COCONUT NUTRITION AND FERTILIZER REQUIREMENTS — THE PLANT APPROACH

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SUMMARY

Though the theoretical basis for fertilizing a crop is relatively simple, the real problem facing the plant nutritionist is the actual determination of the exact quantities of the nutrients that would have to be added to ensure optimum growth of his crop.

The broad view now taken is that the conditions required for the satisfactory completion of a plant's vegetative and reproductive cycles of growth must be sought principally from facts of both plant physiology and soil science.

The method of field experimentation with chemicals, has been extensively applied to various crops for the purpose of evaluating optimum fertilizer dosages and new cultural practices. At the present time however, it has been recognized that the field trial is not necessarily the best method for investigating the fertilizer requirements of all crops under all conditions. In order therefore, to meet the need for broader methods of estimating the fertilizer requirements of crops, two general types of tests have now been developed, namely soil tests and plant tests. The paper pinpoints the fact that diagnostic techniques using the plant have been widely and successfully applied to a whole range of crop plants both for the evaluation of their nutrient requirements and as a guide to their optimum fertilization.

A survey of the pertinent literature relating to the application of plant methods to nutritional problems of the coconut has been made in chronological order. The conclusion is reached that past work has been mostly empirical in nature with no physiological basis. So far there have been no systematic studies, owing probably to the unwieldiness of the crop for experimental procedure, and also because of inadequate evaluation of pre-requisite fundamental knowledge pertaining to the pattern of nutrient distribution within the coconut palm.

The author has projected a phased programme of study with the ultimate objective of taking a complete nutrient inventory of the crop. The salient features of the methods employed and the results that have been obtained so far, are discussed in the paper.

It is to be hoped that the position would be reached during the next decade or so, when the technique of Diagnostic Plant Analysis (including Foliar Diagnosis) could be applied (in a complementary role to soil techniques) to the coconut palm, not only for the assessment of faulty mineral nutrition, but also as a reliable guide to optimum fertilization during different phases of its growth and reproduction.

INTRODUCTION

The theoretical basis for fertilizing a crop is relatively simple and easy to understand. In general, all that would appear necessary is to add as a fertilizer, only that amount of material which would be required to make up the difference between the nutrients needed by the crop and those supplied by the

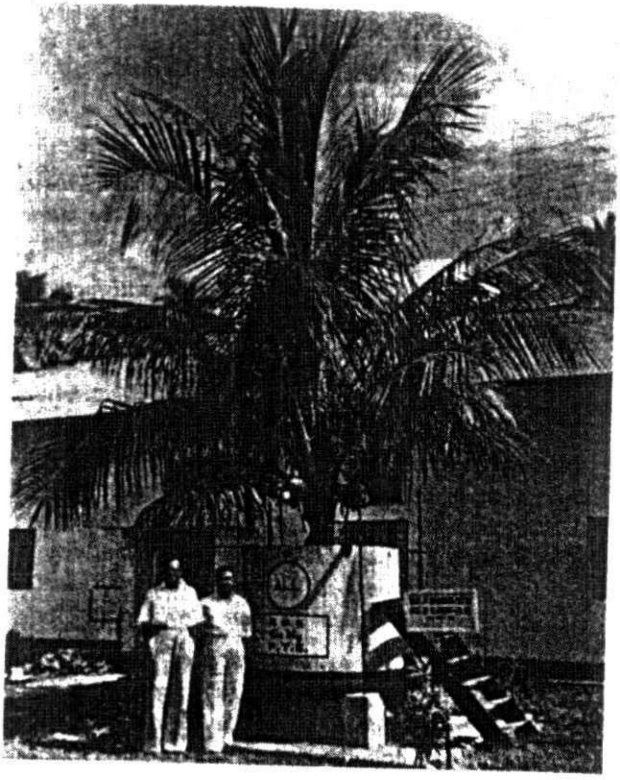

Figure 1

The author (left) with Mr. A.K. Wimaladasa, Technical Assistant, beside the young coconut palm that reached its productive phase in a pot, in the SAND-CULTURE Experiment that is in progress at the Coconut Research Institute, Ceylon.

Mr. Wimaladasa has been mainly responsible for the maintenance of this experiment.

soil. This would imply that crop performance could be improved, if we are in a position to estimate *firstly* the amount of a particular nutrient required by the plant for unrestricted growth, and *secondly* the amount that is actually supplied by the soil medium. The difference, if any, would of course have to be applied as a fertilizer.

In spite of the apparent simplicity of the basic principles of fertilization, the real problem facing the crop nutritionist is the actual determination of the exact quantities of the nutrients that would have to be added in order to ensure optimum growth of his crop. This problem however is complicated, owing to the fact that the grower is dealing with a dynamic system, the outcome of which, in terms of crop production, is dependent upon a constellation of factors associated with the soil, the plant and the climatic environment, which would require manipulation in such a manner as not to restrict plant growth.

Since the system influencing plant growth in a natural or agricultural environment cannot be defined, except in broad terms, the amount of growth to be made by the plant and the supply of nutrients to be delivered from the soil cannot be estimated too readily or with great precision. In fact, the problems of crop nutrition are legion and in attempting to solve them, research ranging under many branches of study are not infrequently required. The broad view now taken is that provided genetic factors are constant, the conditions required for the satisfactory completion of a plant's vegetative and reproductive cycles of growth must be sought principally from facts of both plant physiology and soil science.

Ever since *Justus von Liebig* (in 1840), enunciated his mineral theory of crop nutrition, soil and plant scientists, over the years, have developed and used many tests for estimating the nutrient requirements of crops. Among these, the method of field experimentation with chemicals, which is perhaps the oldest, has been applied with increasing importance to various crops for the purpose of evaluating optimum fertiliser dosages and new cultural practices. Even today, the *field trial* is considered to have the last word before adopting a new idea for enhancing crop production.

Whilst it is known, that any fertiliser only becomes of real value when it is effective in the field, it does not follow that the field experiment is for all crops and under all conditions the best method for investigating fertilizer requirements. In fact, in many countries, field trials over a number of years using mineral fertilizers have been reported to give erratic results. It may be said, that the correct criterion for assessing the value of any diagnostic method purporting to be applicable to the determination of fertilizer requirements, lies in the agreement between the responses that have been forecast and the actual yields obtained with the prescribed treatments.

To meet the need for broader methods of estimating the fertilizer requirements of crops, two general types of tests have now been developed, namely, soil tests and plant tests. Further, in view of the fact that single methods of nutritional diagnosis have not and cannot always be relied on to give a complete and unequivocal answer in all circumstances, the summation of the experience of workers at the present time, is to employ soil and plant diagnostic methods in complementary roles. It is the purpose of this paper to briefly consider the latter aspect in the context of the assessment of the nutritional requirements of the coconut palm.

DIAGNOSTIC METHODS USING THE PLANT

The principles underlying the main diagnostic methods using plants, concern basic physiological concepts in the processes of plant nutrition. These concepts relate in particular to processes of absorption and translocation of the nutrients from the soil to the leaf, their interactions and relative mobilities within the plant tissues and the fundamental relationships between the concentration of ions in the plant, particularly in actively functioning leaves. The accumulation of organic products which determine the yields and quality of the crops has also been recognized to be of significance from the physiological point of view.

The principal diagnostic methods that are based on the use of plants, and which are now in vogue, could be categorised conveniently into the following groups:—

1. The Visual Method of Diagnosis (Symptomology), including the use of special indicator plants.
2. Plant injection and spraying methods.
3. Sand and water culture methods.
4. Chemical Methods of diagnostic plant analysis including foliar diagnosis.

It should be appropriate at this stage to briefly review in chronological order, recorded evidence in the literature, where chemical and other quick methods for routine diagnostic purposes (using the plant) have been applied for the evaluation of the internal nutrient status of the coconut palm, its uptake of nutrients or where such methods have been used in connection with nutritional problems of coconut in general.

The earliest work on record in this field is that of SAMPSON, which was carried out in INDIA (1923).[1] The work does not comprise any planned experiments but embraces very valuable analytical studies on the moisture, dry matter, ash and mineral nutrient contents of the vegetative, floral and fruit components of individual plants of different ages. It is clear that the studies have been made principally for the assessment of the 'plant food requirements' of the crop during different stages of its growth, so that a basis could be found for evolving a scheme of systematic manuring.

Reference should next be made to the work of GEORGI and TEIK in MALAYA (1932).[2] The object of the investigation has been to assess the annual exhaust of nutrients by the coconut crop. The results are based on the chemical analysis of six samples of leaves, seven samples of inflorescence and eight samples of drupes. Further, there is evidence in the literature, that with the same objectives, and on the basis of similar criteria, computations have been made by other workers too, pointing to the heavy demands of the coconut palm for the major nutrient factors. Among these workers, GEORGI and TEIK alone provide adequate factual data in support of their estimates. The different figures that have been arrived at are charted in Table I, and will be seen to be very variable indeed.[3] This could not be viewed with surprise since they have been reported from different countries, and we also know that the consumption or removal of nutrients could be affected by a host of factors including age of plantation, soil type, variety of palm, factors of the climatic environment, soil fertility status, and soil management practices. Whilst the data presented are of comparative rather than absolute value, they certainly serve to emphasise the fact that the coconut palm could rapidly deplete a soil of the essential mineral elements, owing to its very heavy demands for these nutrient factors. The overall average figures that have been worked out from the eight available separate estimates show, that the quantitative sequential order of importance of the major nutrients for the palm, will be as follows:—potassium, nitrogen, phosphorus, magnesium and then calcium.

Next in order, should be considered the work of SANKARASUBRAMONY, PANDALAI and MENON which has been reported from SOUTH INDIA (1952).[11] They have employed leaf analysis to study certain disorders causing chlorosis and necrosis of the foliage of coconut palms in Travancore and Cochin. The analyses of leaf tissues have been carried out on samples drawn from the outer, middle and inner regions of the crown of healthy and diseased palms. Significant accumulations of the nutrient

TABLE I

Estimates of the Annual Removal of Plant Nutrients from the Soil by the Coconut Palm

1	2	3	4				
NO.	*AUTHORITY*	*BASIS*	*NUTRIENTS (In pounds per acre)*				
			N	P_2O_5	K_2O	*CaO*	*MgO*
1	PILLAI (1919)[4]	2,000 nuts per acre per year	18	5	38	—	—
2	JACOB AND COYLE (1927)[5]	From one acre per year	57	26	85	—	—
3	COPELAND (1927)[6]	2,800 nuts per acre per year	82	37	122	—	—
4	GEORGI AND TEIK (1932)[2]	Soil rich in plant nutrients	66	27	123	15.7	28.6
5	ECKSTEIN *et al* (1937)[7]	Annual removal from one acre	81	36	117	—	—
6	PATEL (1938)[8]	Recommendation for annual addition per acre	24	12	60	—	—
7	CARVALHO (1947)[9]	156 mature palms per hectare (2.5 acres)	81 to 126	27 to 45	108 to 144	—	—
8	COOKE (1950)[10]	60 palms per acre with 25 nuts each per annum	26	8	24	13.0	20.0
OVERALL AVERAGE FROM EIGHT ESTIMATES			57	23	87	14.4	24.3

factors were found to be present in the diseased leaves, which they have adduced to inadequate translocation resulting from an impairment of the vital metabolic processes of the palm. It has been reported that the problem is being pursued further from the physiological angle.

It is on record, that for the first time the technique of plant injection has been applied to coconut palms for curative purposes by DAVIS, ANANDAN and MENON (1954).[12] The injection of solids is stated to do more harm than good to the palm. Various methods of liquid injection have been tried out, including the gravitation method through the stem and petiole, and the syringe method through the soft parts of the crown, tips of the main rachis and leaflets. It is reported that all these trials failed to give satisfactory results. The credit goes entirely to these workers for evolving a very effective technique of injection through roots. which has now been confirmed as the best part of the palm for such studies. The cut end of a single mature root that is actively functioning has been observed by these workers to have a very high suction or absorbing capacity for liquids. As much as 250 to 400 ml. of liquid has been found to be imbibed by a single excised stump in 24 hours. The present writer has confirmed some of these observations in his own studies, and is firmly convinced that it is indeed a most promising technique. with definite potentialities for application in diagnostic work on the coconut palm.

The most recent work in the field under discussion is that of SALGADO (1955)[13] on the use of the nutrient content of coconut water (milk), for diagnostic purposes. Apart from the unique advantage, that sampling errors can be kept at a minimum, he claims superiority for this method over the conventional method of soil analysis, on the ground that the former measures the 'capacity factor' whereas the latter measures only the 'intensity factor'. In other words while soil analysis attempts to measure the nutrient supply of a limited stratum of the soil, the nut water technique which measures the 'capacity factor' takes into account not only the nutrient status of the soil but also the volume of soil from which the palm is drawing its nutrients. The method is discussed on the basis of experimental data showing the increase in potash content of coconut water as a result of NPK manuring. It is generally concluded, that coconut water is analogous to plant sap and accordingly would indicate the physiological status of the palm, and also the soil conditions in which it grows.

In order to complete this review of work on the coconut palm, reference should lastly be made to literature records of subsidiary importance relating to certain micro-nutrient aspects.

Based on certain studies on the fruit of the coconut palm, BERTRAND and BENZON (1928)[14], were not able to detect the presence of zinc and DODD (1929),[15] could find only a minute trace of boron.

On his investigations on the etiology of the 'UNKNOWN disease' of coconut in JAMAICA, INNES (1949),[16] found no evidence that manganese deficiency was the cause of the disease, and that the limit of manganese in the leaves and inflorescence of the coconut was probably not above 10 parts per million. SANKARASUBRAMONEY et al (1952),[17] have confirmed the findings of Innes based on the manganese content of leaf tissue and coconut soils in connection with the 'Root disease' of coconut in India. In discussing the status of research on micro-nutrients, CHILD (1950),[18] states that there is little information on the micro-nutrient requirements of the coconut palm.

If on the basis of the above literature review of past work, we are to make a critical and balanced appraisal of the present status and the advances that have been made in the field under discussion, we would have to concede that the ideas underlying some of the approaches and methods are fluid and the conclusions drawn in some cases, even erroneous. Though we cannot discount the practical merits of some of the work done and the value of any factual information that has been consolidated, yet most of the work has been purely empirical with no physiological basis. There have been no systematic studies on the crop to excite the gratitude or evoke the interest of future workers on the trail. Even the range of estimates on the annual removal of nutrients by the palm are of no general significance or practical applicability, since they have not been evolved from planned experiments on carefully selected plant material, with a view to the establishment of norms. The literature records only serve to demonstrate the mere futility of attempting to solve involved problems without an adequate evaluation of fundamentals. For instance, there is incontrovertible proof that the technique of foliar diagnosis is sound, yet it would be fallacious to assume that it could be applied blindly to a new crop.

The literature review makes it abundantly clear that past workers have not recognized the fact that a quantum of fundamental knowledge pertaining to each particular crop is an essential pre-requisite for a successful application of the technique of diagnostic plant analysis. Apropos this statement, MACY,[19] an eminent authority in this field mentions that, 'The central concept of plant analysis is the *critical percentage* of each nutrient in each kind of a plant above which there is *luxury consumption*, below which there is *poverty adjustment*, which is almost proportional to the deficiency, until a *minimum percentage* is reached'. In other words, it has been established that the evaluation of the critical nutrient concentration is a keystone for assessing the nutrient status of a crop. This however by itself could not be considered adequate, since it is known that preliminary assessments of certain other factors of cardinal importance pertaining to a crop are also essential. A thorough understanding for instance, of periodical phenomena such as diurnal and seasonal cycles of the nutrient concentrations within the leaves is always imperative. Further, it is necessary to pre-determine (on a proper physiological basis) not only the leaf rank, its position and part best suited for diagnostic analysis, but also the time and technique of sampling. Unless and until these preliminaries have been worked out, further progress of the diagnostician could very well be 'in shallows and in miseries', with only slender or negative chances of solving any of the major problems confronting the agricultural community growing the crop.

Literature records provide incontrovertible and overwhelming evidence that various techniques of diagnostic plant analysis have been widely applied with success for nutritional studies on a whole range of annual semi-perennial and perennial crop plants. A critical evaluation of the literature records that have been cited above however reveals that as far as the coconut crop is concerned past work in this field is truly meagre and haphazard. It should therefore be appropriate to conclude that little consideration has as yet been given to plant analysis techniques in relation to studies on the nutritional problems of the coconut, or at least that past approach from this angle has not been systematic.

COCONUT NUTRITION AND SCOPE FOR APPLICATION OF PLANT METHODS

A survey of the pertinent literature would show that empirical information of much practical value on the manuring of the coconut palm has been obtained in many countries. Comprehensive manurial experiments however have been in progress only in CEYLON.[20] In a recent publication on the coconut palm, MENON and PANDALAI[3] report that a start in this direction has also now been made in India. For the sake of emphasis it might be appropriate at this stage to epitomise their observations on some of the difficulties which beset systematic work with coconut, as follows:

1. Difficulty of laying out statistically designed experiments due to lack of uniformity in experimental material.
2. Lack of knowledge of the previous history and the practices carried out prior to the start of manurial trials.
3. The comparatively large extent of area required for experimentation which increases considerably the soil variability factor.

4. Differential response of individual palms to manuring.
5. Difficulties involved in the supervision of harvesting and recording of yield data all the year round.
6. The considerable effect of weather on the annual performance of the palms and the consequent need for continuing the experiment for long periods.
7. The long 'time lag' before conclusions on the manurial effects could be drawn.

In view of these facts, it should be legitimate to infer that the results of any manurial experiments that have been reported from Ceylon or elsewhere would have been obtained under the conditions and handicaps enumerated above. Not only would these apply to past experiments, but it should be reasonable to assume that even in the future such obstacles are likely to constitute a bottle-neck in the matter of most fertilizer field trials on the coconut palm.

It is the author's firm conviction that where soil techniques with their inherent limitations have failed to provide the answers, the 'plant approach' is a *sine qua non* if the diagnostician is to achieve any measure of success in his attempts to resolve the multitudinous problems associated with the nutrition and physiology of the coconut. Where problems associated with the application of the plant technique are not insuperable, it is maintained that with a modicum of ingenuity and imagination, it should be possible to design and standardise the requisite experimental procedure for the accomplishment of a particular trial or study. It would appear that the principal disability that has hampered progress in the past in the application of plant techniques is a definite lack of fundamental knowledge on certain vital aspects. If plant analysis for instance, is to be applied as a diagnostic technique it is essential to have precise knowledge on the uptake of nutrients, their pattern of distribution and how they drift with time and supply, during adolescence, maturity and senescence of the various plant organs in the crown and suspensory elements of the palm. Besides a consideration of the mineral nutrients, the behaviour of carbohydrates, nitrogenous constituents and the dry matter in the various plant organs should also be carefully followed in such a scheme of studies. With a full appreciation of the problems involved, the author maintains that there is a *prima facie* case for projecting systematic and intensive investigations for making an integrated picture on these aspects of the subject, for which the coconut palm offers more scope than any other crop so far studied.

The coconut palm is an extreme type of perennial, and is unique in that once it starts flowering, the productive phase lasts not only throughout the year but all through its economic life, which may average seventy years. The palm has many distinct developmental stages in its vegetative and reproductive cycles of growth. Once these are carefully identified and defined, then it should be possible to plan systematic studies covering every stage in its ontogeny. An evaluation and integration of these studies could then be expected to provide a reliable foundation for taking a complete nutrient inventory of the crop. In order to ensure a full appraisal of the nutrient status of the crop in all its bearings, and a thorough knowledge of all its growth manifestations a three prong approach is in fact envisaged. The *first phase* would constitute the establishment of norms for selected palms of comparable age and optimum performance grown under standard or typical conditions of cultural management and fertilizer regime. The *second phase* would be the study of reactions to known changes in fertilizer regime and levels of nutrient supply on the basis of long range field experiments on differential manuring involving single and multiple elements. The *third phase* would be the institution of plant nutritional surveys for the diagnosis of causative factors of deviations from established norms. In this connection the root transfusion technique of DAVIS et al (loc. cit.) could be employed to advantage for quick confirmations. The three phases of the proposed investigations would combine fundamental long range work with short-term studies covering seedlings in the nursery stage and adult palms in their vegetative and productive stages of the life cycle. In addition, collateral sand culture experiments would be carried out on seedlings and young palms under five years of age.

The programme envisaged would of course entail years or decades of patient research. The successful completion of this scheme along the lines formulated above should however cover the entire spectrum of nutritional diagnosis of the coconut and afford a sound basis for the evaluation of optimum fertilizer dosages, covering the entire life history of the palm from infancy to senescence.

With a view to assessing its nutrient uptake and requirements, the author has already initiated research on the COCONUT (falling within the first phase of the projected long range study) which bears relevance to the plant approach. The results that are being obtained will be published elsewhere from time to time as the work progresses. From the point of view of this paper however, a synoptical account alone is presented of the salient results that have so far been obtained along with a descriptive summary of the experimental techniques that are being employed towards the achievement of the objectives that have been set for the future.

SALIENT FEATURES OF EXPERIMENTS IN PROGRESS

There is no doubt, that as a means of determining the nutrient status of plants and their fertilizer requirements, plant analysis techniques are very well known and have been widely applied to a whole range of crops. In the foregoing discussion however, it has been made abundantly clear that in order to make the fullest use of chemical plant analyses for diagnostic purposes it is extremely important to obtain a certain amount of pre-requisite fundamental knowledge pertaining to the pattern of nutrient uptake and distribution for the particular crop under study. With the object of obtaining a thorough preliminary elucidation of such knowledge for COCONUT, the author is conducting certain experiments from which it has already been possible to elicit some information.

The research in progress is deep rather than broad and is restricted to certain chemical and physiological aspects of the internal nutrient status of coconut and its uptake of nutrients during its development and germination. The desired coverage has been obtained by projecting the research along three trunk lines of approach:—

1. DEVELOPMENT: From early initiation of the inflorescence to complete maturity of the fruit 25 developmental stages (D I to D XXV) have been identified and defined. Utilising representative experimental material and accurate chemical procedures, the changes in the uptake and distribution of the nutrients have been carefully followed. In this context, the analytical characteristics of the sap which nourishes the inflorescence have also been studied.
2. GERMINATION: From the embryo to the two year old seedling, 16 stages (G I to G XVI) have been distinguished and translocation and other changes in the nutrients within the plant have been carefully investigated. In order to complete the picture it is proposed to continue this study further until the productive phase in the life history of the palm is reached.
3. SAND CULTURE EXPERIMENTS: For the first time on record, crucial sand culture experiments have been initiated on coconut seedlings using a subtractive intermittent flowing technique. There is ample evidence of the results providing a thorough understanding of (*a*) the fundamental reactions of the coconut seedling to simple combinations of factors and (*b*) the chemical composition of the different plant organs characteristic of each particular deficiency.

It is reckoned that this research not only opens up a fertile field of inquiry with unlimited scope for enterprising entrepreneurs, but also constitutes an appropriate foundation on which the entire edifice of the 'plant approach to diagnosis' of nutritional problems of coconut could be built up. It explores certain fundamental aspects of a hitherto untouched field of investigation and the results that have been obtained already show promise of positive value in the appraisal of the chemical status of coconut during the early phases of its ontogeny.

The Sap of the Coconut Palm (Toddy)

On the basis of a carefully planned experiment — with definite objectives, comprehensive factual information regarding the yield characteristics and composition of coconut sap (toddy) has been consolidated.

The experimental data have provided the essential basis for computing that fraction of the total uptake of the essential macronutrients which is directed to the developing floral branch. The importance of this assessment rests on the fact, that the tender spathe is a vital structure of the palm, the nutrient supply to which could profoundly influence not only its floral biology but also various aspects of the later ontogeny of other organs.

Without an incursion into experimental details and computational procedures the final summaries of the overall findings from this study are presented in Tables II and III. It is maintained that whilst the figures in Table II accurately reflect the gross uptake of the macronutrients N, P, K, Ca and Mg, and the micronutrient manganese, those in Table III give the actual macronutrient concentrations and their ratios in the sap. From the diagnostic viewpoint, the ranges of nutrient concentrations and the nutrient ratios that have been established from the current studies for the different nutrient elements, are recognized as 'standards' for normal healthy palms.

The results show that the uptake figures of the macronutrients (in kilos/acre/annum) are in the following sequential order of decreasing magnitude:—K(52.47), N(12.93), P(3.10), Mg(1.59) and Ca(0.52). The fact that calcium gives the lowest uptake figure is perhaps not surprising, in view of the fact that it is a structural component and also that it is the least mobile of the mineral nutrients. In the chemical examination of the sap, we have in effect really estimated the soluble calcium in it. This in proportion to the Calcium that gets actually fixed in the tissues could be low. It would appear that once the element calcium is delivered to a particular organ by the transpiration stream, it does not apparently recirculate.

The present study has revealed that the phenomenon of sap exudation from the coconut spathe has certain distinctive features. It does not correspond precisely to phenomena of 'guttation' and 'bleeding' which are widely observed in other plants. From a consideration of the mechanics of tapping, the physiology of the palm, and the properties and composition of the sap, the concept has been synthesised that toddy is not the pure xylem or tracheal sap. It is the blended *vascular sap* containing apart from mineral nutrients (derived principally from the xylem) also all the elaborated nutrients organic compounds and re-exported nutrients, that are usually transported in the phloem elements. It is the composite sap available for the spontaneous nourishment of, and utilization by, the spathe and its developing floral components. This is borne out by the fact that the composition of the sap does not significantly alter with the particular region of the spathe that is being tapped.

Attempts have been made to use the composition of 'bleeding sap' as a guide to the nutritional status of agricultural crops. Lack of information of factors influencing the nature and concentration of nutrients in such sap however, has so far prevented wide application of such methods. The coconut

TABLE II

Uptake of Mineral Constituents and Production of Organic Components from the Coconut Flower Spathe at its Tapping Stage

1	2	3		4	
CONSTITUENT	*PER SPATHE* (*Grammes*)	*PER PALM*		*PER ACRE* (64 *PALMS*)	
		PER DAY (*Grammes*)	*PER YEAR* (*Grammes*)	*PER DAY* (*Grammes*)	*PER YEAR* (*Kilogrammes*)
MINERAL CONSTITUENTS (Ash) ..	227.73	7.28	2,656.18	465.70	169.98
NITROGEN (as N) ..	17.33	0.55	202.10	35.43	12.93
PHOSPHORUS (as P) ..	4.16	0.13	48.51	8.50	3.10
POTASSIUM (as K) ..	70.30	2.25	819.95	143.76	52.47
CALCIUM (as Ca) ..	0.69	0.02	8.08	1.42	0:52
MAGNESIUM (as Mg) ..	2.13	0.07	24.83	4.35	1.59
CHLORIDE (as Cl') ..	54.46	1.74	635.17	111.36	40.65
TOTAL DRY MATTER ..	9,158.60	292.67	106,824.55	18,729.29	6,836.19
TOTAL SUGARS ..	7,920.95	253.12	92,388.80	16,198.31	5,912.38
	MANGANESE IN MICROGRAMMES (1 Microgramme 0.000001 gm.)				
MANGANESE (as Mn) ..	25,248	807	294,489	51,632	18.85 (grammes)
	SAP YIELD IN GALLONS (1 gallon = 4.546 litres)				
SAP YIELD ..	10.89	0.35	127.03	22.27	8,130.10

TABLE III

Overall Summary of Nutrient Ratios and Concentrations in the Sap

RATIO OF MACRONUTRIENTS IN THE SAP

N/P = 4.17	P/N = 0.240	P/K = 0.059	Ca/P = 0.167	Ca/K = 0.010
N/K = 0.246	K/N = 4.06	P/Ca = 6.00	Mg/P = 0.512	Mg/K = 0.030
N/Ca = 25.00	Ca/N = 0.040	P/Mg = 1.95	K/Ca = 101.43	Ca/Mg = 0.326
N/Mg = 8.14	Mg/N = 0.123	K/P = 16.90	K/Mg = 33.02	Mg/Ca = 3.07

1	2	3	4
CONSTITUENT	*CONCENTRATION (G/100 ml.)*	*CONCENTRATION (as % of Dry Matter)*	*CONCENTRATION (as % of Ash)*
POTASSIUM (as K)	0.142	0.77	28.4
NITROGEN (as N)	0.035	0.19	—
PHOSPHORUS (as P)	0.0084	0.045	1.68
MAGNESIUM (as Mg)	0.0043	0.023	0.86
CALCIUM (as Ca)	0.0014	0.008	0.28
CHLORIDE (as Cl)	0.110	0.59	22.0
TOTAL SUGARS	16.0	86.5	—
	MANGANESE IN MICROGRAMMES (1 Microgramme = 0.000001 gm.)		
MANGANESE (as Mn)	51 (per 100 ml.)		0.010

sap is unique in that large volumes over protracted periods can be extracted from the intact plant. There is concrete evidence, that it will prove an ideal diagnostic tool for studies on both macro and micro-nutrients. In the light of the additional knowledge that has accrued from this study, it is felt that the claims that have been made for coconut water as a diagnostic material, would require very careful re-appraisal.

Development of the Coconut

Unlike herbaceous annuals or annually renascent plants, the progressive changes that occur in the coconut palm during ontogenesis are far more complicated and unwiedly for experimental procedure. In view of the problems concomitant with its higher level of organization, it becomes a logical necessity therefore to initiate separate investigations covering distinct phases in the growth cycles of the palm, and also study at any one time only the general ontogeny of the totality of organs of a single type, such as the inflorescence or the leaf. On the other hand, the fact that the development of new leaves, new floral branches, and new fruits takes place at such regular intervals, the coconut palm offers wide scope for studies on nutrient uptake and distribution during its different phases of growth. The fruit itself takes such a long time (12 to 13 months) to mature that it is possible to take samples for chemical analysis at definite predetermined stages in its morphogenesis.

Fifty selected palms, each bearing a full complement of 25 developmental stages, ranging between the rudimentary inflorescence and the cluster of dead ripe nuts (as harvested), were used for the study. Using reliable sampling and analytical procedures, it has been possible to evaluate on the basis of the results obtained, the uptake of nutrients and their distribution during the development of the floral branch and the drupe derived therefrom.

Based on a summation of the overall findings from this study, a tabular summary (Table IV) has been prepared showing macronutrient uptake during the development of the floral branch. It will be seen that the uptake figures (in kilos/acre/annum) are in the following sequential order of decreasing magnitude :—

ASH (108.02), K (16.43), N (15.33), Mg (2.91), P (2.45) and Ca (2.41).

In addition to the evaluation of the above quantitative uptake data, the present development studies have also revealed that the patterns of uptake and distribution are fairly definite, with centres of accumulation for particular nutrients. Any changes in this pattern or shifting of the centres of accumulation would of course be of diagnostic value, provided they could be established on the basis of proper statistical layouts.

On the same lines as for the floral branch, it is proposed to repeat the above study for the gamut of fronds in a healthy palm, covering the range between the most rudimentary frond in the folded cabbage head, and the subtending frond of the ripest cluster of drupes corresponding to stage D XXV. It is proposed to project the study along three lines in order to determine experimentally :—

(*a*) Variations in composition between different parts of the same pinna.

(*b*) Variations in composition of the same sections of the pinnae in different parts of the same frond and

(*c*) Variations in composition between different fronds, as determined by sampling a definite section of a definite pinna from each frond.

The author has observed that there are concentration gradients in the distribution of particular macronutrients — between the fronds, between the pinnae and also within the pinnae. For certain

TABLE IV

Uptake of Macronutrients by the Spadix and Drupes derived therefrom

1	2	3	4		5		6	
CONSTITUENT	*Gamut of Stages DI to DXXV at any one time (Gms.)*	*Tapping Stage DVIII to DXXV, at any one time (Gms.)*	*PER PALM PER YEAR (Grammes)*		*PER ACRE PER YEAR (64 palms) (Kilogrammes)*		*PER PALM PER DAY (Grammes)*	
			(*a*) 12 clusters of DXXV	(*b*) 6 clusters of DXXIV and 6 clusters of DXXV	(*a*) 12 clusters of DXXV per palm	(*b*) 6 clusters of DXXIV and 6 cluster of DXXV per palm	(*a*) DXXV Calculated from 4(*a*)	(*b*) DXXIV and DXXV Calculated from 4(*b*)
MINERAL CONSTITUENTS (ASH) ..	1,425.02	1,380.80	1,756.80	1,687.86	112.44	108.02	4.81	4.62
NITROGEN (as N) ..	187.72	179.06	259.92	239.58	16.63	15.33	0.71	0.66
PHOSPHORUS (as P) ..	28.35	27.10	41.46	38.35	2.65	2.45	0.11	0.10
POTASSIUM (as K) ..	267.85	258.57	284.52	256.68	18.21	16.43	0.78	0.70
CALCIUM (as Ca) ..	46.21	43.88	33.91	37.66	2.17	2.41	0.09	0.10
MAGNESIUM (as Mg) ..	53.36	51.20	42.24	45.53	2.70	2.91	0.12	0.12
DRY MATTER (production)	29,386.0	28,955.5	50,169.6	46,114.2	3,210.85	2,951.31	137.45	126.34

elements these gradients increase in the order of increasing maturity, whereas in others the changes in concentration take place in the reverse direction. It would therefore be essential to determine on the basis of proper experiments the best region or regions that would reflect deficiency or sufficiency nutrient levels, and would accordingly be suited for sampling in diagnostic work. In other words, it would be necessary to determine which parts of the frond or pinnae would be most consistent in composition, where these concentration gradients are minimal and thus most sensitive to reflect any changes in the current nutrient status of the crop.

Germination of the Coconut

For a complete study of germination proper, it is necessary to cover not only that phase which represents its onset but also the subsequent growth and development of the seedling, when it is dependent on the utilization of the main food reserves of the seed, and the eventual establishment of photosynthesis.

The present study has revealed that at the time of nursery planting the coconut possesses a small cylindrical embryo weighing only about 0.109 gramme (wet basis) containing 0.028 gramme dry matter, whilst the weight of the rest of the seednut is of the order of 1053 grammes. On the basis of a carefully planned experiment the present study has been objectively projected in order to determine the uptake and distribution of the macronutrients during the growth, differentiation and development of the coconut embryo during a period of two years. In further elucidation, the main objectives of the study could be elaborated on, as follows :—

(*a*) The dormancy of the coconut embryo and changes associated with its germination from the physiological angle.

(*b*) Determination of the growth pattern of the coconut seedling from its embryonic stage up to the end of two years.

(*c*) Determination of the total uptake of macronutrients considered as a function of time, during each of 16 germination and growth stages G I to G XVI, covering a period of 2 years. [NOTE. In the study on *Development*, 25 preselected stages representing distinct metabolic ages were employed. In the present case however, seedlings were examined at pre-determined time intervals from the time of planting in the nursery].

(*d*) Determination of what proportion of the total nutrients taken up is drawn from the reserves in the seed-nut components and what proportion from the soil medium.

(*e*) Determine the distribution of the macronutrients, and take a complete nutrient inventory of all the structures developed during germination and growth, covering a period of 2 years.

In almost every biological investigation the spectre of excessive *variability* rears its ugly head and often limits the extent to which conclusions can be drawn. Even in genetically uniform material different degrees of induction may take place making the experimental material physiologically inhomogeneous. Further, *reproducibility* which is a factor of paramount importance in most experiments has to be ensured in their layout and in the evaluation of any results therefrom. In contending with these problems the experimentalist has to resort to techniques of pre-selection and control of environment (coupled with statistical elaboration) as aids not only in cutting down the coefficient of variability but also distinguishing between genuine and fortuitous differences in his data. For example, it is known, that the variability between sister plants not only decreases as the environment is better controlled but the variability within a single individual also decreases.

The main germination experiment that has been projected involves quantitative studies employing the drupes themselves at the seedling stage in the ontogeny of the coconut palm. As the drupes are characterised by extreme variability and marked heterogeneity (particularly in size), it has been reckoned important to determine any systematic errors due to size variability of the drupes, so that they could be reduced, excluded or accounted for. The value of this would be particularly evident in the evaluation of the significance of quantitative experimental results between parallel groups of seed material in a trial. In order therefore to ensure experimental precision, effective design and execution of the main germination experiment, certain ancillary studies have had to be conducted in order to determine the size variability of the drupes and the errors of random sampling within the *typica* variety of coconut.

As a consideration of the experimental details of the study on germination would be superfluous in the context of this paper, it is necessary to make only brief mention of some of the significant results that have been obtained.

The study has revealed that the coconut seedling is so adapted that it is only partly dependent on the nutrient reserves in the *drupe components* for its growth activities, during the two year period following the onset of germination. In fact, the bulk of its requirements towards the end of this period are drawn from its medium of growth. Though a reticulum of roots and rootlets characterise the exocarp as the process of germination advances, yet roots have been found to permeate the soil as early as two months from planting. These observations would imply the need for judicious and proper fertilization of the soil during early field culture of coconut seedlings All the same, it must be stated that the fruit components are doubtless an important source of mineral nutrients from which the seedling makes demands throughout a period of 2 years. The study has revealed that *via* the cotyledon (*scutellum*) practically all the nutrients contained in the endosperm and nut water are eventually absorbed by the growing seedling.

The study has revealed that a *typical* seed coconut at the time of planting in the nursery (after a month's withering in the field), would contain about 2.65 gms. N, 0.429 gm. P, 6.16 gms. K, 0.505 gm. Ca and 0.638 gm. Mg. Regarding the gross uptake of the different macronutrients by the growing seedling, the totals during the 16 predetermined stages have been found to appear in the order K —> N —> Mg $\rightleftharpoons$ Ca —> P, so far as relative magnitudes are concerned — which incidentally is precisely the same sequence as that established for the Development study as well.

The experiment has shown that the *endosperm* and then the *husk* are the most important *fruit components* from the point of view of nutrient supply to the young seedling. Whilst certain amounts of all the macronutrients (excepting Ca) are supplied by the former, the husk is an important source of K. It has been observed that the endosperm reserves of almost all the nutrients are utilised fairly completely during the first two year period. The endosperm though a poor source of calcium has been found a particularly rich source of nitrogen. The following experimental data relevant to the endosperm have been found specially interesting:—

NUTRIENT	*Amount/Drupe at stage G I (Gms.)*	*Amount/Drupe at stage G XVI (Gms.)*	*Difference (G I-G XVI) Gms.*	*Difference as % of original amount in G I*
Nitrogen (as N)	1.53	0.208	1.322	86.4
Phosphorus (as P) ..	0.268	0.029	0.239	89.2
Potassium (as K)	0.737	0.016	0.721	97.8
Calcium (as Ca)	0.021	0.014	0.007	33.3
Magnesium (as Mg) ..	0.129	0.032	0.097	75.2
Ash	2.96	0.42	2.54	85.8

The above figures give sufficient factual proof that with the exception of calcium (which in any case is present only in a small amount) very high proportions of the other macronutrients actually present in the endosperm are translocated *via* the cotyledon to the growing seedling. Regarding the liquid endosperm (nut water) — the study has revealed that it completely disappears at stage G VIII (5.5 months after planting). In other words, it would be plausible to infer that the nutrients contained therein are also fully absorbed as the liquid soaks up and passes into the spongy cotyledon.

Though a discussion of the full results is not warranted in this paper, it may be said that it has been possible to evaluate from this germination study, the progressive changes and uptake inter-relationships between the drupe components, seedling components and the soil medium. Further, it has been possible to obtain a thorough elucidation of the pattern of nutrient distribution in the different seedling components (including laminae and rachids according to leaf rank) during physiological ontogeny. For the present purpose, the most significant fact that has emerged from this study is the importance of adequately fertilizing the seed beds with calcium and magnesium during nursery culture of coconut seedlings.

Pot Culture Experiments on Coconut

The sand culture experiments on coconut seedlings that are in progress constitute a major project, and the results that are being obtained could very well form the subject of a series of publications.

In the context of seedling culture however, a very interesting point needs mention. When the current studies on the seedling phase of the coconut are completed there is in the writer's opinion the very definite possibility that the coconut seedling itself could be used as a biological indicator of nutrient status and nutrient availability in coconut soils.

From the results of the germination experiment which we have considered, it is not an unlikely inference that sand pot culture studies on coconut seedlings would serve no useful purpose. We have seen that the seed nut components actually contain fair reserves of almost all the macronutrients with the exception of perhaps the element calcium. Further, it has been established that the germinating embryo is partly dependent on these reserves throughout a two year period until it is weaned. This would imply that sand pot culture studies would involve interpretive difficulties consequent on the fact that responses to any specific treatments would be complicated by absorption and translocation changes between the seedling and the seed-nut reserves.

In order to surmount the problem created by seed-nut reserves the author has evolved an 'amputation technique' whereby it has become possible to grow the sprouts alone in sand culture after removal of the entire exocarp and 'stone' by excision. In fact, the success of this technique has facilitated replicated experimental layouts utilising a large number of sprouts.

Pot Culture experiments on the seedling coconut, along the lines that have been developed by the author have not been recorded before, and they have provided a distinct contribution towards advancing knowledge on the nutritional deficiency aspects of the coconut during early phases of its ontogeny.

These experiments have yielded very valuable information of diagnostic value both from the point of view of (*a*) the internal chemical status and (*b*) visual effects associated with absolute deficiencies of each of the macronutrients. A proper discussion of the former aspect would have to await the processing of the prodigious volume of plant analyses data that have been accumulated. As regards the visual aspects — on the basis of the results that have been consolidated, the author is now in a position to set out positively the following visual symptoms and morphological effects as characterising the following deficiencies :—

Minus Nitrogen.—Very pronounced restriction in growth of both tops and roots takes place, and highly significant retardation both in height and girth is a characteristic at the close of one year. Reduction in the number of leaves is also significant. Leaves small and remain webbed (i.e. without pinnating) much longer than in other treatments. Younger leaves a diffuse pale yellowish green in colour, the yellow tint becoming more pronounced in the older leaves. Petioles yellow green to canary yellow. Drying and defoliation of the old leaves premature. The stunted spindly growth and lack of succulence of the plant coupled with the visual symptoms make identification easy.

Minus Phosphorus.—Significant restriction in growth becomes evident much later than with nitrogen deficiency. Retardation in root development also not so pronounced as with a deficiency of nitrogen. Though plant is stunted in growth, it remains darker green in colour than those in the complete culture. In the early stage the plants were not distinctly different from those in the (+ ALL) pot, but after six months growth, shorter petioles and rosetting of leaves was a characteristic. Phosphate deficient plants were found to be more susceptible to attack by *Helminthosporium*. Leaflets remained dark green throughout and hardly turned yellow before drying. It should be noted that unlike some other crops the symptoms are quite distinct from nitrogen deficiency.

Minus Potassium.—Quite contrary to what is generally believed and accepted, a remarkable fact has been established regarding K deficiency. On the basis of consistent results and repeated confirmations obtained in the giant experimental pots as well as in Mitscherlich vessels (on both *nana* and *typica* varieties) it can be categorically stated that during the *first year* of growth an absolute deficiency of K produces no retardation in growth or any visual symptoms. Except for the girth factor during certain stages, all seedlings have appeared at least deceptively healthy with perfectly normal development of both shoot and roots. In fact, in one instance amputated seedlings in the (—K) treatment were found to be definitely better than the (+ ALL). There is of course no doubt that K is a dominant requirement in the later growth stages. At what precise stage, K actually assumes importance could very well form the subject of future study.

Minus Calcium.—Significant retardation in growth takes place, and as far as the aerial parts are concerned, a somewhat imperceptible transformation gradually takes place in the seedlings whereby they assume a slender form with a sparse appearance of leaves. Slight distortion of the young leaves, with tips hooking back, has also been sometimes noticed. The outstanding symptom of calcium deficiency which the present experiments have revealed, is the significant retardation of root development, characterised by a proliferation of short roots — a symptom not shown by any of the other deficiencies.

Minus Magnesium.—For the first time on record, and much against current beliefs, the most spectacular results (with marked foliage symptoms) have been obtained with magnesium deficiency. Except for leaf number, the seedlings suffer highly significant retardation.

The seedlings make anarchic growth and the leaves tend to become tattered. Some of the younger leaves emerge with difficulty and before they are fully exserted, the distal end of succeeding ones may pinnate into leaflets. A characteristic inter-vascular yellowing of an ochreous to chrome yellow tint (quite distinct from the minus N symptom) commences initially with the older leaves, and proceeds systematically towards the younger ones. Mosaic blotches and brown spots symptomatic of chlorotic effects appear in the older leaves as the deficiency becomes more acute. Root development is not severely retarded as with minus N deficiency. Bronzing followed by defoliation is sometimes severe. Mg deficiency is so very conspicuous that it could easily be picked out from the rest of the plants even from a distance.

It is usual to attribute yellowing of seedlings during nursery culture to K deficiency. The present study has conclusively demonstrated that this is not so. Yellowing (at the transplantation stage) could result only from nitrogen and/or magnesium deficiency. The visual effects and concomitant symptoms of these two deficiencies however, are so unmistakably different from each other, that there could be no possible confusion over their identification.

CONCLUSION

During the last few decades, a great deal of work has been directed exclusively towards the application of chemical plant analyses as a means of diagnosing the nutrient requirements of plants and soils[21]. There is in fact overwhelming evidence, that diagnostic techniques using the plant have been widely and successfully applied to a whole range of crop plants. A survey of the literature however, reveals that as far as *Coconut* is concerned any available records are purely of an empirically descriptive nature. In fact, it would be a legitimate inference that there has been no systematic approach from the plant angle in the past, for the evaluation of the nutrient requirements of the coconut palm.

Unlike other crops where the integrated unity of the whole plant could be treated as an organism, the coconut palm owing to its morphological features and higher level of organization is no doubt unwieldy for experimental procedure. In spite of these handicaps, the writer has taken the view that the palm has certain unique features and offers unlimited scope for the application of 'plant diagnostic techniques', provided separate investigations covering distinct phases in the growth cycles of the palm could be planned and executed.

The sap of the coconut palm nourishes the inflorescence, and this inflorescence through a process of elaborate development eventually produces the ripe fruit. This ripe fruit contains the germ or embryo, which germinates to produce the young plant or coconut seedling. The growth and reactions of this seedling from infancy to senescence cover many phases, which are all interlocked with factors associated with the general environment.

Starting with the sap — followed by the floral branch, and then the young seedling, an endeavour has been made by the author to study as systematically and intensively as possible how the fundamental aspects of uptake and distribution of the macronutrients characterise the development of the drupe, and thereafter the seedling which is produced from the embryo by a process of germination.

The lack of a sound plant technique suitable for the nutritional diagnosis of a unique crop like the coconut is no doubt a lacuna which needs filling. It is maintained that some preliminary fundamental knowledge pertinent to this subject has been gained from the author's studies, but this could only be regarded as touching the fringe of the ultimate objective, where the nutrition and fertilizer requirements of the adult palm itself in its productive phase, have to be assessed.

The field is fertile and the scope is indeed wide. With the knowledge gained and the techniques that have been evolved, it is proposed to pursue the studies and develop the work along the lines that have been adumbrated in this paper, until every phase in the ontogenesis of the palm is covered.

It is to be hoped that the position would be reached during the next decade or so, when the technique of Diagnostic Plant Analysis (including Foliar Diagnosis) could be applied (in a complementary role to soil techniques) to the coconut palm, not only for the assessment of faulty mineral nutrition, but also as a reliable guide to optimum fertilization during different phases of its growth and reproduction.

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