= 0,05	Sign.interact. at P=0,01
% K	+0,09	-0,16	+0,16	+0,28	-0,35	+0,02	+0,04	0.615	0,828
% P	-0,019	+0,134	+0,315	+0,348	+0,284	+0,401	+0,084	0,133	0,179
% Ca	-0,003	+0,120	+0,186	+0,110	+0,725	+0,302	+0,176	0,255	0,343
% Mg	+0,001	+0,108	+0,191	+0,308	+0,194	+0,070	-0,058	0,112	0,151

DATA ASH A % OF ASH

Element in leaf	Febr.	March	April	May	June	July	Aug.	Sign.interaction at P= 0,05	Sign.interact. at P=0,01
% K	+3,2	-5,1	-3,8	-8,2	-16,0	-7,1	-10,6	not sign.	not sign.
% P	-0,32	+0,37	+2,43	+1,85	+1,24	+3,16	-0,32	1,84	2,47
% Ca	+0,45	+1,24	+0,43	-2,42	+5,21	+1,14	+0,21	4,00	5,39
% Mg	+1,41	+0,97	+1,44	+2,08	+0,90	-0,30	-1,49	1,,76	2,37
Ash as a % of dr.m.	-0,52	+0,74	+1,74	+2,88	+3,11	+2,18	+1,95	2,27	3,05

NOTE: the interactions are represented by the differences between the columns.

TABLE 17

MINERAL DEFICIENCIES AND LEAF COMPOSITION

PHOSPHORUS DEFICIENCY

Average leafcomposition of complete and - P treatments

Treatment	Potassium		Phosphorus		Calcium		Magnesium		Ash as a % of dry matter
	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	
Complete	2,19	31,2	0,319	4,57	0,642	9,04	0,284	4,12	7,27
Without P	2,19	32,2	0,247+	3,66++	0,609	9,08	0,269	4,01	6,90
Sign. diff. at P=0,05	0,24	2,45	0,066	0,53	0,096	1,64	0,039	1,17	0,84
Sign. diff. at P=0,01	0,32	2,80	0,090	0,73	0,131	2,24	0,045	1,60	1,14

CHANGES IN LEAF COMPOSITION OF COMPLETE AND WITHOUT P TREATMENT, DURING 7 MONTHS. (data as a % of dry matter)

Element in leaf	Febr.	March	April	May	June	July	Aug.	Sign. interaction at P=0,05	Sign. interact at P=0,01
% K	+0,33	-0,03	+0,01	+0,04	-0,02	-0,19	-0,151	0,615	0,828
% P	-0,043	-0,058	-0,078	-0,053	-0,075	-0,117	-0,077	0,133	0,179
% Ca	+0,064	+0,075	+0,023	-0,079	-0,092	-0,072	-0,035	0,255	0,345
% Mg	-0,020	+0,031	-0,026	+0,045	-0,025	-0,034	-0,074	0,112	0,151

DATA AS A % OF ASH

Element in leaf	Febr.	March	April	May	June	July	Aug.	Sign. interaction at P=0,05	Sign. interact at P=0,01
% K	+4,2	+0,2	-0,6	-2,4	+5,2	+0,7	-3,7	not sign.	not sign.
% P	-0,38	-0,74	-1,42	-1,44	-0,58	-1,22	-0,62	1,84	2,47
% Ca	-0,02	+2,08	+0,10	-1,98	-0,41	+0,08	+0,02	4,00	5,39
% Mg	-0,08	+0,57	-0,85	+0,24	+0,06	+0,09	-0,79	1,76	2,37
Ash as a % of dry matter	-0,18	-0,16	+0,12	+0,72	-0,69	-0,88	-0,47	2,27	3,05

are expressed on ash, the recognition of N deficiently is less easy.

It may be seen that, in the latter stages of N deficiency, when growth has stopped completely, there is a tendency for the concentrations of major elements in the leaf, to assume their "normal" level again.

B. Phosphorus Deficiency

Phosphorus deficiency in the leaves is characterised by the following changes in leaf composition:

Potassium

The K content did not change significantly during the 7 months of the treatment.

Phosphorus

The P content, both expressed on dry matter and on ash, has decreased, as compared with complete treatment.

From table 17 it may be seen that there is a tendency for the P content, on ash, to increase again after 4 months of the treatment. This increase did not attain statistical significance.

Calcium

Ca on dry matter appeared to decrease below the "normal" level after 3 months of the treatment, although the average effect over a 7 months period was not significant.

Despite significant changes in the Ca content, expressed on ash, after the 2nd month of the treatment, the average Ca content during 7 months, did not change.

Magnesium

The Mg content of the leaves, expressed on dry matter, decreased significantly below the "normal" level but the difference in average Mg content between the complete and the OMg treatment, was not significant.

Ash as a % of dry matter

No significant changes in the ash content could be detected.

Thus it may be seen that P deficiency in palms is characterised by a decrease in the P content, whether expressed on ash or on dry matter, but that the P content on ash appears to increase again as the deficiency accentuates. The Ca and Mg contents, when expressed, on dry matter decrease.

C. Potassium Deficiency

The following changes in leaf composition were found to take place in K deficient palms:

Potassium

The average treatment effect, resulting in a decrease of the K content, when expressed on dry matter, is highly significant. Although it may be seen from table 18 that the K content decreases with time, the interaction between month and K treatment did not attain significance at P = 0.05.

Phosphorus

The average P content over a period of 7 months is significantly higher in the K deficient palms than in the ones which received the complete treatment, both if the data are expressed on dry mat-

TABLE 18

MINERAL DEFICIENCIES AND LEAF COMPOSITION

POTASSIUM DEFICIENCY

Average leaf composition of complete and - K treatment

Treatment	Potassium		Phosphorus		Calcium		Magnesium		Ash as a % of dry matter
	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	
Complete	2,19	31,2	0,319	4,57	0,642	9,04	0,294	4,12	7,27
Without K	1,48++	23,8++	0,450+	5,79++	0,749+	12,23++	0,348++	5,73++	6,37+
Sign. diff. at P=0,05	0,24	2,45	0,066	0,53	0,096	1,64	0,039	1,17	0,84
Sign. diff. at P=0,01	0,32	2,80	0,090	0,73	0,131	2,24	0,045	1,60	1,14

CHANGES IN LEAF COMPOSITION OF COMPLETE AND WITHOUT K TREATMENTS, DURING 7 MONTHS

Element in leaf	Febr.	March	April	May	June	July	Aug.	Sign. interaction at P=0,05	Sign. interaction at P=0,05
% K	-0,12	-0,54	-0,70	-0,48	-1,13	-1,33	-0,81	0,615	0,828
% P	-0,030	+0,001	+0,001	+0,010	+0,016	+0,096	+0,116	0,133	0,179
% Ca	+0,107	+0,154	+0,171	+0,047	+0,069	+0,067	+0,200	0,255	0,345
% Mg	+0,011	+0,101	+0,091	+0,090	+0,139	+0,040	-0,025	0,112	0,151
DATA AS A % OF ASH									
% K	+1,6	-6,9	-8,2	-8,9	-9,0	-12,7	-13,2	not sign.	not sign.
% P	+0,07	+0,38	+0,36	+0,11	+1,87	+3,27	+2,35	1,84	2,47
% Ca	+2,04	+3,63	+3,17	+0,66	+4,38	+4,59	+3,91	4,00	5,39
% Mg	+0,54	+1,78	+1,15	+1,38	+3,65	+2,62	+0,30	1,76	2,37
Ash as a % of dry matter	-0,55	-0,46	-0,59	+0,07	-1,39	-1,90	-0,61	2,27	3,05

ter and on ash. The increase in P content with intensified K deficiency is significant.

Calcium

The average Ca content (average 7 months) expressed on dry matter or on ash, is significantly higher in the K deficient palms. The fluctuations in Ca content are considerable; no consistent increase or decrease was noticed.

Magnesium

The average Mg content on ash and on dry matter, is significantly higher in the K deficient palms. It may, however, be seen that the Mg content decreases after 5 months, both if the data are expressed as a % of dry matter or on ash. These decreases in Mg content are significant.

Ash as a % of dry matter

The ash content as a % of dry matter was significantly lower in the K deficient palms. The changes in ash content with progressing K deficiency are irregular and no definite trend could be seen.

Thus, K deficiency is characterised by a decrease in the K content of the leaves and an increase in P, Ca and Mg contents; expressed as a % ash or on dry matter. The ash content as a % of dry matter is below "normal". As the K deficiency worsens, there is a decrease in Mg content after an earlier increase.

D. Calcium Deficiency

Calcium deficiency resulted in the following changes is leaf composition:

Potassium

No change in K content has been observed.

Phosphorus

The average P content of the palms of this treatment, expressed on dry matter, was lower than "normal" although the difference was not significant. When the P content was expressed on ash, the Ca deficient palms had a significantly lower P content than the complete treatment. The interaction between Ca treatment and month was not significant. No definite trend in the change in P content could be determined.

Calcium

The average Ca content, based both on a dry matter and on ash basis, was highly significantly lower in the Ca deficient palms. The decrease in Ca content with the time was significant for both methods of expression.

Magnesium

No significant difference in the average Mg content expressed on ash and on dry matter, was found; however it may be seen from table 19 that the Mg content on dry matter at first increased and, affer 5 months, decreased, this being at a level below "normal". This interaction was significant. Expressed as a % on ash, the Mg content fluctuated slightly around the "normal" value.

Ash as a % of dry matter

No significant differences in ash content have been found between the complete and O Ca treatments.

TABLE 19

MINERAL DEFICIENCIES AND LEAF COMPOSITION

CALCIUM DEFICIENCY

Average leafcomposition of complete and without Ca treatments

Treatments	Potassium		Phosphorus		Calcium		Magnesium		Ash as a % of dry matter
	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	
Complete	2,19	31,2	0,319	4,57	0,642	9,04	0,284	4,12	7,27
Without Ca	2,29	31,8	0,283	3,88+	0,458++	6,34++	0,288	4,01	7,41
Sign. diff. at P=0,05	0,24	2,45	0,066	0,53	0,096	1,64	0,039	1,17	0,84
Sign. diff. at P=0,01	0,32	2,80	0,090	0,73	0,131	2,24	0,045	1,60	1,14

CHANGES IN LEAF COMPOSITION OF COMPLETE AND WITHOUT Ca TREATMENTS, DURING 7 MONTHS. (data as a % of dry matter)

Element in leaf	Febr.	March	April	May	June	July	Aug.	*Sign. interaction at P=* 0,05	*Sign. interaction at P=* 0,01
% K	+0,30	-0,01	+0,16	+0,39	+0,24	-0,32	-0,05	0,615	0,828
% P	-0,050	+0,020	+0,001	-0,046	-0,086	-0,016	-0,043	0,133	0,179
% Ca	-0,019	-0,042	-0,092	-0,220	-0,263	-0,336	-0,251	0,255	0,345
% Mg	-0,001	+0,073	+0,030	+0,040	+0,038	-0,055	-0,097	0,112	0,151

DATA AS A % OF ASH

% K	+4,4	-4,0	+1,0	+0,2	+3,0	-2,7	-1,1	not sign.	not sign.
% P	-0,78	-0,43	-0,34	-1,55	-1,32	-0,37	-0,08	1,84	2,47
% Ca	-0,76	-1,95	-1,42	-4,87	-3,80	-4,16	-2,57	4,00	5,39
% Mg	-0,08	+0,32	-0,14	-0,16	+0,56	-0,48	-0,79	1,76	2,37
Ash as a % of dry matter	+0,20	+1,14	+0,29	+1,16	+0,12	-0,40	-0,52	2,27	3,05

TABLE 20

MINERAL DEFICIENCIES AND LEAFCOMPOSITION

MAGNESIUM DEFICIENCY

Average leafcomposition of complete and without magnesium treatments

Treatments	Potassium		Phosphorus		Calcium		Magnesium		Ash as a % of dry matter
	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	
Complete	2,19	31,2	0,319	4,59	0,642	9,04	0,284	4,12	7,27
Without Mg	2,38	30,4	0,324	4,09	0,797++	10,32	0,252	3,29	7,90
Sign. diff. at P=0,05	0,24	2,45	0,066	0,53	0,096	1,64	0,039	1,17	0,84
Sign. diff. at P=0,01	0,32	2,80	0,090	0,73	0,131	2,24	0,045	1,60	1,14

CHANGES IN LEAF COMPOSITION OF COMPLETE AND WITHOUT Mg TREATMENTS DURING 7 MONTHS (data as a % of dry matter)

Element in leaf	Febr.	March	April	May	June	July	Aug.	Sign. inter-action at P= 0,05	Sign. inter-action at P= 0,05
% K	+0,17	+0,13	+0,33	+0,15	+0,34	-0,04	+0,20	0,615	0,828
% P	-0,050	+0,010	+0,007	-0,006	-0,010	+0,050	+0,038	0,133	0,179
% Ca	+0,076	+0,103	+0,136	+0,081	+0,135	+0,177	+0,257	0,255	0,345
% Mg	-0,018	-0,013	-0,037	+0,041	-0,034	-0,036	-0,126	0,112	0,151

DATA AS A % OF ASH

Element in leaf	Febr.	March	April	May	June	July	Aug.	Sign. inter-action at P= 0,05	Sign. inter-action at P= 0,05
% K	+3,6	-1,3	+0,8	-4,3	-0,8	-3,2	-5,1	not sign.	not sign.
% P	-0,57	-0,48	-0,53	-1,36	-0,70	+0,32	-0,07	1,84	2,47
% Ca	+1,12	+1,36	+0,62	-0,59	+3,15	+1,52	+1,83	4,00	5,39
% Mg	-0,12	-0,48	-1,19	-0,27	-0,83	-0,82	-1,99	1,76	2,37
Ash as a % of dry matter	-0,12	+0,92	+0,94	+1,30	+0,98	+0,63	+1,11	2,27	3,05

It may be concluded that Ca deficient palms have a lower Ca content and P content of the leaves. The Mg content expressed on dry matter, first increases but at a latter stage of the deficiency of Ca, decreases below the "normal" level.

It should be noticed that the palms did not show any external deficiency symptoms and were still growing reasonably well. It may thus be possible that not all the characteristic changes in leaf composition have yet been determined.

E. Magnesium Deficiency

The following changes in leaf composition were found in the Mg deficient palms:

Potassium

No significant changes in K content were detected.

Phosphorus

No significant changes in P content were observed.

Calcium

The average Ca content was higher than "normal" but the difference was only significant when the data were expressed on dry matter (table 20). The rise in Ca content, expressed on dry matter, with increasing deficiency, was significant.

Magnesium

Although the average Mg content expressed on dry matter and also on ash, appears to be lower, the difference did not attain significance at $P = 0.05$; However, the decrease in Mg content with accentuating deficiency, was significant for both means of expression.

Ash as a % of dry matter

The average ash content appears to be lower than for the complete treatment, but just failed to attain significance at $P = 0.05$.

Magnesium deficiency, therefore causes a decrease in the Mg content and an increase in Ca content of the leaves.

When the changes in leaf components for all the deficiencies are considered, the tables 16-20 may be sumarised in the following way:

"Normal" composition is represnted by O.
A level higher than "normal" by +
A level lower than "normal" by -

The various stages of the deficiencies may be compared as follows:

Deficiency	leaf K		leaf P		leaf Ca		leaf Mg	
	dr. mat.	ash	dr. mat.	ash	dr. mat.	ash	dr. mat.	ash
N. 1st stage	0	-	+	+	+	0	+	+
N. 2nd "	0	-	0	0	0	0	0	-
P. 1st "	0	0	-	-	-	-	0	0
P. 2nd "	0	0	-	0	0	0	-	0
K. 1st "	-	-	0	+	+	+	+	+
K. 2nd "	-	-	+	+	+	+	-	-
Ca. 1st "	0	0	-	-	-	-	+	0
Ca. 2nd "	0	0	-	-	-	-	-	0
Mg. 1st "	0	0	0	0	+	+	-	-
Mg. 2nd "	0	-	0	0	+	+	-	-

TABLE 21

RATIOS BETWEEN ELEMENTS IN THE FIRST LEAVES AND MINERAL DEFICIENCIES

Treatments	Month	K+Ca+Mg as a % of dr. m.	K as a % of total	Ca as a % of total	Mg as a % of total
	Febr.	2,815	67	22	11
	March	2,718	68	23	9
	April	2,886	70	21	9
Complete	May	2,801	68	23	9
	June	3,592	75	18	7
	July	3,365	70	20	10
	Aug.	3,591	73	16	11
	Febr.	2,909	68	22	10
	March	2,786	61	26	13
	April	3,432	64	23	13
Without N	May	3,498	63	22	15
	June	4,164	57	33	10
	July	3,746	63	26	11
	Aug.	3,748	71	21	8
	Febr,	3,189	70	22	8
	March	2,795	65	25	10
	April	2,893	70	22	8
Without P	May	2,821	69	21	10
	June	3,445	78	16	6
	July	3,058	70	19	11
	Aug.	3,340	74	17	9
	Febr.	2,813	63	26	11
	March	2,433	54	32	14
	April	2,468	54	32	14
Without K	May	2,457	58	29	13
	June	2,660	59	27	14
	July	2,142	47	36	17
	Aug.	2,956	61	27	12

TABLE 21, continued.

Treatments	Month	K+Ca+Mg as a % of dr. m.	K as a % of total	Ca as a % of total	Mg as a % of total
	Febr.	3,095	71	20	9
	March	2,739	68	21	11
	April	2,984	73	18	9
Without Ca	May	3,043	76	14	10
	June	3,608	82	11	7
	July	2,653	76	12	12
	Aug.	3,195	80	11	9
	Febr.	3,027	68	23	9
	March	2,938	68	25	7
	April	3,314	71	23	6
Without Mg	May	3,073	67	24	9
	June	4,033	76	20	4
	July	3,466	66	24	10
	Aug.	3,912	72	22	6

The ratios between the major elements in the leaves, related to the various deficiencies, have been compared in the table 21 for the K, Ca and Mg contents. From this it may be seen that considerable differences obtain between the ratios of K, Ca and Mg, according to the particular deficiency. When compared with the complete treatment, the palms with N deficiency have an average K/Ca ratio of + 2.6 (complete treatment K/Ca = ± 3.5). The K/Mg ratio of the N deficient palms is + 4.8 against 6-8 for the complete treatment. In the case of K deficiency, the K/Ca ratio may decrease to less than 2 and the K/Mg ratio to 3-4. Calcium deficiency is characterised by a high Ca/Mg ratio of 2.5-5 as compared with 2-2.5 for the complete treatment.

The ratios between K, Ca and Mg have been plotted in a triangular diagram in fig. 17. This indicates that:

a) The complete treatment coincides with the area of "optimal" leaf composition, as found for palms in plantations and fertiliser experiments:

b) Palms deficient in K, Mg, Ca or N, occupy a different area in the triangular diagram;

c) In the K, Ca, Mg diagram, there is no characteristic area for P deficient palms.

Conclusions

From the results of the sand culture experiment, it may be seen that there are possibilities for the recognition of deficiencies in palms by means of leaf analysis only.
In general it has been observed that the first stage of a deficiency is characterised by a decrease of the particular element deficient in the leaves. However the reverse of this finding, i.e.

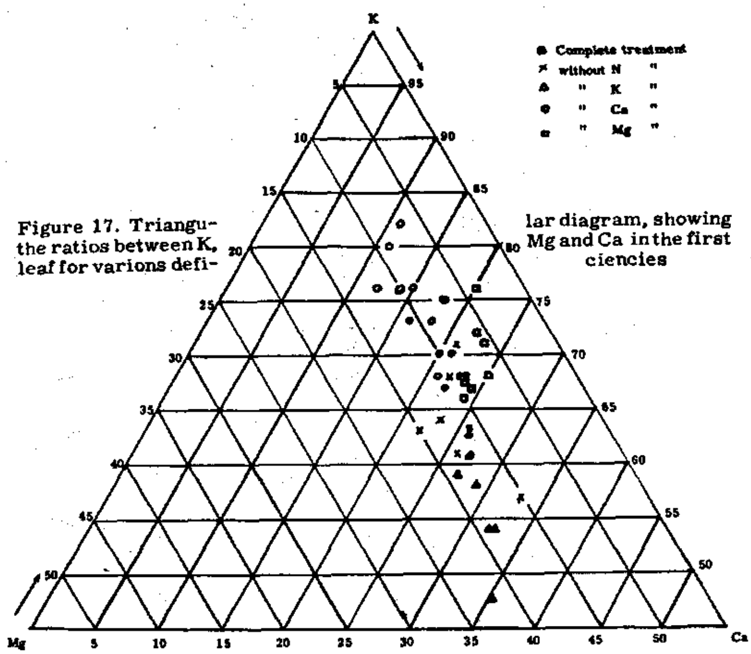


Figure 17. Triangular diagram, showing the ratios between K, Mg and Ca in the first leaf for varions deficiencies

the conclusion that a palm is deficient in a particular element, when its content in the leaves is low, is not necessarily true. For instance it has been shown that in the cases of N, P, Ca as well as in the case of Mg deficiencies, the Mg content of the leaves may decrease far below its "normal" value, as the deficiencies worsen.

When P is deficient, leaf Ca may decrease simultaneously with the P content, whereas the P content increases again with intensified P deficiency.

Although the behaviour of leaf P is the case of P deficiency may seem rather paradoxical, similar changes in leaf composition have been found by STEENBJERG, for the Cu content of oats. These results may be explained by the sigmoidal shape of the yield curve (giving yield as a function of the concentration of an element in the nutrient medium). The classical presentation of hyperbolic or parabolic yield curves does not hold for cases of extreme deficiency. At a certain stage in the deficiency, growth almost ceases; this may be due to an advanced stage of the deficiency, but other factors may also be involved, such as climate or disease incidence. The plant accumulates as much as possible and may remain alive for a long period, without displaying any marked change in external symptoms. The supply of the deficient element causes a growth response but a decrease of the particular element in the leaves, due to the "dilution" effect in the growing tissues, so that uptake cannot keep pace with the plants requirements. At a later stage, when the root system is re-established and ion uptake is able to follow the production of new leaves, the deficient element starts to accumulate.

The above facts show clearly that the absolute level of a single element may never serve as reliable indication of a deficiency.

Much the same may be said in respect of ratios between elements, as shown in triangular diagrams. When an element is deficient, the dots, representing the ratios between the elements in the leaves, may occupy a certain "characteristic" area in the triangular diagram, but again, the reverse is not necessarily true. The first stages of K deficiency are identical with N deficiency as regards the ratios between K, Ca and/or Mg.

The ratios between K, Ca and Mg, when P is deficient, may be similar to those when Ca or Mg are deficient.

Thus, the representation of data in triangular diagrams, or as ratios does not provide any more essential information for the determination of deficiencies than the changes in actual concentration of the various elements in the leaves.

The actual changes in the concentration of leaf components, as have been observed in the sand culture experiment, may serve as a preliminary guide for qualitative diagnosis of deficiencies in the plantations. Their validity will need to be confirmed by means of foliar analysis after fertiliser applications.

(ii) Deficiency Symptoms of the Oil Palm

During the course of the sand culture experiment, the palms receiving certain treatments displayed definite deficiency symptoms. These are described below.

It is emphasized that the symptoms apply, to young palms. It is probable that identical symptoms will be shown by adult palms but apart from Mg (BULL 1954) this has not yet been proven.

1) Potassium

The earliest symptoms to develop was a chlorosis of the old leaves. This consisted of a yellowing at the tips and edges of the leaflets at the distal end of the leaves, which spreads inwards to the midrib of the leaflets and also downwards to the base. The lamina in the immediate vicinity of the mid-rib remained dark green. These symptoms were first observed after 7-8 months.

3 of the 6 palms, deficient in K, showed abnormal symptoms on the younger leaves after 10 months. This abnormality was the presence of small, pale, almost white longitudinal spots, scattered over the laminae of the leaflets, and was most noticeable in the central part of the leaflets.

Growth of the palms was not greatly affected by the deficiency.

2) Nitrogen

This resulted in very poor growth of the palms and a homogenious yellowing of the leaflets of all the leaves. The youngest fully opened leaf was a very pale yellow-green while the older leaves were definite yellow. The leaflets of the oldest leaves showed some scorching at the tips and, occacionally at the edges. The veins of the leaflets were yellow and the leaf rachis was yellow at the distal end.

3) Magnesium

The oldest leaves were first affected and showed symptoms after 3-4 months. The leaflets at the distal end of the oldest leaves showed an ochreous - yellowing of the laminae at the distal part. The discoloured area spread and changed to a more definite yellowing and later to a bright orange colour, which eventually affected the whole of the oldest leaves. The tips and edges of the severely affected leaflets became scorched and brown coloured and finally grey, following desiccation.

There was a considerable similarity between the early symptoms of Mg deficiency and the chlorosis resulting from K deficiency.

4) No external deficiency symptoms were observed in the palms deficient in Ca and P.

VII. FOLIAR ANALYSIS AND FERTILISER EXPERIMENTS

In the preceding chapters, it has been shown that the chemical composition of the leaves of palms, growing under widely different conditions of soil and climate, varies within narrow limits, provided growth and production are "normal". As soon as a particular deficiency occurs, a characteristic change in leaf composition is noticed. This enables a diagnosis of possible mineral deficiencies in the field to be made. The next step in the investigations should be:

1) to check whether the characterictic changes in the leaf composition for each particular deficiency, as observed in the sand culture experiment, also occur in palms, growing in the plantation;

2) In that event, it remains to be shown that these deficiencies may be remedied by means of appropriate fertiliser applications.

3) Evidence should be obtained to determine to what extent growth/production - responses correspond with changes in leaf composition towards the "optimal" leaf composition.

For this purpose, a number of fertiliser experiments in the Congo, which had given significant responses to fertiliser applications, were at our disposal. They were mainly designed to investigate responses to applications of K, P and Mg. To date, no positive growth or production responses to N or Ca applications have been obtained.

(i) The Effect of Potassium Fertilisers

1) On young palms.

In a plantation in the Kasai region, a fertiliser experiment on young palms had been laid down, to determine whether positive growth responses couldbe obtained by means of various fertiliser treatments, including Potassium applications at two levels.

The experiment consisted of 27 randomised plots of 15 palms per plot with 9 replications at each level of Potassium. The treatments comprised:

1. No Potassium;
2. 100 gr. K_2O per palm per annum;
3. 250 gr. " " " "

Growth increases, as measured by height, were determined for each individual palm, 2 years after application of the fertilisers; bulk leaf samples of the 1st and 9th leaves of each palm were taken per plot, giving representative samples. The height increases and leaf analysis data are tabulated in tables 22 and 23 and figure 18. It was unfortunate that the leaf samples could not be properly dried, prior to despatch to the central laboratory, and consequently, the ash content as a % of dry matter could not be

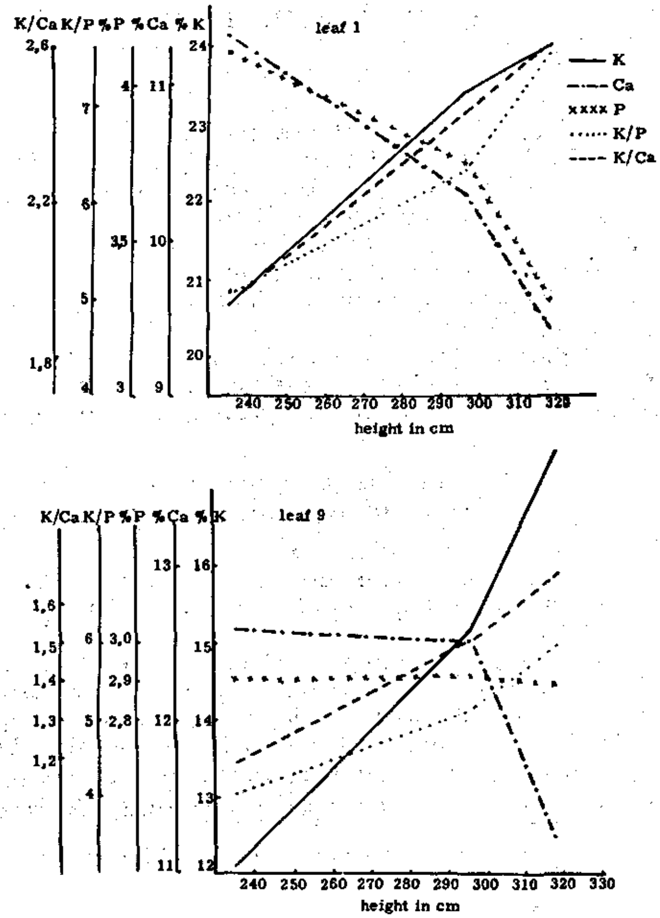


Figure 18. Changes in leafcomposition and growth responses of fertiliser experiment on young palms (data as % of ash)

TABLE 22

GROWTH RESPONSE AND LEAF ANALYSIS OF FERTILISER EXPERIMENT ON YOUNG PALMS

(Leaf, as a % of ash)

Treatment	Average height in cm	% K	% Ca	% Mg	% P	K/P	K/Ca
No K	235	20, 7	11, 3	3, 83	4, 12	5, 04	1, 96
Low K	296	23, 4	10, 3	3, 60	3, 75	6, 36	2, 33
High K	318	24, 0	9, 41	3, 53	3, 24	7, 51	2, 60
Sign. diff. at P=0, 05	18, 5	1, 8	1, 06	insign.	0, 25	0, 67+ 0, 97++	0, 29

TABLE 23

GROWTH RESPONSE AND LEAF ANALYSIS OF FERTILISER EXPERIMENT ON YOUNG PALMS
(Leaf 9 as a % of ash)

Treatment	Average Height	% K	% Ca	% Mg	% P	K/P	K/Ca
No K	235	12,1	2,6	5,28	2,90	4,08	1,19
Low K	296	15,2	2,5	5,25	2,91	5,17	1,50
High K	318	17,5	11,4	5,07	2,89	5,99	1,68
Sign. diff. at P=0,05	18,5	2,2	insign.	insign.	insign.	0,85^{+} 1,2^{++}	insign.

determined. For this reason the data in tables 22 and 23 refer only to figures expressed on ash. The results indicate that:

a) The first leaves of the non treated palms have a K content below the optimal value for K.

Ca, Mg and P on the other hand are high, as compared with the optimal levels. The K/P and K/Ca ratios are low in comparison with those, normally found for palms growing under optimal conditions. This would seem to suggest that, in this case, the K content of the soil is the limiting factor.

b) As was to be expected, applications, of Potassium to the palms resulted in significant positive growth responses. The palms, receiving the low level of application, showed a growth increase of 61 cm over control.

The higher level of application resulted in a growth response, significantly better than the other treatments (22 cms increase over the low rate of Potassium treatment).

c) The change in leaf composition corresponds closely with the K applications and growth response. The effect of the low level of application may be observed in an increase of K in the 1st and 9th leaves and decreases in Ca, Mg, and P contents; this applies particularly in the case of the 1st leaf. The K/P and K/Ca ratios increased after the application of Potassium, as could be anticipated. The application of the high rate of K, resulted in a further increase in leaf K which is more apparent for the 9th than for the 1st leaf. The Ca, Mg and P contents decreased, whereas the K/P and the K/Ca ratios increased further, as the result of the higher K applications. In general, variation in the data, especially for Ca and P is greater in the 9th than in the 1st leaves. Although, as a general rule, changes in leaf composition in the 9th leaves were similar to those in the first, the variation in the latter appears to be much less.

This stresses the advantage of sampling the 1st leaf as a routine practice.

Growth responses and corresponding changes in leaf composition, induced by the Potassium applications, are further demonstrated in fig. 18.

2) Productive palms.

In the same area, a fertiliser experiment on 14 year old palms was laid down to, determine whether yields could be increased by means of fertilisers, and whether positive production responses would correspond with changes in leaf composition.

The experiment consisted of a randomised plot design with 3 treatments and 3 replications. Each of the 45 palms per plot received the following treatments:

a) A potash dressing of 2300 gr of potassium sulphate per palm per annum.
b) A complete fertiliser application of:
   2300 gr of potassium sulphate;
   3700 gr of rock phosphate;
   5000 gr of ammonium sulphate;
   3600 gr of lime stone;
   5200 gr of magnesium sulphate.
c) Control.

The production in kg of bunches per individual palm was recorded from the start of the experiment. In table 24, the average production for each of the treatments, covering a period of two years after the first fertiliser applications had been made, are given.

Leafsamples were taken from individual palms, and bulked for the total palms per plot, two years after the first application of fertilisers had been made. The analytical results for the 1st and 9th leaves are given in table 24. Again, no ash content could be determined, due to incomplete drying of the samples, prior to despatch to the central laboratory.

From the results given in table 24, the following conclusions may be drawn:

1) The K content of the 1st leaves from the control plots is below the optimal value, whereas the P and Ca contents are materially higher. Consequently, the ratios between K and Ca or P are much lower than normally found. This leaf composition is, as has been seen in the case of the sand culture experiment, characteristic for K deficiency.

2) In accordance with the expectations, the experiment showed a significant response to the application of K and the complete fertiliser treatment. The application of K, alone, resulted in doubling the production, as compared with the control. The difference in production between the plots, receiving a complete fertiliser application, and those with K only, does not attain statistical significance.

3) The changes in the leaf composition, induced by the fertiliser treatments, are in the direction of optimal composition; both the application of K and the complete fertiliser increased the K content of the 1st and 9th leaves as compared with the control; further, the Ca and P contents of the 1st leaves decreased as the result of fertilisers, and consequently the K/P and K/Ca ratios increased. In the 9th leaves, the Ca and Mg contents decreased as the result of treatments. The K/P and K/Ca ratios in the 9th

leaves increased, when fertilisers were applied. Thus, the application of K alone, had the same effect on production as the complete N, P, K, Ca, Mg applications and induced changes in the chemical composition of the leaves towards optimal composition.

Conclusions

a) The qualitative diagnosis of K deficiency of the control plots of the experiments, as was suggested by the previous conclusions of the sand culture experiment, proved to be correct.
b) The results obtained from the experiments suggest that the concept of "optimal" leaf composition and the characteristic deviation in leaf composition in the case of K deficiency, are reliable criteria under practical conditions.

(ii) The effect of Phosphate Fertilisers

1) Young Palms.

In a plantation in the Central Congo basin, located on a medium to heavy red latosol, with a high content of active iron and aluminium, a fertiliser experiment on young palms, entering into production, had been laid down with the object of determining whether production responses to applications of N and P could be obtained. The experiment comprised the following treatments:

a) Two rates of applications of rock phosphate of 900 and 2000 gr per palm/year respectively.
b) An application of sulphate of ammonia of 1200 and of 2400 gr per palm/year respectively.
c) Control.

The design of the experiment was a 3x3 factorial with 3 replications in blocks of 9.

The production responses were recorded by counting the number of bunches and female inflorescences per plot, at regular interfalls.

Leaf samples were taken from the 1st and 9th leaves of all palms in the experiment. The samples from each plot were bulked and analysed in the laboratory, one year after the first fertiliser application had been made.

Table 25 shows the response in production to each of the fertiliser treatments, and the leaf analytical data of the 1st and 9th leaves expressed both on ash and dry matter. From the table it follows that:

a) The composition of the 1st leaves from the control plots suggests that P is the limiting factor.

The P content of 0.182% of dry matter and 3.08% of ash lies below the optimal value. On the other hand, the K content of the 1st leaves of 1.86% of dry matter or 31.5% of ash is "normal". The K/P ratio at $\pm$ 10 is higher than the optimum of 8. The Ca content on dry matter is slightly below the optimum. The Mg

TABLE 24

PRODUCTION RESPONSES AND LEAFANALYSIS DATA OF FERTILISER EXPERIMENT ON 14 YEAR OLD PALMS
(figures as a % of ash)

Treatments	Average Prod. in kg bunches per palm	% K	% P	% Ca	% Mg	K/Ca	K/P
		LEAF 1					
Potash	76,8	26,2	2,22	7,02	3,33	3,73	11,8
N P K Dolomite	62,2	28,3	2,87	7,00	3,57	4,11	9,84
Without Potash	30,7	25,4	3,75	10,4	3,42	2,41	6,9
Sign. diff. at P = 0,05	15,0	2,66	0,32	0,85	0,33	0,32	0,90
		LEAF 9					
Potash	76,8	27,4	2,43	7,68	3,30	3,61	11,2
N P K Dolomite	62,2	24,8	3,21	8,54	4,28	3,02	7,96
Without Potash	30,7	19,9	2,94	10,8	4,87	1,87	7,15
Sign. diff. at P = 0,05	15,0	2,40	0,26	0,55	0,41	0,24	0,88

content is higher than the optimal figure when expressed on ash. The composition is characteristic for the first stage of P deficiency as shown previously.

b) From table 25 and also from figure 19, it may be seen that the applications of P to the palms resulted in positive production responses, which were significant. N applications showed a negative response.

c) The production responses to P resulted in a simultaneous significant increase in the P content of the 1st leaf, both when expressed on dry matter and ash.

The N applications which gave a negative response did not change significantly the leaf composition.

From the significant differences in production between the high and low P treatments and the increase in P content of the 1st leaves which is almost proportional to the production responses, the conclusion may be drawn that it is probable that even heavier applications of rockphosphate than 2000 gr/palm might have reresulted in greater production responses.

The 9th leaf did not show any significant increases in P content as a result of the P applications.

The experiment was continued with increased applications of rock phosphate, 5 and 10 kgs per palm applied, with a view to

TABLE 25

FOLIAR ANALYSIS OF FIRST LEAF AND RESPONSES OF FERTILISING EXPERIMENT ON YOUNG PALMS
(1e year)

Treatments (low Phosphate application	Number of female flowers + bunches as a % of control	Potassium		Phosphorus		Calcium		Magnesium		% ash of dry matter
		% dr. m.	% ash	% dr. m.	% ash	% dr. m.	% ash	% dr. m.	% ash	
N_0P_0	100	1,86	31,5	0,182	3,08	0,531	8,97	0,440	7,39	5,94
N_1P_0	85	1,93	30,8	0,188	2,96	0,564	9,15	0,388	6,07	6,56
N_2P_0	81	1,94	29,1	0,181	2,70	0,524	7,86	0,365	5,48	6,68
N_0P_1	107	1,91	27,3	0,198	2,87	0,548	7,87	0,386	5,55	6,96
N_1P_1	112	1,52	27,6	0,201	3,68	0,538	9,82	0,356	6,45	5,53
N_2P_1	84	1,89	27,0	0,194	2,79	0,546	7,77	0,339	4,83	7,04
N_0P_2	113	1,95	33,3	0,213	3,69	0,506	8,71	0,388	6,66	6,03
N_1P_2	105	2,18	36,2	0,258	4,24	0,561	9,48	0,364	5,89	6,21
N_2P_2	105	1,67	31,1	0,216	4,06	0,612	11,45	0,381	7,02	5,41
Main effects										
P_0	100	1,91	30,4	0,184	2,91	0,540	8,66	0,387	6,31	6,39
P_1	114	1,77	27,3	0,198	3,10	0,544	8,49	0,360	5,61	6,51
P_2	122	1,93	33,5	0,229	3,99	0,560	9,88	0,378	6,52	5,88
N_0	100	1,90	30,7	0,198	3,20	0,528	8,52	0,405	6,53	6,31
N_1	94	1,88	31,5	0,216	3,62	0,554	9,49	0,369	6,14	6,10
N_2	84	1,83	29,0	0,197	3,18	0,561	9,03	0,362	5,77	6,38
Sign. main effect at P = 0,05		not sign.	not sign.	0,027	0,64	not sign.	not sign.	not sign.	not sign.	not sign.
Sign. main effect at P = 0,01		" "	" "	0,038	0,88	" "	" "	" "	" "	" "

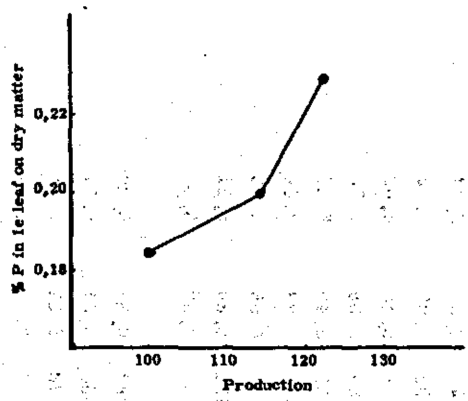


Figure 19. Number of bunches + female flowers as a % of control (after 1 year, and the changes in P content of the 1e leaf)

determining the optimal level of application which according to the leaf analytical data, had not yet been attained.

The production records over the period of one year after the heavy application, have been compared with the leaf analytical data in table 26. The data show that the control plots suffer from a more advanced degree of P deficiency, as compared with the previous year; the P content is still much below the optimum, but the K content of the leaves has increased considerable, whereas the Mg content has decreased. This stage of P deficiency is similar to the latter stages of the P deficiency in the palms of the sand culture experiment.

The high applications of rockphosphate during the 2nd year after the experiment was started, resulted in very marked production responses; moreover it is shown in the table 26 that the production increase during the second year is proportional to the increased P content of the leaves (see also figure 20). However, the chemical composition of the leaves of the high P treatments is still not "optimal", as suggested by the relatively high K and ash content of the leaves. An explanation for the fact that the optimal composition has still not been established, cannot be deduced from the data, presented in the table 26. It may be that the P fixation capacity of the soil is so extreme that even the very high applications of rockphosphate have not been able to restore the "optimal" conditions in the leaves in one year. On the other hand, the shock dose of rock phosphate may have induced another deficiency such as Mg or minor elements.

In order to find out whether elements other than P are factors limiting the production, especially when regular applications of N and P are made, an experiment was laid down in the same area, comprising the following treatments:

a) 1100 gr of potassium sulphate per palm per annum;
b) 1500 gr of magnesium sulphate " " " "
c) 6400 gr of calcium carbonate " " " "
d) 320 gr of copper sulphate " " " "
e) 320 gr of manganes sulphate " " " "
f) 32 gr of borax " " " "
g) 13 gr of a mixture of equal weights of zinc sulphate, nickel

TABLE 26

FOLIAR ANALYSIS OF FIRST LEAF AND RESPONSES OF FERTILISING EXPERIMENT ON YOUNG PALMS (2e year)

Treatments (high Phosphate application)	Number of female flowers + bunches as a % of control	Potassium		Phosphorus		Calcium		Magnesium		Ash as a % of dry matter
		% dr. m.	% ash	% dr. m.	% ash	% dr. m.	% ash	% dr. m.	% ash	
N_0P_0	100	2,73	31,9	0,197	2,31	0,521	6,09	0,278	3,25	8,55
N_1P_0	105	2,72	32,9	0,222	2,67	0,524	6,36	0,355	4,31	8,26
N_2P_0	114	2,88	31,5	0,209	2,30	0,488	5,31	0,326	3,61	9,19
N_0P_1	131	2,93	34,9	0,214	2,59	0,430	5,19	0,379	4,56	8,46
N_1P_1	108	2,76	31,1	0,236	2,67	0,531	6,01	0,293	3,27	8,88
N_2P_1	125	3,06	34,0	0,236	2,61	0,496	5,50	0,286	3,16	9,04
N_0P_2	159	2,49	28,7	0,272	3,15	0,480	5,53	0,270	3,13	8,69
N_1P_2	129	2,76	32,1	0,255	2,98	0,591	6,91	0,354	4,14	8,58
N_2P_2	114	2,62	29,1	0,237	2,68	0,628	7,06	0,225	2,39	9,00
Main effects										
P_0	100	2,78	32,1	0,209	2,42	0,511	5,92	0,320	3,72	8,67
P_1	114	2,92	33,4	0,229	2,60	0,486	5,57	0,319	3,66	8,79
P_2	127	2,62	30,0	0,255	2,93	0,567	6,50	0,283	3,25	8,76
N_0	100	2,72	31,9	0,228	2,68	0,477	5,60	0,309	3,64	8,57
N_1	88	2,75	32,1	0,238	2,76	0,549	6,43	0,334	3,91	8,57
N_2	91	2,85	31,5	0,227	2,53	0,538	5,96	0,379	3,09	9,08
Sign. main effect at P = 0,05		not sign.	not sign.	0,024	0,37	not sign.	not sign.	not sign.	not sign.	not sign.
Sign. main effect at P = 0,01		" "	" "	0,033	0,51	" "	" "	" "	" "	" "

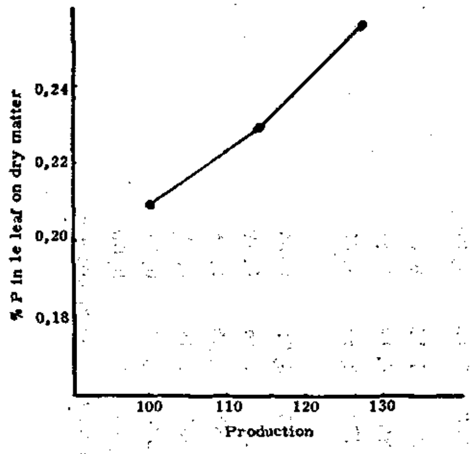


Figure 20. Number of bunches + female flowers as a % of control (after 2 years, and the changes in P content of the first leaf

sulphate, cobalt sulphate and ammonium molybdate per palm per annum.

All palms received a dressing of 900 gr of rockphosphate + 1200 gr of ammonium sulphate during the first year of the experiment. After the first year, the application of phosphate was increased to 10 kg per annum.

The design of the experiment was a 2^7 factorial in 16 plots (one eight replicate), allowing for the determinations of the 7 main effects only.

Each plot comprised 36 palms.

Table 27 gives the foliar analysis results after the first year.

This shows that none of the treatments changed the leaf composition considerable, but that all palms show a definite P deficiency, as suggested by the extremely low P contents of the leaves, despite the application of 900 gr rock phosphate, In accordance with expectations, no significant production responses resulted from the various fertiliser treatments.

The heavy application of rock phosphate, however, during the second year after the experiment had been laid down resulted in a serioud attack of the Little Leaf disease, expecially in the plots receiving potassium, but not a single case in those, where boron was included in the fertiliser application. The fact thet Little Leaf Disease in the oil palm is due to boron deficiency had been shown previously by FERWERDA and KOVACHICH (1954).

This may partly explain why the heavy P dressings failed to restore the "optimal" leaf composition, despite the very significant effect of P applications on the production, which correspond with significant increases in P content of the leaves.

The very high P fixation capacity of many Congolese soils, to which further reference will be made later in this work, necessitates the application of very heavy doses of the relatively insoluble rock phosphate. It has been shown that these heavy applications increase the production of the palms and, at the same time, the P content of the leaves. On the other hand, shock doses of rock phosphate may induce other deficiencies as was suggested by the fact that these heavy P dressings did not reestablish the "optimal"

TABLE 27

CHEMICAL COMPOSITION OF LEAVES OF FERTILISER EXPERIMENT ON YOUNG PALMS
Data on dry matter.

Leaf 1

Treatments	% K	% P	% Ca	% Mg	% Ash
+ K	2,23	0,191	0,620	0,377	7,32
- K	2,00	0,186	0,654	0,381	6,79
+ Mg	2,00	0,186	0,619	0,380	7,07
- Mg	2,23	0,191	0,654	0,380	7,05
+ Ca	1,91	0,183	0,659	0,373	6,87
- Ca	2,31	0,194	0,616	0,385	7,24
+ Cu	2,08	0,183	0,609	0,388	7,24
- Cu	2,15	0,194	0,665	0,371	6,87
+ Mn	2,17	0,184	0,663	0,371	6,49
- Mn	2,06	0,193	0,611	0,387	7,62
+ B	2,12	0,194	0,612	0,370	7,22
- B	2,11	0,183	0,661	0,388	6,90
+ minor elements	2,16	0,193	0,654	0,416	7,47
- minor elements	2,07	0,184	0,620	0,342	6,64

composition of the leaves. As, however, the control plots in the N, P experiment had a much higher K and a lower Mg content after the second year than after the first year, indicating an increased degree of P deficiency, the boron deficiency, as found later, may be indirectly caused by the P deficiency; the influence of the increase in leaf K content as a result of P deficiency may be responsible for a decrease in leaf boron content, in the same way as the high K content has a depressing effect on the Mg content.

Although the correct interpretation of the different phenomena does not follow directly from the data in the tables, leaf analysis has been shown to be a valuable aid in the interpretation of the results of field experiments and in predicting the possible responses before the actual growth and production increases have been obtained.

2) Fertilising of Productive 10-year-old palms.

In a plantation in the Central Congo basin, the chemical composition of the leaves was characterised by:
a) a low P content, much below the "optimal" level;
b) a medium to high K content;
c) a Ca content slightly below the "optimum";
d) a "normal" Mg content.

TABLE 28

FOLIAR ANALYSIS OF FERTILISER EXPERIMENT ON 10 YEAR OLD PALMS
(Data as a % of ash)

Treatments		Potassium		Phosphorus		Calcium		Magnesium		
		% dr. m.	% ash	% dr. m.	% ash	% dr. m.	% ash	% dr. m.	% ash	ash as a % of dr.m.
					1e Leaf					
After 2 years appl. of 1 kg. super Phosphate	Treatments + P	2, 07	25, 8	0, 184	2, 30	0, 574	7, 16	0, 314	3, 92	8, 01
	Treatments - P	2, 09	25, 8	0, 195	2, 40	0, 572	7, 06	0, 308	3, 80	8, 11
After 6 months appl. of 10 kg. Rock Phosphate	Treatments + P	2, 15	26, 4	0, 246	3, 04	0, 642	7, 98	0, 322	3, 57	8, 17
	Treatments - P	2, 12	25, 9	0, 225	2, 76	0, 595	7, 44	0, 332	4, 04	8, 21
Sign. diff. at P = 0, 05				0, 0094	0, 11					
Sign. diff. at P = 0, 01				0, 0141	0, 67					
					9th Leaf					
After 6 months appl. of 10 kg. Rock Phosphate	Treatments + P	1, 93	24, 8	0, 216	2, 77	0, 618	8, 12	0, 397	5, 02	7, 86
	Treatments - P	2, 00	24, 8	0, 215	2, 73	0, 623	7, 94	0, 377	4, 71	8, 00

This composition would seem to indicate P deficiency. A fertiliser experiment had already been laid down in this area, comprising the following treatments:

a) 0. 425 kg urea per palm per annum;
b) 1.000 kg of super phosphate per palm per annum;
c) 0.900 kg potassium sulphate " " " "
d) 0.700 kg magnesium sulphate " " " "
e) 0,800 kg ground limestone " " " "
f) 0.200 kg copper sulphate " " " "

The lay out of the experiment was a 2^6 factorial with confounding of some higher order interactions for the estimation of the error variance. Each experimental plot comprised 51 palms. The data of the foliar analyses of samples taken after one year, are given in table 28. The results show:

1) That the application of 1 kg of super phosphate did not alter the chemical composition of the leaves significantly;

2) That the palms were still P deficient.

In order to determine whether the lack of response to phosphate was possibly due to a high P fixation capacity of the soil, soil samples were taken from the experimental area, on which the following investigations were carried out:

A bulk sample was devided into 14 sub-samples, from each of which 10 gr were weighed out. To these, solutions of NaH_2PO_4 of known concentrations were added and shaken during one hour.

One series of 7 samples was washed with water and the other with 1% citric acid.

P was determined in the filtrate.

The results of these analyses are shown in table 29. The P fixation capacity has been expressed as a % of the difference between the amount of P added and the amount of P found in the soil as extracted by water or citric acid.

Figure 21 shows the P fication capacity of the soil as a function of logarithm of the added quantity of P, both for the water and the citric acid extraction. For purposes of comparison, the added quantities of P have been expressed in tons of rock phosphate added per Ha. Although this is not justified, as the conditions, under which the P was fixed in the laboratory, are entirely different from those in the field, the results serve to illustrate the extremely high P fixation capacity of the soil. It will be seen that an extraction with 1% citric acid did not remove important quantities of P. from the soil, despite the fact that the citric acid anion is able to replace the adsorbed PO4 ions in the soil.

When this fact became known, all the plots receiving P in the fertiliser, were given an additional 10 kg of rock phosphate per palm, applied in a narrow band on the surface. Six months after this heavy application had been made, leaf samples were again taken, the analytical results of which are given in table 28.

It may be seen that the application of rockphosphate resulted in a highly significant increase in the P content of the 1st leaves, expressed as a % of dry matter. The P content, expressed on

TABLE 29

PHOSPHATE FIXATION IN SOIL OF FERTILISER EXPERIMENT AT YALIGIMBA

N°Sub. sample	Extraction	Aeq. appl. of Rock Phosph. in Tons/Ha	γP added to 10 gr. soil.	γP found per 10 gr. soil.	γP fixed per 10 gr. soil.	% Fixation
1	H_2O		0	0	0	
2	1% citric acid		0	0	0	
3	H_2O	80 Kg	100	0	100	100
4	1% citric acid		100	10	90	90
5	H_2O	4 Tons	500	170	330	66
6	1% citric acid		500	300	200	40
7	H_2O	8 Tons	1000	650	350	35
8	1% citric acid		1000	800	200	20
9	H_2O	40 Tons	5000	3760	1240	25
10	1% citric acid		5000	4400	600	12
11	H_2O	80 Tons	10000	8200	1800	18
12	1% citric acid		10000	9860	1040	10
13	H_2O	400 Tons	50000	45400	4600	9
14	1% citric acid		50000	46400	3600	7

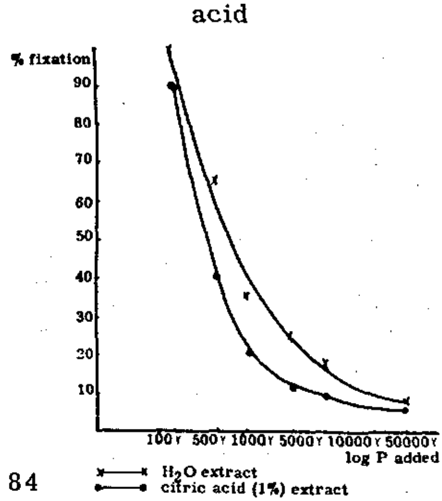


Figure 21. Phosphate fixation

ash, is significantly higher in the palms, which received applications of rock phosphate, at P = 0.05.

There were no other significant changes in leafcomposition. No changes in the composition of the 9th leaf were noticed (see table 28).

Positive production responses six months after the heavy P applications had been made, were significant for P and negative for K, as shown in table 30.

TABLE 30

PRODUCTION RESPONSES OF 10-YEAR-OLD PALMS TO HEAVY APPLICATIONS OF ROCK PHOSPHATE

Treatments	Total weight of bunches as a % of average of plots
K + P	101
P	110
K	98
control	90
sign. diff. at P = 0.05	6

The above results indicate a production increase of 23% as compared with the treatments without K and P, six months after the first heavy application had been made, together with a significant increase in the leaf P content.

In this case, leaf analysis was able to diagnose P deficiency, but it was necessary to carry out additional soil analysis to explain the lack of response to the low phosphate application.

(iii) The Replanting of Oil Palms

In a plantation in the Kasai region of the Belgian Congo, an experiment was laid down with a view to finding out the "optimal" conditions for the replanting of old oil palm plantations. The design of the experiment was a 4 x 4 Latin square, comprising the following treatments:

a) The old stand of oil palms was felled before the young palms were planted but no fertilisers were given;
b) The young palms received a complete fertiliser application and were planted under the shade of the old stand of palms;
ab) The old stand was felled and the young palms received fertilisers;
i) Control; the young palms were planted under the shade of the old palms without fertilisers.

Leaf samples were taken from the 1st leaf only, from the 3 year-old palms.

Table 31 shows the analysis of variance of the composition of the 1st leaves and the growth measurements, made at the same time as the sampling; increase in number of leaves and length of the leaves were taken as growth criteria.

TABLE 31

GROWTH RESPONSE AND LEAF ANALYSIS RESULTS REPLANTING EXPERIMENT

Treatments	% K	% P	% Ca	% Mg	Increase in number in leaves
Felling (a)	28, 4	4, 35	9, 05	3, 5	8, 22
Fertilising (b)	24, 7	4, 07	8, 02	4, 95	6, 60
Felling + Fertilising (ab)	28, 6	3, 2	6, 45	3, 8	11, 11
Control (i)	13, 4	6, 8	13, 9	4, 2	4, 26
Sign. diff. at P=0, 05	4, 4	0, 7	1, 9	0, 4	0, 38
Main effects					
A. Felling	9, 4^{++}	-1, 6^{++}	-3, 2	-0, 8^{++}	4, 24
B. Fertilising	5, 7^{++}	-1, 9^{++}	-4, 3	0, 5^{+}	2, 62
Sign. Main eff. P=0, 05	3, 1	0, 5	1, 5	0, 3	0, 27
Interaction A x B	-11, 3^{++}	1, 5^{+}	3, 3^{+}	-0, 45	0, 55
Sign. interac. at P=0, 05	6, 3	1, 0	2, 7	0, 6	0, 54
General mean	23, 7	4, 6	9, 4	4, 1	
Error	2, 4	0, 4	1, 1	0, 23	
Error/% mean	10	8, 7	11	5, 6	

The figures 22 and 23 illustrate the effect of the treatments on leaf composition.

It may be seen that:

1) The chemical composition of the palms of the i) treatment (grown under the shade of the old palms, without any applications of fertilisers), is typical of K deficient palms. The K content is very low, whereas the Ca and P contents are much higher than "optimal". The growth of the young palms was very poor and compared unfavourably with that in the other treatments.

2) In treatment b) (when the palms are fertilised but are still growing under the old palms), the K deficiency disappears, as is shown by the significant increase in leaf K content and the significant decrease in leaf Ca and P.

3) When the old stand on the a) plots was felled, the leaf K content increased, leaf Ca and P contents decreased, (as in the case of the b treatment), but leaf Mg content appeared to decrease to a very low level, significantly lower than in all the other treatments. Although the early growth of the palms was very good, a serious chlorosis developed, some time after the felling of the old stand, the older leaves turning yellow to orange, entirely comparable with the Mg deficiency symptoms, obtained in the sand culture trials. The conclusion was drawn that the felling of the

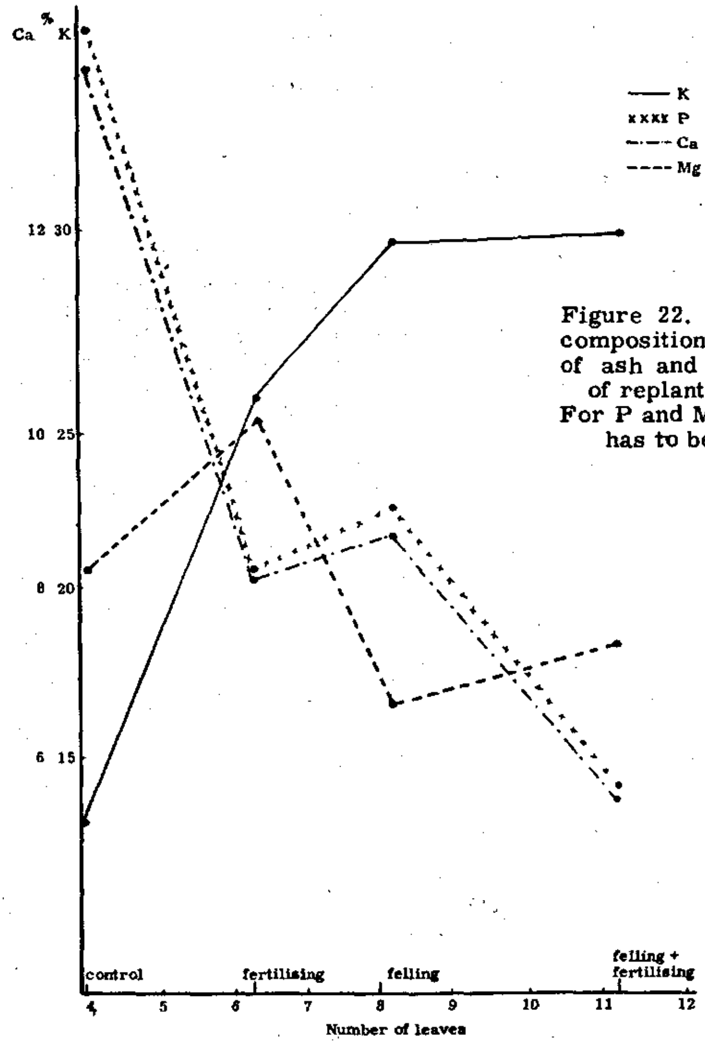


Figure 22. Changes in leaf-composition of 1e leaf as a % of ash and growth responses of replanting experiment For P and Mg, the Ca scale has to be divided by 2

old palms induced a Mg deficiency as a result of the considerable quantities of K which are liberated by the decomposition of the felled palms.

This phenomenon has also been noticed on other replanted areas in the Northern and Southern Congo and could be explained in the same way. The chemical composition of the leaves shows relatively high K and Ca contents and a low Mg content. Mg, expressed as a % of the sum of K + Ca + Mg amounts to only 8-9% whereas 10-11 is normally found for the "optimal" composition.

4) Felling and fertilising (treatment ab), gave the best results of all the treatments. The higher Mg and lower Ca contents in palms of these plots, explain the almost complete absence of chlorosis.

The general conclusion may be drawn that, when replanting an old oil palm plantation, the felling of the old stand and subsequent

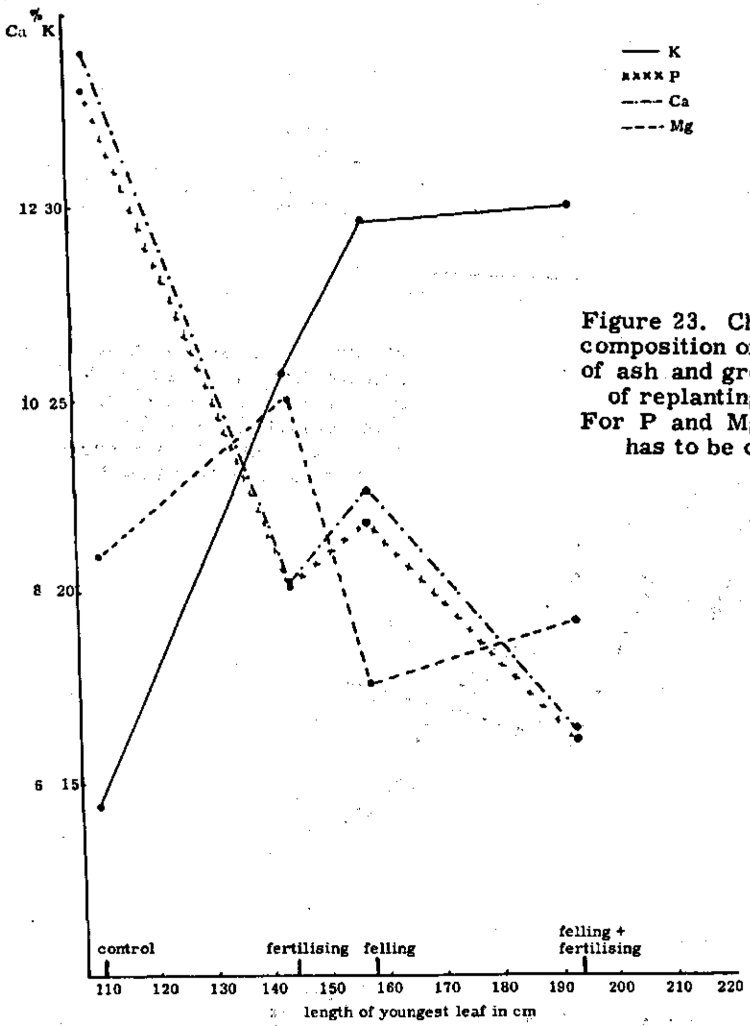


Figure 23. Changes in leaf-composition of 1e leaf as a % of ash and growth responses of replanting experiment For P and Mg, the Ca scale has to be divided by 2

release of large quantities of K from the decomposing material, may induce Mg deficiency, even if the soil be deficient in K.

This induced Mg deficiency is only of a temporary nature, as the K is not fixed in Congo soils and heavy losses of K occur, due to leaching. As soon as a more favourable balance between K and Mg in the soil has been reached, the Mg deficiency symptoms disappear and the young palms resume normal growth. This effect is comparable with the appearance of Mg deficiency in crops, growing in temperate regions, where, during wet periods, Mg deficiency symptoms frequently appear, being induced by the excess of K in the soil, resulting from previous heavy Potassium applications (SCHUFFELEN 1940, 1954).

The present case demonstrated again the value of the method of foliar analysis in the interpretation of the results of field experiments.

VIII. THE APPLICATION OF FOLIAR ANALYSIS IN PRACTICE

A few samples may be given to show the way in which foliar analysis may be applied in practice as a basis for advice on fertiliser policy.

(i) A Plantation in the Kasai Region

In a plantation in the Kasai region, it was noticed that big differences in production existed between the riverine and non riverine blocks. To obtain information on the possible causes for these considerable differences in production, a series of blocks, all planted in the same years (1938-1939) were selected, the production figures for which were known over a period of 4 years.

From those blocks, each of 20 Ha, leaf samples were taken, bulked and analysed. All the blocks were situated in a line, running from the river across the plantation. The average production in tons of bunches per Ha per year varied from 6-7 tons in the riverine blocks to 3 tons in the non-riverine area.

Table 32 shows the production and foliar analysis data for the selected blocks. Production as a function of leaf composition is shown in figure 24.

TABLE 32

FERTILITY GRADIENT IN PLANTATION IN SOUTHERN CONGO (Planting 1938 and 1939) 9th leaf

Block	Average yield in tons bunch/Ha/year (4 years)	% K	% Ca	% Mg	% P	K/Ca	K/P
1	5, 5	19, 5	10, 6	4, 72	1, 88	1, 84	10, 4
2	6, 5	21, 2	10, 2	4, 50	1, 90	1, 07	11, 1
3	5, 7	16, 7	9, 86	3, 01	1, 75	1, 69	9, 5
4	4, 7	16, 0	11, 2	3, 58	2, 05	1, 43	7, 8
5	4, 0	14, 0	11, 3	3, 40	1, 90	1, 24	7, 4
6	3, 7	16, 3	11, 1	4, 06	2, 15	1, 47	7, 9
7	4, 1	15, 2	10, 2	3, 45	1, 94	1, 90	7, 8
8	3, 2	14, 8	11, 0	3, 84	2, 15	1, 34	6, 9
9	3, 9	14, 5	11, 6	4, 11	2, 18	1, 25	6, 6

From the results, it may be concluded that this is a typical case of K deficiency, as shown by the low leaf K contents of the low producing blocks and their relatively high Ca and P contents. The positive correlation between the production and leaf K content, the positive correlation between K/P and K/Ca ratios and pro-

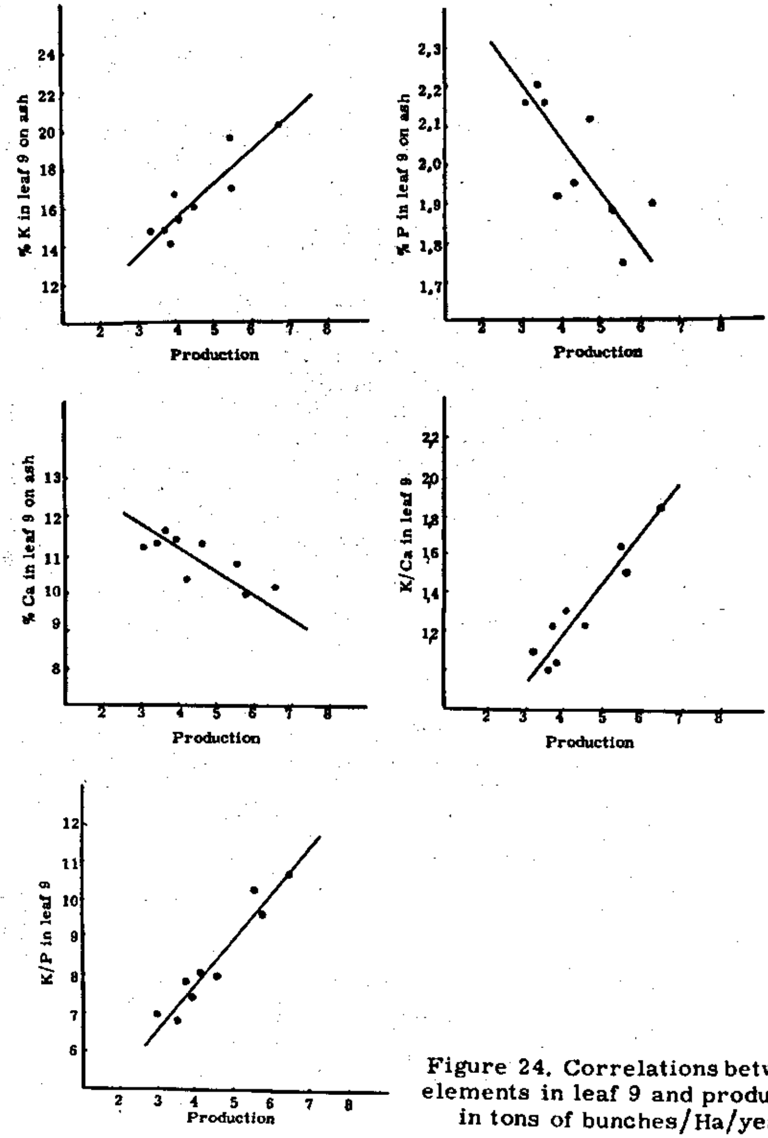


Figure 24. Correlations between elements in leaf 9 and production in tons of bunches/Ha/year

duction and, on the other hand the negative correlation between production and leaf Ca and P contents confirm our previous findings in respect of growth responses to K dressings on areas, deficient in K.

The conclusion may be drawn that differences in production are caused by differences in the degree of K deficiency of the riverine and non-riverine areas, and, as a consequence, applications of K fertilisers may be recommended.

As the variations in K deficiencies of the palms were thought to result from differences in the K status of the soils, representative soil samples were taken from all the blocks. They were extracted for one hour with boiling concentrated hydrochloric acid and the K content of the extract determined. Previous experience with soil analysis in our laboratory had shown that the readily available nutrients are almost indetectable in the highly degraded soils of the Southern Congo and that the only possible way of establishing differences in the chemical characteristics of these soils exists in the determination of their total mineral reserves.

The results of the soil analyses are shown in table 33 and figure 25.

TABLE 33

TOTAL K CONTENT OF SOIL IN PPM(HCl EXTRACT) AND PRODUCTION PER BLOCK OF THE FERTILITY GRADIENT

Block	Production	ppm K
0	8, 0	125
1	5, 5	72
2	6, 5	84
3	5, 7	70
4	4, 7	42
5	4, 0	36
6	3, 7	44
7	4, 1	30
8	3, 2	30
9	3, 9	30

It may be seen that there is a very close positive correlation between the K content of the soil and the production of the palms. As this seems to be linear, the regression coefficient and its significance have been calculated. The regression function, giving the production as a function of the determined quantity of K in the soil, is represented by:

$$X = 4.93 + 0.04628\ (Y - 56.3)$$ in which

X = the average production expected when the ppm K in the soil is taken at a certain level Y.

The regression coefficient of 0.04628 has a standard deviation of $\pm$ 0.0126 and is highly significant at $P = 0.01$.

For Y = 100 ppm K, the corresponding average production would be 7 tons of bunches per Ha per year. It is obvious that the formula only holds for this particular case and not for other plantations.

Here again, confirmatory evidence was obtained on the significance of a diagnosis on the basis of foliar analysis.

(ii) Foliar Analysis of a Replanted Area (near Coquilhatville)

In an area, recently replanted, the young palms suffered badly

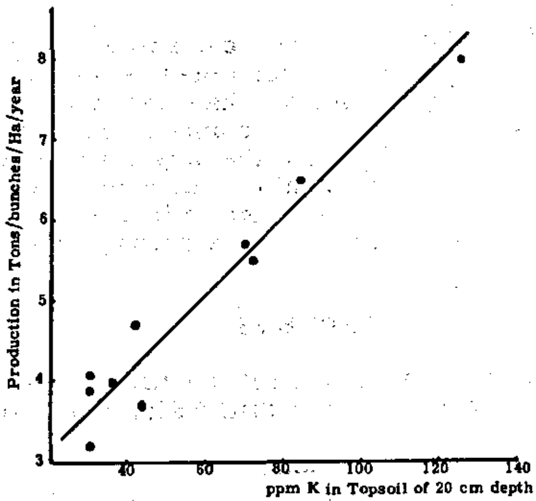


Figure 25. Production as a function of the Potassium content of the Topsoil (plantation in Kasai region)

from an attack of Cercospora and the older leaves showed many yellow and scorched leaflets. To find out whether this condition was associated with a mineral deficiency, 12 representative bulk leaf samples, each comprising 20 palms, were taken. The results of the foliar analyses of these samples are given in table 34.

The majority of the samples had the following composition:

a) The K content is low, below the "optimum";
b) P is normal to high;
c) Ca and Mg are normal to high.

This composition suggests that K is a limiting factor in this area, although the deficiency does not seem to be advanced. In this case an application of K, either as sulphate or muriate or of bunchash, would seem ot be justified.

The quantity to be applied cannot be determined by the leaf analytical data at this stage. After an application of 1 kg has been made, the effect should be followed up by means of foliar analysis to determine whether this has resulted in a change towards the "optimal" composition.

(iii) Foliar Analysis of Nurseries in the Coquilhatville Area

In the same area, the nurseries showed marked signs of Mg deficiency. The foliar analysis data of a few representative bulk samples confirmed the existence of a Mg deficiency. Table 35 shows:

a) K is very high;
b) P is normal to high;
c) Ca is low
d) Mg is very low;
e) the ash content as a % of dry matter is high.

TABLE 34

FOLIAR ANALYSIS REPLANTING

No Sample	Potassium		Phosphorus		Calcium		Magnesium		Ash as a % of dry matter
	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	
1	1,58	23,3	0,214	3,15	0,740	10,88	0,394	5,80	6,80
2	1,87	21,9	0,243	2,85	1,137	13,33	0,451	5,29	8,53
3	1,54	22,5	0,260	3,79	1,100	16,04	0,303	4,42	6,86
4	1,58	20,1	0,260	3,29	0,874	11,07	0,251	3,18	7,90
5	2,07	24,0	0,270	3,13	0,614	7,12	0,457	5,30	8,63
6	1,73	22,5	0,284	3,70	0,740	9,63	0,383	4,98	7,68
7	1,87	24,6	0,278	3,66	0,577	7,59	0,234	3,08	7,60
8	1,78	22,6	0,251	3,19	1,086	13,76	0,297	3,77	7,88
9	1,29	19,1	0,256	3,81	0,714	10,64	0,274	4,08	6,71
10	1,76	21,9	0,288	3,59	0,797	9,93	0,257	3,20	8,30
11	1,67	19,2	0,293	3,37	1,028	11,82	0,360	4,14	8,70
12	2,00	24,6	0,286	3,51	0,628	7,73	0,366	4,50	8,13

TABLE 35

FOLIAR ANALYSIS NURSERY (Bunch refuse applied)

No Sample	Potassium		Phosphorus		Calcium		Magnesium		Ash as a % of of matter
	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	
1	3,47	37,5	0,307	3,32	0,466	5,03	0,134	1,45	9,26
2	3,44	38,3	0,253	2,81	0,497	5,53	0,154	1,72	8,98
3	2,24	24,1	0,310	3,33	0,803	8,63	0,168	1,81	9,30
4	3,31	35,0	0,263	2,77	0,386	4,07	0,146	1,54	9,47

TABLE 36

FOLIAR ANALYSIS NURSERY (No bunch refuse applied)

No Sample	Potassium		Phosphorus		Calcium		Magnesium		Ash as a % of dry matter
	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	
1	1,90	26,3	0,338	4,56	0,731	9,85	0,263	3,54	7,43
2	2,64	30,7	0,227	2,64	0,577	6,71	0,348	4,05	8,60

Although Mg deficiency is often associated with a high leaf Ca content, it is evident that, in this case, the K content has become so high that the Ca content decreased, due to the antagonism between K and Ca.

The cause of the high leaf K content may be explained by the fact that the nursery had received a very heavy mulch of bunch refuse with a high K content, which on decomposition liberated sufficient K, to induce Mg deficiency. This explanation was confirmed by the foliar analysis data for a part of the nursery, which had not been mulched with bunch refuse. Table 36 shows that this had a leaf composition which was almost "optimal". No deficiency symptoms were apparent in this latter area.

(iv) Foliar Analysis of a Young Plantation in the Northern Congo Basin (Yaligimba)

In one of the plantation extensions, the palms had a very good start. However, six months after planting, growth ceased almost completely and the palms suffered from an attack of Cercospora.

Some representative leaf samples were taken with a view to finding out whether this attack was associated with a mineral deficiency of the soil.

Table 37 gives the chemical composition of 10 representative bulk leaf samples (20 palms per bulk sample). The leaves have a chemical composition showing:

a) a high K content, far above the "optimum";
b) a normal Ca content;
c) a low to normal Mg content;
d) a very low P content, much below the "optimum".

TABLE 37

FOLIAR ANALYSIS OF YOUNG PLANTATION YALIGIMBA

No Sample	Potassium		Phosphorus		Calcium		Magnesium		Ash as a % of dry matter
	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	% dr.m.	% ash	
1	2,28	27,8	0,190	2,31	0,683	8,30	0,268	3,26	8,23
2	2,07	24,2	0,176	2,05	0,688	8,03	0,263	3,07	8,57
3	2,03	26,8	0,181	2,40	0,848	11,23	0,217	2,87	7,56
4	2,23	24,7	0,196	2,17	0,771	8,56	0,297	3,30	9,01
5	1,74	23,5	0,171	2,31	0,737	9,94	0,228	3,08	7,41
6	2,30	26,9	0,161	1,89	0,771	9,03	0,211	2,47	8,54
7	2,21	26,3	0,183	2,17	0,797	9,46	0,246	2,91	8,43
8	2,07	23,8	0,180	2,07	0,786	9,05	0,240	2,76	8,68
9	2,56	28,4	0,196	2,18	0,831	9,25	0,200	2,22	8,98
10	2,17	26,2	0,196	2,36	0,857	10,33	0,177	2,13	8,30

This is characteristic for P deficiency. Applications of at least 2 kg rock phosphate may be recommended, as the soil appears to have a high P fixation capacity.

Earlier experience with applications of rock phosphate on young palms, growing on P fixation soils had shown that even higher applications of P still resulted in significant growth responses. In this case, soil analysis and field experiments together supplied information for the determination of the quantity of rock phosphate to be given.

(v) Foliar Analysis of a Plantation in the Central Congo Basin (Yaligimba)

A more complicated example will be given for a large plantation, situated in the Northern Part of the Central Congo Basin.

The plantation covers an area of about 8000 Has and consists of blocks of one square km (see maps). The plantation comprises an area of light sandy yellow soil and of a heavier reddish sandy clay. The production has been recorded as from the establishment of the plantation in 1939.

This plantation was sampled at the end of the rainy season (November and December) 1953. Bulk samples of the 1st leaves were taken from 20 palms (4 rows of 5 palms) along a trace work of 500 x 500 m, a total of 297, representing 5940 palms.

Dealing with such a large area, it is possible that more than one deficiency may occur. Due to variations in soil fertility conditions, some of the samples may show a pronounced deficiency of a particular element, others a characteristic composition for another deficiency, whereas another series may shown an "optimal" composition.

In the case of two or more major elements being deficient at the same time in one sample, it may prove difficult to draw direct conclusions. When dealing with a large number of samples, however, the major deficiencies may be determined, even if more than one occurs, making use of the variation in soil fertility conditions and its influence on leaf composition. When the deficient elements are known, their actual percentages, as found in the samples may serve as a guide for the deficiency to indicate the main deficient areas in the plantation.

The interpretation of the analytical data comprises three stages:

1) A classification of the samples according to possible deficiencies;

2) Mapping on the data to indicate the areas deficient in one or more element(s);

3) The evaluation of a possible relationship between deficiencies and actual production of the palms.

1) Classification of Samples according to Deficiencies.

In table 38 all the samples have been classified, according to the concentrations of the various components in relation to the optimal composition.

In the first column all the possible combinations of high or low K, P, Ca or Mg are given. A concentration below the "op-

TABLE 38

CLASSIFICATION OF SAMPLES IN RELATION TO OPTIMAL LEAF COMPOSITION - YALIGIMBA PLANTATION

Deviations from optimal composition				Number of samples per class	Possible deficiency
K	P	Ca	Mg		
+	+	+	+	44	
+	+	+	-	17	Mg
+	+	-	+	34	Ca
+	+	-	-	7	Mg
+	-	+	+	42	P
+	-	+	-	11	P, Mg
+	-	-	+	24	P, Ca
+	-	-	-	17	P
-	+	+	+	17	K
-	+	+	-	6	K
-	+	-	+	2	
-	+	-	-	4	
-	-	+	+	25	K, P
-	-	+	-	9	K, P, Mg
-	-	-	+	18	
-	-	-	-	7	

timal" value is indicated by a minus sign (-) and "optimal" or higher than "optimal" by a plus sign (+).

According to table 38, 128 out of 284 samples show P to be the limiting factor, whereas 57 samples indicate K, 58 Ca and 33 Mg deficiency. When the actual figures are considered, however, it appears that:

a) Nearly all the P figures, classified as low, (P < 0, 22) are less than 0. 20%;

b) The majority of the K figures classified as low, (< 1. 7%) are lower than 1. 6%;

c) The Ca content of nearly all the samples appears to be within the limits op the optimum values of 0. 5-0. 6%;

d) 15 samples have Mg content which is very low, (< 0. 25%).

e) The low P and Ca figures suggest that N is not deficient in this area.

This suggests that P deficiency is important in this plantation, whereas K and Mg deficiency are of less importance, and Ca deficiency does not seem to exist.

The low Ca contents, which are generally very close to the "optimum" value of 0. 6%, are characteristic for the occurrence of P deficiency.

2) Location of Areas of Deficiencies.

On the maps, the areas for K, P and Mg deficiencies have been delimited. The area most deficient in P ($P < 0.20\%$), is mainly found in a band, which ranges from blocks 0 and 1 to blocks 53 and 63.

K deficiency is generally found in a part of the area also deficient in P, with the exception of the blocks 29, 30 and 31, which are deficient in K only.

Low Mg content is most frequently found in the blocks 6, 7, 16, 17 and 27. In this part of the plantation, yellow and orange colouration of the older leaves were frequently noted especially during the dry season.

3) Deficiencies and Actual Production of the Palms.

To determine whether a relationship exists between the areas deficient in K, P or Mg and production, the average production in tons of bunches per Ha, for the year 1953 has been subdivided into following classes (table 39):

TABLE 39

PRODUCTION AS A FUNCTION OF LEAF COMPOSITION

K, P, Mg optimum		K deficient		P deficient		K and P deficient		Mg deficient	
Block N°	Production	Block N°	Production	Block N°	Production	Block N°	Production	Block N°	Production
5	10, 5	29	7, 4	0	7, 0	13	6, 9	6	9, 0
15	9, 6	30	6, 2	1	8, 5	18	8, 2	7	10, 0
48	9, 7	31	7, 4	2	9, 4	36	7, 9	16	9, 7
49	9, 5	Average	7, 0 Tons	3	9, 3	39	8, 8	17	9, 1
50	9, 3			4	8, 7	40	7, 7	27	9, 0
60	10, 2			14	8, 8	41	6, 8	Average	9, 3 Tons
61	9, 3			25	8, 0	46	8, 0		
64	10, 9			26	7, 2	51	8, 8		
69	7, 3			28	7, 4	62	9, 2		
70	11, 0			63	9, 3	37	7, 1		
73	9, 7			Average	8, 4 Tons	47	7, 7		
74	8, 1					52	9, 0		
Average	9, 6 Tons					Average	8, 0 Tons		

Blocks only deficient for a small part, have not been included.

To check the significance of the production differences between the 5 classes, the Standard Deviations of the mean production of the classes have been calculated, as well as the Standard Deviations of the production differences between the classes (table 40). A certain fraction of the standard deviations will be due to variations, introduced by the deficiencies, but a part of the variations in production may be explained by differences in year of planting, spacing, origin of seed and errors in the determination of block yields.

From the tables 39 and 40 the following conclusions may be drawn:

a) The areas deficient in P, produce 1.2 tons of bunches per Ha/year less than the blocks not deficient for K, P or Mg;

b) The blocks 29, 30 and 31 are deficient for K and produce 2.6 tons of bunches/Ha/year less than the blocks not deficient for K, P or Mg;

c) Mg deficiency has no significant effect on the production, as compared with the highest yielding blocks.

d) The blocks both deficient for K and P, produce 1.6 tons/Ha/year less than the blocks not deficient for K, P or Mg.

As the production differences between the areas having a low P, a low K + P or high K + P content, suggest the importance of P as the limiting factor for the production, the average leaf P content in each of the three categories of areas was determined and the corresponding standard deviations calculated (tables 41 and 42).

From these it is evident that the significant differences in production of the areas delimited by means of foliar analysis correspond with significant differences in leaf P contents.

When the production of all the blocks, planted in the years 1939 -1942 (with the exception of blocks 6, 7, 16, 17 and 27, Mg deficient, and the blocks only for a small part deficient in K or P) is plotted against leaf P content, figure 26 is obtained, from which it is clear that leaf P content at its lowest value of ± 0.18% corresponds to a production of ± 8.5 tons bunches/Ha/year.

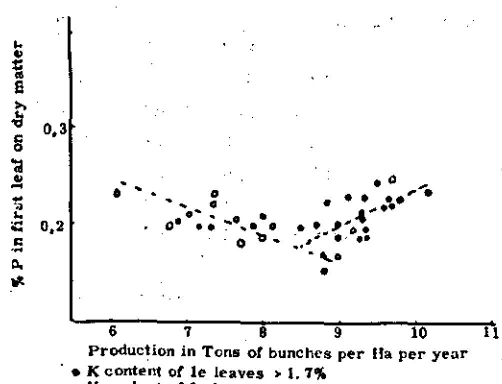


Figure 26. Relationships between the production and the P content of the first leaves of the Yaligimba plantation

TABLE 41

P CONTENT OF FIRST LEAVES AND PRODUCTION OF VARIUNS AREAS IN THE YALIGIMBA PLANTATION

Leaf Composition	Average P content 1° Leaf	Average Production in Tons/Bunches/Ha (1953)
K + P. low	0,193% ± 0,055	8,0 Tons ± 0,23
P. low	0,206% ± 0,033	8,4 Tons ± 0,28
K + P. normal	0,231% ± 0,042	9,6 Tons ± 0,31

TABLE 42

SIGNIFICANCE OF DIFFERENCES IN PRODUCTION AND P CONTENT OF LEAVES OF VARIOUS AREAS IN THE YALIGIMBA PLANTATION

Difference between Classes	Difference in Production	Difference in P content	Degrees of Freedom	Standard deviation of difference in P. content
K + P. high - P. low	1,2 Tons++	0,025%++	20	0,0054%
K + P. normal - K + P. low	1,6 Tons++	0,038%++	22	0,0069%
P. low - K + P. low	0,4 Tons	0,013%	20	0,0082%

+ Significant at P = 0,05
++ Significant at P = 0,01

The left hand part of the curve represents the P content of the leaves from blocks, deficient in both K and P (K < 1.7%). Production is negatively correlated with leaf P. In the right hand part of the curve, are found the data for the areas, deficient in P only, and the areas of optimal leaf composition. In this part of the curve, the production is positively correlated with the P content of the leaves.

In the extreme case of K deficiency (blocks 29, 30 and 31), leaf P content is of the order of 0.23%, thus above the optimum value. As soon as leaf P falls, the influence of K deficiency on the production becomes less pronounced, until the P content reaches the minimum of 0.16-0.18%. At the present time only P is deficient and is positively correlated with production for the range 8.5-11 tons of bunches/Ha/year.

Conclusions:

P, and to a lesser extent, K, are limiting factors in the production of this plantation.

a) The blocks 29, 30 and 31 with an average production of 7 tons of bunches/Ha/year, are deficient in K. An application of incinerator ash to this area would seem to be justified. The effect of the applications should be followed up by means of foliar analysis, to enable the optimal quantity of K to be applied.

b) In blocks 40 and 41, both K and P deficiency are limiting the production (7.7 and 6,8 tons of bunches/Ha/year), but positive production responses to applications of K are likely on account of the low K/P ratio, which suggests that K is the primary limiting factor in this case.

c) In the area, delimited as deficient in both K and P, (with the exception of the blocks 40 and 41), K applications are not recommended, unless P is also applied. Applications of K alone will increase the relative P deficiency and might induce a decrease in production.

d) In the blocks, indicated as deficient in P, applications of P are recommended.

IX. DISCUSSION AND CONCLUSIONS

Considering the data presented in the previous sections, the question may be asked: "Is it possible to obtain from foliar analysis data all the necessary information with regard to:

a) The diagnosis of mineral deficiencies in the field;
b) advice on fertiliser policy, without the aid of soil analysis and of field experiments".

a) As regards the first point, it has been shown that, with the aid of foliar analysis, it is possible to indicate mineral deficiencies in oil palm plantations, provided due attention is given to the following considerations:

(i) Technique

The sampling technique must follow a standard procedure as regards the morphological position of the leaflets sampled and the time of the year of sampling. Only leaflets taken from leaves of the same physiological age from the same part of the frond, may be compared.

The indications obtained to date suggest that the youngest fully opened frond is most suited for routine sampling and compares favourably with older leaves. This does not imply that other elements, not considered in these investigations, would not show up better in older leaves. This remains a subject for further research.

The sampling should be carried out in the rainy season for the following reasons:

1) The interaction between age of the palms and climatic conditions is very pronounced in the dry season, especially when the leaf composition of productive and very young, non-productive palms is being compared. This reaction to changes in climatic conditions is much quicker and often more intense in the case of young than of older palms. As only leaf analysis data from samples taken at the same time of the year may be compared, the rainy season which is much less influenced by changes in climatic conditions offers many advantages.

2) Some plantations, situated close to the Equator, do not have a real dry season or a very short one.

Thus, the possibility for a standard leaf sampling would be greatly reduced if a dry period would be taken as a standard sampling time.

As regards the analytical technique, reasonably accurate methods should be selected for the determination of the leaf constituents. The analytical error should not exceed 10%. In this respect, the rapid "tissue tests" would not seem to be sufficiently accurate.

(ii) Interpretation of Leaf Analytical Data

The interpretation of foliar analysis data is based on the evidence that there is a narrow range of "optimal" concentrations for each of the elements in the leaf tissue. Palms, with an adequate supply of plant nutrients, whether the growing medium is a light sand, a heavy clay or a culture solution, shows this "optimal" leaf composition. It does not depend on soil type and is identical for young and old palms, provided a standard sampling technique is strictly adhered to. Any deviations from this "optimal" composition indicate unfavourable nutritional conditions.

A deficiency in one element is generally associated with a decrease in the leaf content of that element. In an advanced stage of the deficiency, however, the content of the deficient element may increase again to a low to medium concentration. Moreover, any particular deficiency also affects the concentration in the leaves of other elements, which are not deficient in the nutrient medium. The elements not deficient may increase or decrease, depending on the character and the degree of the deficiency.

These findings imply that:

1) Diagnosis should not be based on the concentration of one element in the leaf tissue. The fact that the leaves have a low concentration of a particular element does not necessarily imply that it is deficient, as it may be indirectly caused by another element deficiency. An element in medium concentration in the leaf, only slightly below the "optimum", may be extremely deficient due to the possible parabolic nature of the relation between yield and/or growth and leaf content of the element.

2) The only satisfactory basis for the diagnosis of deficiencies is the recognition of the characteristic changes in the contents of all the elements in the leaf tissue, when one particular element is deficient.

These characteristic changes may, however, depend on the degree of the deficiency; the contents of certain elements may increase at first, as the induced effect of a deficiency, but decrease later, when the deficiency becomes more accentuated.

Resulting from these considerations it will be evident that a reliable diagnosis of deficiencies in plantations may be made only after determining the contents of all the elements in the leaves. Thus in addition to determinations of K, P, Ca and Mg, analysis for N, S, Mn, B, Cu and Zn should also be included. Moreover, whenever possible, the contents of the elements in the leaves should be studied in relation to production and/or growth, to determine the degree of the deficiency.

In that respect oil palm plantations are very suitable for foliar analysis, as production figures are, generally, accurately known. Even if the production figures are not known, an estimate of the production may easily be made by counting the number of bunches and female inflorescenses on the 20 palms, from which the samples are taken. When the composition of the bulk samples is being compared with the production figure for each sample, a yield curve may be drawn.

A complication in the interpretation of leaf analysis is the fact that more than one deficiency frequently occurs in the same plantation. In such cases the several deficient factors can still be determined, as the considerable variations in soil nutritional conditions will result in some of the samples showing a more pronounced deficiency of element a, whereas others will indicate element b as being deficient. From a limited number of samples it may not be possible to draw any safe conclusions, but the information, given by the other samples, enables the estimation of the most deficient elements in the plantations. Once the main deficiencies are known, the actual % contents of the deficient elements in the leaves may be used as a guide for the deficiency and be plotted on maps to delimite the areas deficient and not deficient for that element, provided the degree of the deficiency is known from the yield curves.

b) Advice on Fertiliser Policy.

For practical purposes, it will not be sufficient to indicate only those elements, limiting growth and/or production.
Advice on how to remedy the state of affairs will necessarily have to be of a quantitative nature. The above results have shown that the chemical composition of leaf samples does not give any information on the reserve of nutrients in the soil. In each particular plantation, the optimal fertiliser application will depend on the nature of the soil. In some areas, P deficiency will be remedied by a much smaller dose than in plantations, situated on a soil with a high P fixation capacity. K, applied on the light sandy soils in the Southern Congo, will quickly leach out to deeper horizons and become unavailable to the palm roots. On the other hand, losses by leaching will be materially less on some of the heavy clay soils in the Northern part of the Central Congo basin. It is thus evident that each particular plantation will require individual treatment to cure deficiençies of the same physiological nature.

Several means of determining the "optimal" application of fertilisers may be cited:

1) By means of foliar analysis only; i. e. applying fertilisers and following up changes in leaf composition to see whether these are directed towards the "optimum".

It may be possible that as a result of a fertiliser application, the "optimum" for a particular element may not have been reached. In that case it is obvious that the dose has to be increased.

If on the other hand the application has been excessive, other deficiencies may be induced and the rate of application should be reduced, or the second deficient element included in the fertiliser applications.

2) By the applications of foliar analysis, combined with well designed fertiliser experiments. Much time is saved and a great deal of usefull information obtained with regard to "optimal" levels of fertiliser applications from experiments laid down in areas characteristic for a definite deficiency, as indicated by means of foliar analysis.

If the treatments comprise the application of fertiliser(s) at different levels, the production responses may be compared with the corresponding changes in leaf composition, and the "optimal" level determined. Although, theoretically, foliar analysis should be able to follow up fertiliser applications and determine the "optimal" levels of application after a few years experience, without the aid of fertiliser experiments, it is our opinion that, in our present state of knowledge, field experiments are essential for the determination of the "optimal" level of fertiliser applications.

3) It has already been pointed out that soil analysis, as opposed to foliar analysis does not supply the basic information, necessary for advice on fertiliser policy.

This does not imply, however, that no soil analysis should be done in conjunction with foliar analysis. In fact in some abnormal cases, such as P fixation, soil analysis may prove extremely valuable to explain the lack of response to fertilisers.

(iii) Conclusions

Foliar analysis constitutes a very valuable method as an aid in the determination of qualitative and quantitative fertiliser requirements of oil palm plantations, provided a standard sampling and analytical procedure is adopted.

The interpretation of the leaf analytical data should be based on the characteristic deviations from the "optimum" of all the elements in the leaves.

Yield curves, giving production as a function of leaf composition, are essential as a means of determining the degree of a deficiency.

In no circumstances may reliable conclusions be drawn from the concentration of a single element in the leaf only.

X. SUMMARY

In the previous sections a study was made of the applicability of Foliar Analysis as a means of determining the nutritional status of oilpalm plantations in the Belgian Congo. After a study of the literature and a comparison of the results obtained by other workers, the main factors affecting the chemical composition of oil palm leaves were investigated. It was shown that:

a) It is essential to compare leaflets from the same morphological position, as placement on the frond and age of the leaf have a marked influence on the chemical composition of the samples.
b) The age of the palms has an influence on the chemical composition of the samples. The influence of changes in climatological conditions on the chemical composition is not identical for young and old palms. In general, this will fluctuate more in young than in older, productive palms.
c) Sampling time has a significant effect on leaf composition and samples, taken in the dry season, are not comparable with those, taken in the wet season.
d) Errors in the chemical analysis should not exceed 10%. Bulk samples of 20 to 25 palms should always be taken, these having a sampling variation of the same order as the errors involved in the analytical procedure.

Further it was shown that the internal concentration is directly related to growth and production of the oil palms and that there is an "optimal" leaf composition. Irrespective of the soil characteristics, a palm adequately supplied with nutrients in the correct proportions, has a chemical composition which varies only within narrow limits, provided the sampling and analytical technique follows a standard procedure.

By means of sandculture experiments it was shown that characteristic changes in leaf composition exist for each deficiency, but that the character of the change is a function of the degree of the deficiency. In no circumstances may diagnosis in the field be based on the content of one element in the leaves, as elements not deficient may decrease as the result of another deficiency, and, further, because it has been observed that, under extreme conditions of a deficiency, the concentration of the deficient element in the leaf may increase, when the growth of the palms almost completely ceases.

Qualitative diagnosis of deficiencies should be based on characteristic changes in leaf composition for all the elements in the leaves (N, P, S, K, Ca, Mg, Mn, B, Cu, Zn). It is necessary to include minor element determinations as a deficiency of one of these may affect the concentrations of major elements, thus creating the possibility of a wrong diagnosis.

By means of fertiliser experiments, it has been shown that the chemical composition of treated palms, which resulted in growth or production responses, is closer to the "optimal" than that of the control plots. The changes in leaf composition induced by the fertiliser applications correspond closely with the responses.

The application of leaf analysis in oil palm cultivation offers many advantages over soil analysis on the one hand and field experiments on the other, as shown by examples, given for cases of various deficiencies of plantations in different parts of the Congo. Nevertheless, the data from field experiments and the application of soil analysis, in special cases, may provide useful information at the present stage.

XI. APPENDIX

DETAILS ON SAMPLING AND ANALYTICAL METHODS

a) Sampling

A representative bulk leaf sample for a plantation block, consists of leaflets taken from at least 20 palms in a block of 20 Ha; 40 palms should be sampled in a 40 block Ha, etc.

In fertiliser experiments, all the palms per plot should preferably be sampled.

Only healthy palms are sampled; those, showing disease symptoms, replacements or steriles, should not be considered for sampling.

Samples are taken from the youngest leaf on which the leaflets are fully open. Two leaflets from each side of the middle part of the frond are taken; Each bulk-sample is numbered and wrapped in paper to prevent contamination during the transport in the plantations. The numbers correspond with a map on which the location of the bulk sample is indicated.

When the sampling is being carried out, the following observations should whenever possible be made:

1) Description of the aspect of the palms;
2) The total number of bunches and female flowers on the palms at time of sampling;
3) Date of planting, numbers of palms per bloc and the production per Ha;
4) General remarks concerning soil cover, water table, topography etc.

The sampling is always carried out in the rainy season and in the morning between 7 and 10 o'clock.

b) Preparation of the samples

All leaflets are carefully cleaned with a rag or washed, if necessary, with distilled water.

From the middle of each leaflet, only 10 cm is kept for analysis. The midribs are removed and rejected. The samples are dried in an over for at least 6 hours at a temperature of 100°-105° and stored in glass bottles, while awaiting analysis.

c) Preparing of extracts

700 mg is weighed out accurately and heated in a muffle furnace, care being taken that the temperature does not exceed 550°. The ash, which is light grey in colour and slightly cintered, is cooled, weighed and the ash content as a percentage of dry matter calculated. The ash is transferred into a glass tube with a flat bottom, and, subsequently, 1 ml concentrated sulfuric acid and 1 ml nitric acid are added. The tubes are placed on a hot plate and the content is allowed to digest until the last traces of carbon have been oxidised and the digest is clear, leaving only an insoluble deposit of silica on the bottom of the tubes. The digest is transferred into a 100 ml measuring flask, diluted with distilled water and neutralised with caustic soda, using phenolphthaleine as indi-

cator. 3 ml of acetic acid are added and the solution made up to 100 ml with distilled water. Silica is filtered off, and K, P, Ca and Mg analysed in the filtrate,

d) Chemical Analyses

Potassium determination

The following solutions are required for the determination of K:

1) 100 gr sodium colbaltinitrite in 600 ml sodium nitrite solution, containing 200 gr of sodium nitrite;
2) 8 gr of Silver nitrate in 20 ml of water;
3) Concentrated acetic acid.

For the preparation of the cobaltinitrite solution, used to precipitate Potassium, solution 2 is added to 1 and diluted to 800 ml with water. 8 ml of solution 3, is added and well mixed. The solution, thus obtained, is cooled and connected to a filter pump and air is aspirated through the solution for an hour to remove nitrous fumes.

The solution is stored in a refrigerator for a period of 12 hours and filtered through a Whatman N^{o} 42 filter paper. Immediately before use, the solution is centrifuged and only the supernatant layers used for the analysis. The reagent may be used for a period, nor exceeding two weeks.

4) 30% acetene;
5) Pure acetone;
6) 200 ml concentrated nitric acid diluted to 1 liter with water, to which one drop of Teepol has been added;
7) 20 gr of ammonium thiocyanate in 1 L of ethylalcohol;
8) Standard solutions containing 20, 40, 60, 80 and 100 ppm K., in 3% acetic acid.

Procedure.

3 ml extract is pipetted into a centrifuge tube of 15 ml and made up with water to 5 ml. Of each of the standard solutions, 5 ml is pipetted into centrifuge tubes. 2 ml freshly centrifuged cobaltinitrite solution are added and mixed with the contents of the tubes by rolling the tubes between the hands. The tubes are left for at least 1 hour in the refregerator for precipitation of the Potassium. After precipitation, the tubes are centrifuged in an M. S. A. angle centrifuge (for 3 minutes at 10.000 rpm). After centrifuging, the supernatant liquid is removed by means of a thin glass tube, connected to a suction pump. The precipitate is wahed twice with 5 ml of 30% acetone and once with pure acetone. Between each washing the tubes are centrifuged for 3 minutes and the supernatant acetone is removed in the way, as described above.

The washed precipitate in the centrifuge tube is dried in an oven (100^{C}) and 1 ml of the nitric acid solution added. The tubes are heated on a sand bath until the precipitate has gone into solution, apart from the insoluble residue of silver chloride.

After cooling the tubes, 8 ml of ammonium thiocyanate in alcoholic solution are added at 2 minute intervals. Each batch of determinations comprises 24 tubes, of which 8 tubes are reserved for the standard solutions. All determinations are made in duplicate.

The intensity of the blue colour is measured by means of a Hilger Spekker photo-electric colorimeter using red glass filters.

The actual K contents of the extracts are found by comparison of the Spekker readings of the aliquots of the extracts with those of the standards. This is done by means of a graph giving readings as a function of K content. A series of standard solution is included in every batch.

Phosphorus Determination

The following solutions are required for the determination of Phosphorus in the extract:

1) 25 gr ammonium molybdate in 1 L 10 N sulfuric acid;
2) 0.8 gr of stannous chloride in 10 ml hydrochloric acid and made up to 100 ml with water. This solution is made up daily;
3) Standard solutions containing 1, 2, 3, 4 and 5 ppm P. in 3% acetic acid.

Procedure

An aliquot of 1 ml extract is pipetted into 100 ml graduated flasks. This is diluted with water to ± 90 ml. To the solutions thus obtained, 1 ml of acetic acid is added. Further, at two minute intervals, 4 ml molybdate solution and 1 ml stannous chloride is added. Batches of 24 solutions comprise 6 for the standard solutions (three in duplicate). The intensity of the colours is determined by means of the Hilger Spekker photo-electric colorimeter, using red filters. The actual percentages of Phosphorus are read off a graph in the same way as for the Potassium method.

Magnesium Determination

Solutions required:
1) Titan yellow, 0,15 gr in 100 ml 95% ethyl alcohol;
2) Sodium hydroxyde 8%;
3) Hydroxyl amine/dextrose solution, containing 20 gr hydroxyl amine/L and 95 gr dextrose/L;
4) Standard solutions of 4, 6 and 8 ppm Mg and made up with a filler solution containing;
   30 ml acetic acid per liter;
   40 ppm K;
   10 ppm P;
   20 ppm Ca;
   60 gr Sodium nitrate per liter;
   52 gr Sodium sulphate.

Procedure

An aliquot of 1 ml extract is pipetted into a wide test tube and made up to 5 ml with filler solution. From the standards, 5 ml is pipetted. To all tubes 1 ml of hydroxylamine/dextrose solution is added and well mixed with the contents of the tubes.

0,15 ml Titan yellow, immediately followed by 2 ml caustic soda, are added to the tubes at two minute intervals. A batch of 12 tubes comprises 6 standards (3 in duplicate). The colour intensities are compared by means of the Hilger Spekker photo-electric colorimeter, using green glass filters. The actual percentages of Mg in the extracts are red off a graph in the same way as for the K and P determinations.

Calcium Determination

Solutions required:
1) Ammonia 10%;
2) Ammonia 2%;
3) Ammonium oxalate 4%;
4) Sulfuric acid 2 N.;
5) Potassium permanganate N/100;
6) Standard solutions containing 30 and 50 ppm Ca.

Procedure

An aliquot of 5 ml extract is pipetted into a 15 ml centrifuge tube and, subsequently, 1 ml ammonia 10% and 2 ml ammonium oxalate are added. The contents are well mixed by rolling the tubes between the hands. The precipitation of calcium takes at least one hour.

After precipitation, the tubes are centrifuged during 3 minutes in an M.S.A. angle centrifuge (10.000 rpm). The supernatant luquid is sucked off by means of a thin glass tube connected to a vacuum pump and the precipitate is washed 3 times with 2% ammonia, each time centrifuging for 3 minutes between the washings.

The precipitate of calcium oxalate is dissolved in 5 ml sulfuric acid 2/N and heated on a water bath to 80° C.

The calcium content is determined by titration with 0.01 potassium permanganate in the centrifuge tubes. The actual percentages are, however, not calculated as usual but determined graphically. Each bath of 24 tubes contains 4 standards (in duplicate) for this purpose.

XII. LITERATURE

1. Broeshart, H. — The Use of Foliar Analysis in Oil Palm Cultivation. Tropical Agriculture Volume 31, N° 3, July 1954.
2. Bull, R. H. — A Preliminary List of the Oil Palm Diseases encountered in Nigeria. Journal of the West African Institute for Oil Palm Research. Sept. 1954.
3. Carolus, R. L. — The Use of Rapid Chemical Plant Nutrient Tests in Fertiliser Deficiency Diagnosis and Vegetable Crop Research. Virginia Truck Experiment Station Bulletin January, 1938.
4. Chapman, G. W. — Leaf Analysis and Plant Nutrition. Soil Sci., 111, 63-81, 1941.
5. Chapman, G. W. and Gray, H. M. — Leaf Analysis and the Nutrition of the Oil Palm. Annals of Botany, N. S. Vol. XIII N° 52, October 1949.
6. Cochran, W. G. — Some consequences when the assumptions for the analysis of variance are not satisfied. Biometrics March 1947.
7. Cochran, W. G. and Cox, G. M. — Experimental Designs, John Wiley & Sons, Inc; second printing December 1950.
8. Drosdoff, M. and Paiter, J. H. — A chlorosis and necrosis of Tung leaves associated with low potassium content. Proc. Amer. Soc. Hort. Sci., 41, 1942.
9. Emmert, E. M. — Plant-Tissue Tests as a Guide to Fertiliser Treatment of Tomatoes. Kentucky Agricultural Experiment Station, Bulletin 430, June 1942.
10. Ferwerda, J. D. — Boron Deficiency in Oil Palms in the Kasai Region of the Belgian Congo. Nature Vol. 173, June 5, 1954.
11. Ginneken van, — Mededelingen van het Instituut voor rationele Suikerproductie deel XIII 1943.
12. Goodall, D. W. — Studies in the diagnosis of mineral deficiency I. The distribution of certain cations in apple foliage in early autumn. J. Pomol., 20, 1943.
13. Goodall, D. W. — Studies in the diagnosis of mineral deficiency II. A comparison of the mineral content of scorched and healthy leaves from the same apple tree. J. Pomol., 21, 1943.
14. Goodall, D. W. — Studies in the diagnosis of mineral deficiency III. The mineral composition of different types of leaf on apple trees in early summer. J. Pomol., 21, 1945.

15. Goodall, D. W. and Gregory, F.G. Chemical Composition of Plants as an Index of their Nutritional status. Imperial Bureau of Horticulture and Plantation Crops, Technical Communication N° 17, July 1947.

16. Hale, J. B. Mineral Composition of Leaflets in Relation to the Chlorosis and Bronzing of Oil palms in West Africa. Journal of Agricultural Science Vol. 37. Part 3, 1946.

17. Itallie, Th. S. van De Chemische Samenstelling van Gewassen in Verband met Landbouwkundige Vraagstukken. Dep. van Economische Zaken, Rijks uitgeverij, Dienst van de Nederlandse Staats Courant, 1938.

18. Kovachich, W. G. Little Leaf Disease of the Oil Palm. (Elaeis Guineensis) in the Belgian Congo. Tropical Agriculture, Vol. XXIX Nos 4 - 6 April, June 1952.

19. Krantz, D. A. Nelson, W. L. Burkhart, L. F. Plant-Tissue Tests as a Tool in Agronomic Research. Diagnostic Techniques for Soils and Crops. Published by the American Potash Institute, Washington 6. D. C.

20. Larson, C. A. Effect of fertilisers on irrigated Ephrata fine sand and apple tree response in the Wenatchee orchard district. J. Amer. Soc. Agron. 25, 1933.

21. Lindner, R. C. Rapid Analytical methods for some of the more common inorganic constituents of plant tissues. Plant Physiol. 19, 1944.

22. Lindner, R. C. and Harley, C. P. A rapid method for the determination of Nitrogen in plant tissue. Science (N. S.) 96, 1942.

23. Lundegårdh, H. Leaf Analysis (Translation by R.L. Mitchell of die Blattanalyse). Hilger & Watts LTD, London.

24. Mitchell, H. L. The effect of varied solar radiation upon the growth, development and nutrient content of white pine seedlings, grown under nursery conditions. Black Rock For. Pap. 1, 1936.

25. Mitchell, H. L. Trends in the Nitrogen, Phosphorus, Potassium and Calcium content of the leaves of some forest trees during the growing season. Black Rock For. Pap. 1, 1936.

26. Morgan, M. F. Soil and Plant Tissue Tests for Minor Elements Constituents. Proc. Soil Sci. Soc. Amer. 1, 255-257, 1937.

27. Morgan, M. F. The universal soil testing system. Bull. Conn. Agr. Exp. Sta. 372, 1935.

28. Nicholas, D. J. D. The application of Rapid Chemical Tests to the Diagnosis of Mineral Deficiencies in Horticultural Crops. Parts 1 and 2.

The Journal of Horticultural Science Vol. XXLV N° 2, September 1948.

29. Nightingale, G. T. Potassium and Phosphate Nutrition of Pine Apple in Relation to Nitrate and Carbohydrate Reserves.
Bot. Gaz. 104, 1942.

30. Page, N. R. Burkhart, L. Extraction and distribution of soluble minerals in the peanut plant. Proc. Assoc. south. agric. Workers 42, 1941.

31. Paterson, D. D. Statistical Technique in Agricultural Research. McGraw-Hill Book Company, Inc. New York and London 1939.

32. Pfeiffer, T. Blanck, E. Flügel, M. Wasser und Licht als Vegetations Factoren und ihr Beziehungen zum Gesetze vom Minimum.
Landw. Vers. Sta., 76, 1912.

33. Plant, W., Jones, J. O., Nicholas, D. J. D. The Diagnosis of Mineral Deficiencies in Crops by means of Chemical Tissue tests. Annual Report of the Long Ashton Research Station 1944.

34. Prevot, P., Ollagnier, M. Application du Diagnostic Foliaire a l'Arachide.
Oléagineux 6° année, N° 6, Juin 1951.

35. Prevot, P. Les Bases du Diagnostic Foliaire: Application à l'arachide.
Oléagineux 8° année, N° 2, Février 1953.

36. Prevot, P. and Ollagnier, M. Engrais Minéraux et Oléagineux Tropicaux. Oléagineux 8° année, N° 12, Décembre 1953.

37. Remy, T. Die Blattanalyse als Hilfsmittel zur Feststellung des Düngerbedürfnisses der Hopfenböden.
Jb. Vers. Ans. Brau. Berl. 6, 1903.

38. Reuther, W. and Boynton, D. Variations in Potassium content of the foliage from certain New York orchards.
Proc. Amer. Soc. hort. Sci. 37, 1940.

39. Roach, W. A. Plant injection for diagnostic and curative purposes. Imperial Bureau of Horticulture and Plantation Crops, Technical Communication N° 10, October 1938.

40. Roach, W. A. Plant injection as a physiological method. Annals of Botany New series Vol. III N° 9, January 1939.

41. Scheidecker, D. Prevot, P. Nutrition Minérale du Palmier à Huile à Pobé (Dahomey).
Oléagineux 9° année, N° 1, Janvier 1954.

42. Schuffelen, A. C. De ionenverhouding in de grond en de rentabiliteit der meststoffen.
Landbouwkundig tijdschrift, N° 645, December 1940.

43. Schuffelen, A. C. The absorbtion of Potassium by the plant. Potassium sympossium, page 169 Bern, 1954.

44. Steenbjerg, F. Yield Curves and Chemical Plant Analysis. Plant and Soil III n° 2.

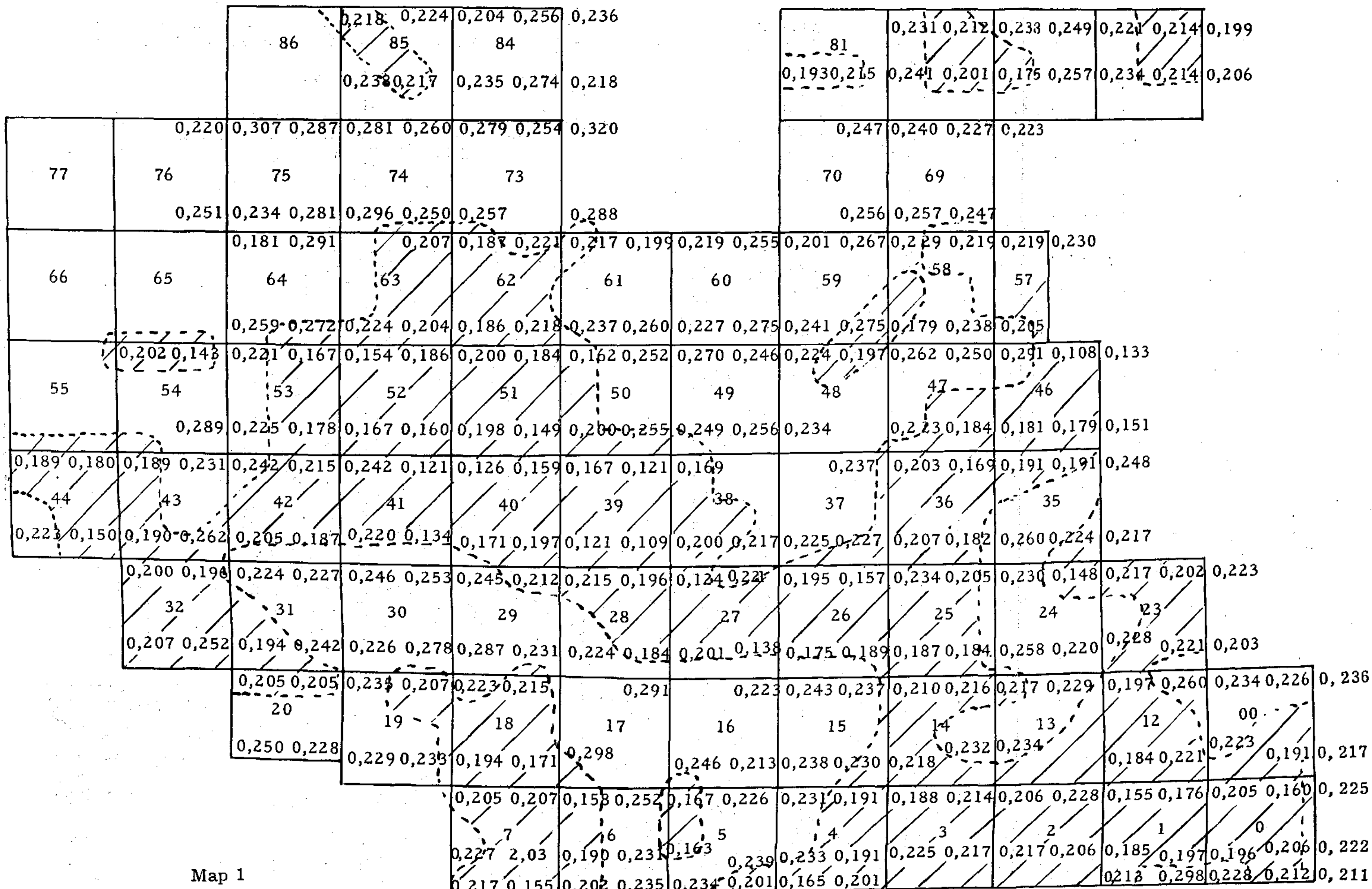
45. Thornton, S. F. Conner, S. D. Fraser, R. R. — The use of rapid chemical tests on soils and plants as aids in determining fertiliser needs.
Circ. Ind. Agr. Experiment Station 204, 1934.

46. Ulrich, A. — Plant analysis as a diagnostic procedure.
Soil Sci. 55, 1943.

47. Ulrich, A. — Plant Analysis- Methods and Interpretation of Results. Diagnostic Techniques for Soils and Crops, Published by the American Potash Institute, Washington 6. D. C.

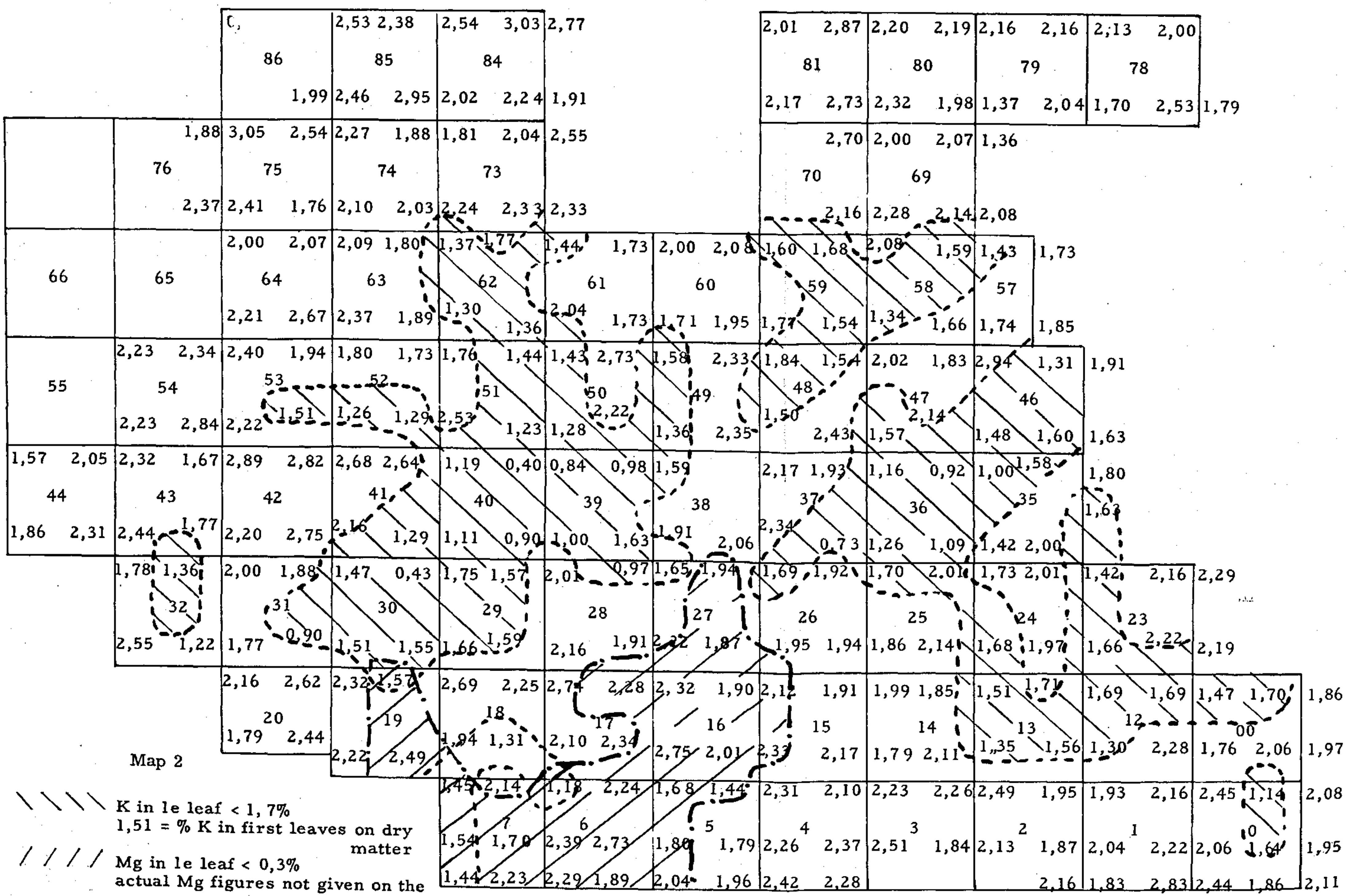
48. Vermeulen, F. H. B. — Control of the reproductibility and accuracy of routine analyses at the laboratory for soil and crop testing in the Netherlands. Plant and Soil IV, n° 3, Jan. 1953.

49. Wallace, T. — The diagnosis of Mineral Deficiencies in Plants.
His Majesty's Stationery Office: 1943. London.



Map 1

/// P in first leaves < 0,22%
0-86 Block numbers
0,225 = percentage P in first leaves on dry matter



Map 2

\\\\ K in le leaf < 1,7%
1,51 = % K in first leaves on dry matter

//// Mg in le leaf < 0,3%
actual Mg figures not given on the map

STELLINGEN

I

Het aannemen van z.g. kritieke concentraties der elementen in het bladweefsel van de oliepalm, als criterium voor een bemestingsadvies, is onjuist.

literatuur: P. Prevot en M. Ollagnier.
Engrais minéraux et oléagineux tropicaux.
Oléagineux, Décembre 1953.
H. Broeshart.
The use of foliar analysis in oil palm cultivation.
Tropical Agriculture, July 1954.
Dit proefschrift.

II

Orienterende bemestingsproeven met éénjarige gewassen, zijn voor overjarige cultures van zeer beperkte betekenis.

III

De bemestingsformule voor oliepalmen, gebaseerd op de onderzoekingen van Homes, heeft weinig practische waarde.

literatuur: M. V. Homes.
l'Alimentation minérale du palmier à huile.
Publication INEAC, ser. scient. 39, 1949.

IV

De bepaling van de bodemvruchtbaarheid door middel van de hoeveelheid uitwisselbare basen, zoals dit door de INEAC wordt toegepast, is, voor tropische gronden, onjuist.

literatuur: INEAC, Rapports d'exercises, 1952 et 1953.

V

De conclusie van de Leenheer en van Wambeke, als zouden verschillen in vruchtbaarheid en vegetatie van de gronden in het Kwango-Kwilu gebied (Zuid-Congo) verklaard worden door verschillen in waterhuishouding, is aanvechtbaar.

literatuur: L. de Leenheer en A. van Wambeke.
Etude d'un axe de prospection pédologique (Kwango)
Bul. Agr. du Congo Belge, Vol. XLV No 2, April 1954

VI

Bij de bodemkartering in de Belgische Congo zal men met de invloed van de mens en de termieten als bodemvormende factoren rekening moeten houden.

VII

Een efficient gebruik van de resultaten der onderzoekingen in de oliepalm cultuur, is alleen mogelijk door internationale samenwerking en integratie op het gebied van wetenschappelijk onderzoek.

literatuur: S. de Blank.
Coöperation and integration in oil palm research.
World Crops, June 1953.

VIII

Het uitzaaien van meerdere zaden per plantplaats met het doel om later één gezonde plant aan te houden, is alleen aan te bevelen als men verzekerd is van een hoog kiem percentage van het zaad.

IX

Voor het aangeven van een verband tussen twee landbouwkundige grootheden, zal in vele gevallen een stippenkaart een betere indruk kunnen geven dan een correlatie coëfficient.

X

2^n factoren-schema's zijn niet aan te bevelen voor orienterende bemestingsproeven op arme gronden.

XI

Het uitplanten van ongetest Dura x Tenera materiaal is te prefereren boven het gebruik van ongetest Dura x Pisifera zaad.

XII

Bij de oliepalm cultuur in de Belgische Congo, moet adaptatie aan het milieu in de eerste plaats gezien worden als een aanpassing aan klimaatomstandigheden en niet aan de eigenschappen van de bodem.