Soil analysis and its relationship with leaf analysis and banana yield with special reference to a study at Carnarvon, Western Australia.

D.W. TURNER, C. KORAWIS and A.D. ROBSON*

SOIL ANALYSIS AND ITS RELATIONSHIP WITH LEAF ANALYSIS AND BANANA YIELD WITH SPECIAL REFERENCE TO A STUDY AT CARNARVON (WESTERN AUSTRALIA).

D.W. TURNER, C. KORAWIS and A.D. ROBSON.

Fruits, Apr. 1989, vol. 44, n° 4, p. 193-203.

ABSTRACT - The place of soil analysis in managing the fertilizer inputs to banana plantations has been reduced by the emphasis placed on leaf analysis. Here we review the way in which soil analysis has been used in various locations throughout the world to assist in the detection of nutrient imbalance in banana plantations. A number of indices and critical concentrations have been proposed and we examine the possibility of these having wide application.

A survey of 58 plantations at Carnarvon, Western Australia, gathered data on soil analysis, leaf analysis and yields. Yield varied from 14 to 80 t ha^{-1} y^{-1}. Associations between soil and leaf analysis and yield were explored and the data interpreted using the indices and critical concentrations established in the literature. These expressions of soil nutrient availability were not appropriate to the soils of Carnarvon, W.A. We think this is because the different indices have been established empirically and have been shown to be associated with a particular response, - nutrient uptake, yield or the occurrence of deficiency symptoms.

The concentration of nutrient at the root surface is only one of several factors influencing nutrient absorption in the field. Other factors are root length and the amount of growth being made. There is a need to explore the interpretation of soil analysis in the light of these factors.

L'ANALYSE DE SOL ET SES RELATIONS AVEC L'ANALYSE FOLIAIRE ET LES RENDEMENTS CHEZ LE BANANIER AVEC REFERENCE PARTICULIERE A UNE ETUDE FAITE A CARNARVON (AUSTRALIE DE L'OUEST).

D.W. TURNER, C. KORAWIS et A.D. ROBSON.

Fruits, Apr. 1989, vol. 44, n° 4, p. 193-203.

RESUME - La place de l'analyse de sol dans la programmation de la fertilisation du bananier s'est trouvée réduite par l'accent mis sur l'analyse foliaire. On examine la façon d'utiliser, en situations variées, l'analyse de sol pour déceler des déséquilibres nutritionnels en bananeraies ; on étudie la possibilité d'appliquer valeur de références et concentrations critiques ainsi proposées.

Pour 58 plantations de Carnarvon ont été regroupées des données : sol, feuilles et rendement (14 à 80 t/ha/an) ; les relations entre les trois sont explorées et les données interprétées d'après les valeurs critiques indiquées dans la littérature ; ces dernières, dans l'expression en éléments du sol utilisables ne conviennent pas à Carnarvon car établies empiriquement et associées au rendement où à l'apparition de symptômes de carence.

La concentration d'éléments à la surface racinaire n'est pas le seul facteur déterminant leur absorption ; longueur de racines et importance de la croissance interviennent aussi et on doit interpréter l'analyse de sol à la lumière de ces facteurs.

INTRODUCTION

Fertilizer requirements for annual field crops are usually estimated from yield response curves obtained in series of field experiments. Soil analysis is seen as a way improving the accuracy of estimating fertilizer requirements as it allows for differences between various soil types and the variation from one paddock to another on an individual farm (COLWELL, 1983). But not all opinions about soil analysis have been favourable.

SMITH (1977) thought that while soil analysis may provide a move accurate indication of fertilizer requirements than an average rate, it might not be as useful as an adviser who can integrate all factors affecting yield using personal and local knowledge.

In bananas emphasis has been placed on plant analysis, rather than soil analysis, for diagnosing nutritional imbalances and in their publication on banana nutrition, LAHAV and TURNER (1983) devoted a whole section to plant analysis but soil analysis didn't rate a separate section.

* - D.W. TURNER and A.D. ROBSON - School of Agriculture - University of Western Australia - Nedlands - W.A. 6009 - Australia
C. KORAWIS - Surat Horticultural Research Centre - Surat Thani - Thailand.

APPROACHES TO SOIL ANALYSIS

Its use in perennial crops.

CHAPMAN (1966) pointed out that plant analysis were more useful than soil analyses for perennial crops for predicting nutrient deficiencies. This is because the availability of many soil nutrients may be altered by seasonal conditions after the soil has been analysed ; the relationship between soil nutrient supply and yield can be changed by seasonal conditions ; there may be large amounts of nutrients available to plants in the root zone beyond the sampled depth ; and the soil cores may not be representative of the whole area or of the various root zones.

Not all of these are good reasons for rejecting soil analysis since the usefulness of soil analysis, like plant analysis, depends on the establishment of a relationship between nutrient concentrations in soils and a particular response by the plant to the added nutrient.

Determining 'critical' concentrations.

Where soil analysis has been used to estimate fertilizer needs in banana growing one approach has been to assess the nutrient status of the soil before planting (STOVER and SIMMONDS, 1987). This assumes that information on 'critical' concentrations of nutrients is available, but few attempts have been made to determine them experimentally.

WALMSLEY *et al.,* (1971) explored a range of methods for assessing the concentrations of N, P and K in the top 18 cm of soil and compared the values with the response of 'Robusta' banana to N, P and K on 32 sites in the Windward Is. While N was deficient at many sites soil analyses were unable to predict a response. P and K were also deficient and soil analyses were able to predict a response to added fertilizer with a 94% success rate for P and 81% success rate for K. The 'critical' values were 40 ppm P (modified Borndorf method) and 0.40 me/100 g exchangeable K (cold H_2SO_4 or exchangeable K).

A broad association between soil nutrient concentrations and plant response has been established for particular locations and varieties, often based on surveys and limited experimentation (PRICE, unpublished). Where deficiency symptoms are recognized in the field the soil nutrient concentrations associated with these are taken as the low end of the spectrum, that is, a response to added fertilizer is expected. Similarly the concentrations of nutrients in the soils of high yielding plantations can be measured. Over time a picture can be put together which allows an assessment of the nutrient supplying capabilities of the soil, at least in a crude way.

LAHAV and TURNER (1983) brought together data from a number of studies to show associations between K and Mg uptake and K and Mg concentrations in the soil. While the asymptotic form of the relationships were evident there were considerable differences in the curves depending on variety and environment (Figs. 1 and 2). Nonetheless it is possible to estimate soil nutrient concentrations above which large amounts of nutrient are not absorbed. These

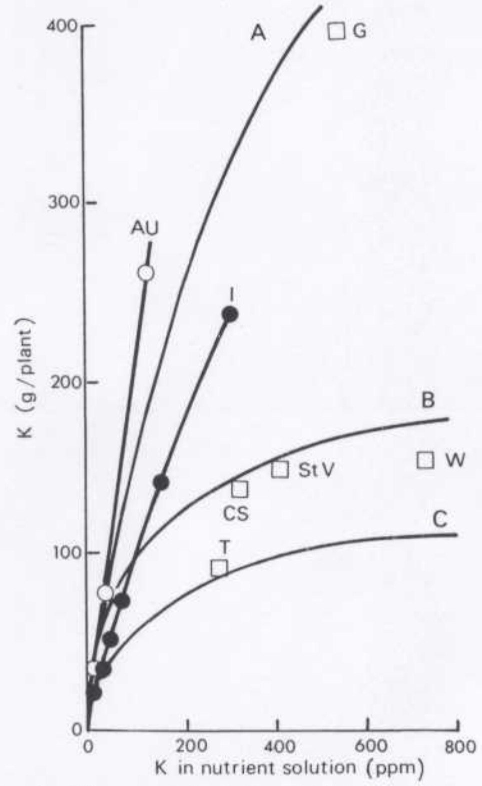

Figure 1 - The expected relationship between K concentration in solution around the roots and total K uptake at fruit maturity. A - normal uptake. B and C - limitations in K uptake. Data from sand culture experiments in Israel (•) and Australia (o) and from field studies in the Windward Islands (□). T - Trinidad ; CS - Cul de Sac, St. Lucia ; W - Winban, St Lucia ; StV - St Vincent ; G - Grenada. (LAHAV and TURNER, 1983).

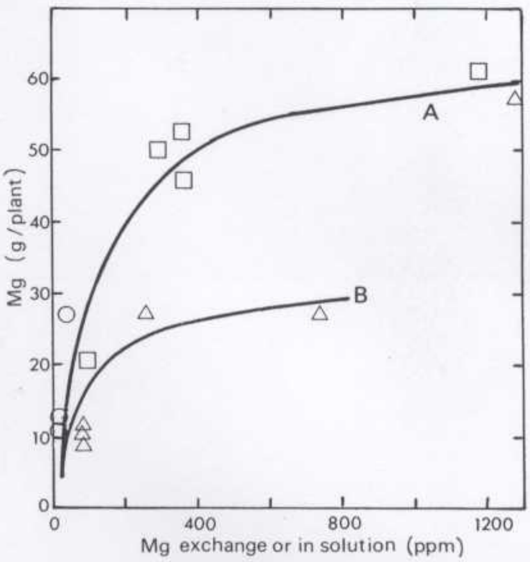

Figure 2 - Whole plant Mg uptake in relation to exchangeable Mg in the soil or in solution. A - normal uptake, B - limitations in Mg uptake. Data from field studies in the Antilles (△), Windward Islands (□) and from sand culture in Australia (o). (LAHAV and TURNER, 1983).

turn out to be about 1.4 me/100 g for exchangeable K and 5.0 me/100 g for exchangeable Mg. This is considerably higher than the 0.4 me/100 g for K estimated as being critical by WALMSLEY *et al.* (1971). However, here we are dealing with the association between nutrient concentration in the soil and nutrient uptake. This may be different to nutrient supply and the response of yield to added nutrient as measured by WALMSLEY *et al.* (1971).

The concept of nutrient balance.

If 1.4 me/100 g K and 5 me/100 g Mg represent 'optimum' values for nutrient uptake and if the optimum proportion of Ca in the sum of exchangeable K, Ca and Mg is 0.7, for maximum Ca absorption (LAHAV and TURNER, 1983), then a Ca concentration of 15.0 me/100 g is required to optimise Ca absorption. This combination gives a Mg/K ratio of 3.6, very close to the 3.3 of 'balanced' soils described by STOVER and SIMMONDS (1987) but much less than the value of 8-15 considered 'normal' for soils in Costa Rica (LOPEZ, 1983). The estimates of 15 me Ca, 5 me Mg and 1.4 me K are based on maximum nutrient absorption. Whether this coincides with maximum yield is not known as the amount of K and Mg in banana plants is not strongly associated with the amount of dry matter accumulated (LAHAV and TURNER, 1983). However a satisfactory uptake of nutrients should mean that these are not limiting growth and yield.

Attention has been drawn to the need to maintain a satisfactory balance between K, Ca and Mg on the soil cation exchange complex for optimum growth and yield. TURNER and BULL (1970) used the ratio of (Ca + Mg)/K to distinguish between bananas which were either deficient in K or Mg or were healthy on the podzolic and krasnozem soils of Northern NSW. Attempts to use the K/Na ratio in soils of the Canary Is. were made by GARCIA *et al.* (1979) to determine the effect of the imbalance of these two elements on growth. LAHAV and TURNER (1983) reinterpreted their data and showed that the variation in the growth of the plants (as measured by pseudostem circumference) was more closely associated with the organic matter content of the soil (the cation exchange capacity ?) and the proportion of K in the sum of the exchangeable cations. These differences in interpretation should not concern us greatly if we remember that we are searching for empirical associations between measured soil characteristics and growth, yield or nutrient uptake. If relationships can be established which appear to be widely applicable across varieties and edaphic environments then we should use them and explore their physiological basis. Until these are found we are likely to use locally based relationships which are useful in guiding fertilizer practice.

SOIL ANALYSIS AND FERTILIZER MANAGEMENT

The use of soil analysis as a diagnostic tool in managing fertilizer application in intensive banana production in West Indies has been described by GODEFROY and DORMOY (1984). This system is based on research which showed the variable nature of nutrient availability in the soil throughout the season (GODEFROY and LOSSOIS, 1966) and the importance of cation exchange capacity in providing a buffering for nutrient supply in the soil. In intensive banana production, large amounts of nutrients are incorporated into the crop (400 kg N ha^{-1} and 1000 kg K ha^{-1}) annually and up to half of this may be removed in the fruit of a high yielding crop. Intensive banana production therefore places a considerable demand on the soil for nutrients.

Experience has shown that even when large amounts of nutrient are supplied, high production is not necessarily sustained and GODEFROY *et al.* (1975) identified leaching as a major source of nutrient loss, especially on soils with a low cation exchange capacity (5-10 me/100 g). The quantities of nutrients lost in drainage and runoff were 260 kg Ca, 90 kg Mg, 380 kg K and 2.2 kg P ha^{-1} yr^{-1} (GODEFROY *et al.*, 1975). In West Indies GODEFROY and DORMOY (1984) describe the use of soil analysis to establish an appropriate fertilizer regime for five soil and climatic zones. Fertilizer regimes are then adjusted as the chemical nature of the soil changes during the years of banana production.

Features of soils under intensive banana production identified by GODEFROY and DORMOY (1984) as being significant are the different behaviour of the different elements (N, P, K, Ca, Mg) throughout the season in the same soil. It may be necessary to apply N 10-12 times annually but P can be applied to the same soil only once each year. The dynamics of the one element may differ greatly from one soil to another. For example on some soils the concentration of K is strongly tied to rainfall as a good deal is leached. On other soils the K is fixed on the adsorbing complex and little is lost by deep percolation. The chemical characteristics of a soil are strongly influenced by fertilization at high rates, especially if fertilizer applications are localized in relation to the plant. This needs to be borne in mind when sampling for soil analysis. Different fertilizers influence the behaviour of other elements. For example calcium and magnesium behave differently depending on the amount of nitrogen applied. In the absence of added N leaching losses of Ca and Mg are low but they are high if large amounts of N are applied.

These features point strongly to the need to understand the amount of nutrient supplied to the roots by the soil. Leaf analysis, useful though it might be, cannot provide these insights. Variations in the concentration in the soil are not necessarily reflected immediately in the plant although the chemical composition of the leaf is strongly associated with the nutrient concentration around the roots during its growth, but the relationship is modified by growing conditions (TURNER and BARKUS, 1980 a).

MESSING (1974) was also concerned about long term changes to concentrations of nutrients in the soils of the Windward Is., especially Ca and Mg. He pointed out that experience in Australia showed that it was not easy to correct magnesium deficiency, for example, when it had developed after decades of banana production without the addition of magnesium (CHALKER and TURNER, 1969 ; TURNER and BULL, 1970). He warned that a similar situation could arise in the Windward Is.

The management of soils which support banana production in West Indies is based on seven soil characteristics

(GODEFROY, 1982). The exchangeable Ca, Mg and K, the ratio of Mg/K, the cation exchange capacity, pH, and phosphorus. Each of these is grouped into six classes: very low, low, limiting, average, high, very high ; and fertilizer added accordingly. Usually each two years adjustments are made to the fertilizer program, based on contemporary soil analyses.

SOME PROBLEMS WITH SOIL ANALYSIS IN BANANAS

Here we focus on analysis of potassium because of its importance in banana nutrition. TWYFORD (1967) thought that a 'critical' concentration of exchangeable K in the soils of the Windward Is. was 0.45 me/100g. WALMSLEY *et al.* (1971), presumably based on the same set of experiments on which TWYFORD made his observation, nominated 0.4 me/100 g as 'critical'. In NSW TURNER (unpublished) recorded K deficiency on soils with exchangeable K as high as 1-1.2 me/100 g but this was associated with very high amounts of exchangeable Ca and Mg. TURNER and BULL (1970) used the ratio (Ca + Mg)/K to distinguish bananas which were deficient in K from those which were healthy although the ratio was much better at separating Mg deficient plants from healthy ones. If the ratio was greater than 60 then K deficiency symptoms were always observed. In the range 25-60 the plants could be healthy or deficient and from 10-25 the plants were always healthy.

The experiment in Hawaii reported by WARNER *et al.* (1974), and WARNER and FOX (1976 , 1977) was conducted on a soil which had high exchangeable Ca and Mg values and the two groups of plots which they used had 0.3 and 0.8 me/100 g of exchangeable K. The (Ca + Mg)/K ratio was 174 and 58 respectively and on the basis of TURNER and BULL'S (1970) observations would have both been deficient in K, the plot with 0.3 me/100 g extremely so. Using the data of WALMSLEY and TWYFORD (1973) the 0.3 me/100 g plot would also be expected to be deficient in K. WARNER *et al.* (1974) stated that yield on either plot was not improved by the addition of K fertilizer. However they thought that the growth was somewhat less on the control plants of both plots and on the basis of an adsorption isotherm they thought that 0.1 me K/l was approximately adequate for bananas. This was associated with 0.8 me/100 g exchangeable K.

The yields recorded in the experiment of WARNER *et al.* (1974) were very high (50 to 90 t ha^{-1} yr^{-1}), much greater than those of similar experiments in other countries (10 to 50 t $ha^{-1} yr^{-1}$). We think the main reason for this is the high plant densities used by WARNER *et al.* (1974) - about 2900 plants ha^{-1}. At densities similar to this commercial yields of 80 t ha^{-1} are obtained at Carnarvon WA (KORAWIS, 1986). At lower densities lesser yields are obtained (ROBINSON and NEL, 1986).

Such high yields would place a considerable demand for K on the soil, and so it is surprising that WARNER *et al.* (1974) and WARNER and FOX (1976, 1977) did not observe a yield response to K supply. They thought that the roots were able to obtain K from deeper in the subsoil, certainly beyond the depths of the samples taken but no data were available to support this hypothesis.

POTASSIUM QUANTITY/INTENSITY RELATIONSHIPS

There is a need to explore the ability of soils to supply K to banana roots beyond the traditional measurement of exchangeable potassium. FERNANDEZ-CALDAS and BORGES PEREZ (1971) attempted this when they assessed the potassium reserves of soils in the Canary Is. which have supported banana growing for many years. They found that soils with from 3.1 to 9.5 me/100 g exchangeable K had reserves which were not always proportional to the value of exchangeable K. MENGEL (1982) points out that the amount of 'available K' in the soil, as measured by exchangeable K, may be 3-5 times greater than that absorbed by the crop. He considers this is because the movement of K from the soil to the plant roots is limiting. K moves to plant roots by diffusion which is dependent on soil water content. The other factors which influence movement to roots are the concentration of K in solution and the buffering capacity of the soil. These factors contribute to the mean concentration of K at the root surface (c).

Following DREW *et al.* (1969), other components of uptake will be root length density (L_T), root radius (r), the efficiency of transfer of nutrient across the root surface (μ) and the duration of the absorption period (t). Then uptake (U) may be expressed as

$$U = L_T \, 2 \pi r \mu c t \qquad 1.$$

If c is low [suspected as being so in WARNER *et al.* (1974) experiment] then uptake U, can be maintained by increasing root length density L_T. With high plant densities was this the reason for the lack of response to K observed by WARNER *et al.* (1974) ? μ is reasonably constant over a range of K supply in banana (TURNER and BARKUS, 1981) and the growth of roots is less influenced by low K supply than tops (TURNER and BARKUS, 1980 b). So it is possible that this may be the reason sufficient K was absorbed even though soil supply appeared low.

The data brought together by MENGEL (1982) highlight the importance of K buffering capacity as a factor influencing c. Buffering capacity b, is defined as

$$b = \frac{\Delta K \text{ (Quantity)}}{\Delta K \text{ (Intensity)}} \qquad 2.$$

Exchangeable K is taken as a measure of Δ(Quantity) and the intensity term is the equilibrated K concentration in the soil solution. Differing buffering capacities have been demonstrated as influencing K supply to bananas (FERNANDEZ-CALDAS and BORGES PEREZ, 1971 ; WARNER *et al.*, 1974) but these measurements are not used routinely in assessing the availability of K to the plant.

Adsorption curves, which enable buffering capacities to be determined, give reasonable estimates of nutrient requirements for crop production if concentrations required in solution by the crop are known. First approximations can come from sand or solution culture (FOX and KANG, 1977).

The components of equation 1 show that c is only one factor influencing plant uptake and L_T may be equally important. Factors which influence it will be planting density and the pressure of root predators and diseases (nematodes, fungi).

THE RELATIONSHIP BETWEEN NUTRIENT CONCENTRATIONS IN SOILS, LEAVES AND CROP YIELD.

Survey of plantations at Carnarvon WA.

To explore the relationships between soil analysis, leaf analysis and yield we chose the banana industry at Carnarvon WA, where good records of yields were available for many plantations. Carnarvon is located at 25°S on the west coast of Australia. The banana plantations are on the banks of the Gascoyne River and grow in an alluvial silty loam (Fig. 3). The average rainfall is 233 mm which is irregularly distributed throughout the year. Banana plantations are irrigated weekly or more often by furrow or low level sprinklers using water pumped from aquifers in the sands of the Gascoyne River. Maximum temperatures average 36°C in the summer months and minimum temperatures average 10°C in the winter. The relative humidity at 0900 hrs is 40-45% throughout the year. The better plantations regularly produce 80 t fresh fruit $ha^{-1}\,yr^{-1}$.

In May 1984, 58 plantations were surveyed out of a total of 136 (Fig. 3). At each site a 10 cm section from the centre of both lamina halves of the third youngest fully expanded leaf of 10 plants was taken. Fifteen soil cores of 20 cm depth were mixed and subsampled. Details of chemical analyses are described by KORAWIS (1986). Yields were the average of the previous 5 years, expressed as t ha^{-1} yr^{-1}.

Results.

• Symptoms.

On most plantations the youngest leaves contained alternating chlorotic and green bands parallel to the veins in the lamina. These were consistent with mild zinc deficiency. Symptoms of severe deficiency (small leaves and stunted plants) were not observed.

• Leaf analyses.

Nutrient concentrations in the dry matter of the third youngest leaves of vegetative plants were mostly above the tentative critical concentrations set by LAHAV and TURNER (1983) except for Zn (Fig. 4). These low concentrations are consistent with the widespread occurrence of mild zinc deficiency symptoms. The proportion of plantations with zinc concentrations in leaves below the critical concentration was 95%. Copper was low in 26% of plantations and potassium was low in 9%.

• Soil analyses.

The plantations has a mean pH of 7.0 with a range from 4.7 to 8.7. The organic carbon content was 0.6 ± 0.029 %, electrical conductivity was 0.2 ± 0.01 mS cm^{-1} and the mean cation exchange capacity was 14.1 ± 0.6

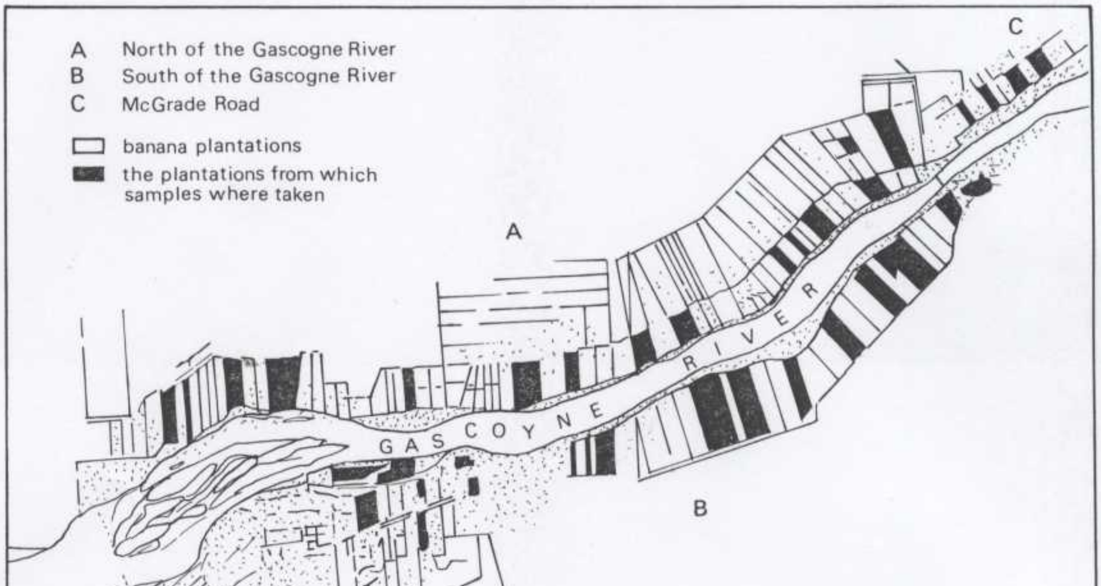

Figure 3 - Location of banana plantations where leaf and soil samples were taken for a survey of the nutritional status of bananas at Carnarvon, Western Australia (From KORAWIS, 1986).

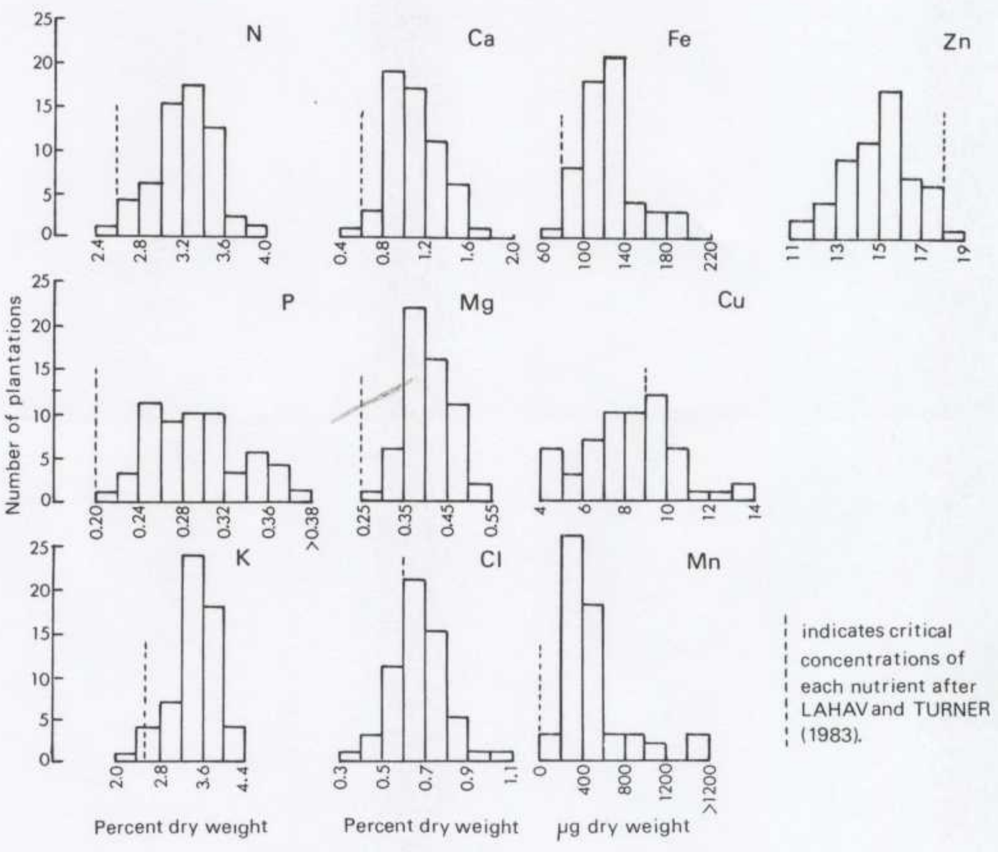

Figure 4 - Frequency distribution of each plant nutrient concentration in leaf samples taken from 58 banana plantations at Carnarvon, Western Australia (KORAWIS, 1986).

me/100 g. The mean concentrations of the main cations were 0.39 ± 0.02 me/100 g for K, 10.7 ± 0.4 me/100 g for Ca and 2.4 ± 0.1 me/100 g for Mg.

Soil pH was significantly ($P = 0.01$) associated with the concentrations of all extractable soil macro and micro-nutrients except for potassium and zinc (Table 1). The strongest association was with bicarbonate extractable phosphorus ($r = -0.81$). The coefficients of variation varied among the nutrients from 27% for Ca and 78% for Fe (Table 2).

• Relationships between soil and plant measurements.

The associations between nutrient concentrations in leaves and soil properties were generally weak. Strong negative associations were found between manganese concentration in the leaves and soil pH ($r = -0.55$, $P = 0.01$). Negative associations were also observed between the concentration of Fe, Cu, Mn, Zn and P in leaf dry matter and soil pH.

We explored the relationship between nutrient concentrations in leaves and the ratios of soil nutrients which other workers have found associated with healthy or deficient plants (Mg/K, (Ca + Mg)/K, Ca/(K + Ca + Mg). Most plantations had Mg/K ratios above the value of 3.3 regarded as optimum by STOVER and SIMMONDS (1987) (Fig. 5). The (Ca + Mg)/K ratio of many plantations fell above 30, a range where K deficiency was possible, based on the relationships established by TURNER and BULL (1970). All plantations were above the optimum Ca/(K + Ca + Mg) ratio of 0.7 for Ca absorption (LAHAV and TURNER, 1983). On the basis of these observations and the fact that over half of the plantations had exchangeable K contents less that 0.4 me/100 g, K deficiency could be expected to be widespread.

Leaf analysis data combined with the absence of symptoms of K deficiency at a time of the year when they could be expected to be present (TURNER and BULL, 1970) support the idea that K was adequately supplied to the plants (Fig. 6, a, b and c).

The Ca/(K + Ca + Mg) ratio was not associated with the concentration of Ca in the dry matter of the leaves (Fig. 7).

• Plant composition and yield.

Variation in yield (14.7 to 67.0 t $ha^{-1} yr^{-1}$) was not associated with any soil property except pH. Increasing pH decreased yield (Fig. 8). Average yields of the plantations which had Cu and Zn concentrations in leaves lower than

TABLE 1 - Correlation matrix for soil properties and extractable soil nutrients. Samples were taken from 58 banana plantations at Carnarvon, Western Australia, (From KORAWIS, 1986).

	pH	Organic carbon (%)	Ec	C.E.C.
pH	1.00			
Organic carbon (%)	0.42**	1.00		
Ec 10^{-3}	-0.18	0.37*	1.00	
C.E.C.	0.38*	0.59**	0.36*	1.00
Mineral N	-0.32*	0.18	0.68**	0.10
$NaHCO_3$ extractable P	-0.81**	-0.10	0.39*	-0.16
Exchangeable K	0.23	0.25	0.20	0.21
Exchangeable Ca	0.65**	0.76**	0.26*	0.75**
Exchangeable Mg	0.62**	0.70**	0.20	0.64**
DTPA Fe	-0.76**	0.03	0.32*	-0.10
DTPA Cu	-0.65**	-0.03	0.41**	-0.12
DTPA Mn	0.56**	0.74**	0.14	0.63**
DTPA Zn	-0.22	0.12	0.23	-0.19
Total Cl	0.36*	0.33*	0.23	0.26*
Exchangeable Na	0.40**	0.56**	0.39**	0.62**

* - Significant at the 5% level of probability
** - Significant at the 1% level of probability
Ec : electrical conductivity (mS cm^{-1})
C.E.C. : cation exchange capacity (me 100 g^{-1} soil)

TABLE 2 - Means and ranges, standard errors, and coefficients of variation of extractable soil nutrient concentrations of soil samples taken from 58 banana plantations at Carnarvon, Western Australia (From KORAWIS, 1986).

Extracted soil nutrient concentrations		Mean and range	S.E.	C.V. %
Mineral	N $\mu g\ g^{-1}$	23.3 (13-85)	1.78	58
$NaHCO_3$ extractable	P $\mu g\ g^{-1}$	91.7 (34-325)	6.59	55
Exchangeable	K $\mu g\ g^{-1}$	153 (64-251)	7.38	37
Exchangeable	Ca $\mu g\ g^{-1}$	2140 (1125-4003)	77.0	27
Exchangeable	Mg $\mu g\ g^{-1}$	284 (120-599)	13.7	36
DTPA extractable	Fe $\mu g\ g^{-1}$	56 (16-200)	5.77	78
DTPA extractable	Cu $\mu g\ g^{-1}$	4.5 (1.2-13.5)	0.34	58
DTPA extractable	Mn $\mu g\ g^{-1}$	48 (51-307)	6.80	35
DTPA extractable	Zn $\mu g\ g^{-1}$	7.9 (2.2-21.7)	0.54	51
Total	Cl $\mu g\ g^{-1}$	34 (18-70)	1.35	30
Exchangeable	Na $\mu g\ g^{-1}$	128 (56-309)	7.40	44

Mineral N, bicarbonate extractable P, and total Cl were determined at the laboratories of CSBP, Western Australia.

the critical concentration were lower than those of the plantations which had the concentrations of these two nutrients in leaves higher than the critical concentration (Table 3). This was not true for those plantations which had concentrations of K in leaves less that the critical concentration. The concentration of Fe in the leaves of only one plantation was less than the critical value and its yield was 14 t ha^{-1} compared to 40 t ha^{-1} for the others.

DISCUSSION

While critical nutrient concentrations in leaves are tentative (LAHAV and TURNER, 1983) and those for soil have not been widely established for many elements, the use of the survey technique in identifying nutrient problems is well demonstrated by these data. Its strength lies in comparisons with yields.

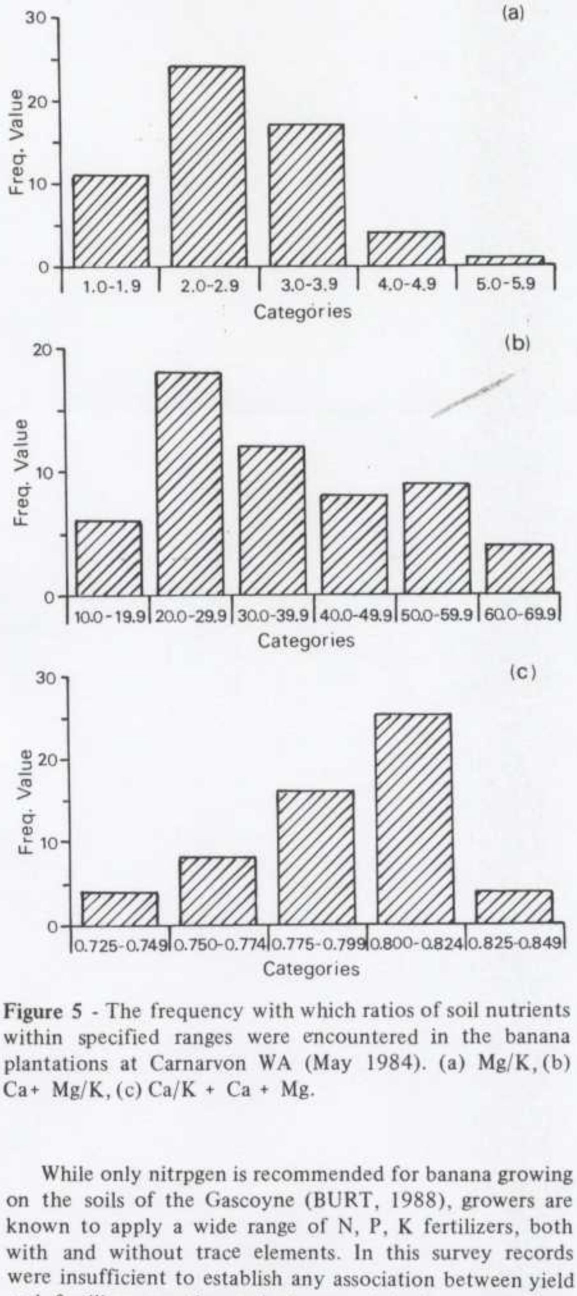

Figure 5 - The frequency with which ratios of soil nutrients within specified ranges were encountered in the banana plantations at Carnarvon WA (May 1984). (a) Mg/K, (b) Ca+ Mg/K, (c) Ca/K + Ca + Mg.

While only nitrpgen is recommended for banana growing on the soils of the Gascoyne (BURT, 1988), growers are known to apply a wide range of N, P, K fertilizers, both with and without trace elements. In this survey records were insufficient to establish any association between yield and fertilizer practice or between nutrient concentrations in the leaves and fertilizer applied.

Zinc deficiency has been identified as the major problem of nutrition in the Carnarvon area. Copper and iron should also be examined in future work. Even though zinc was deficient, an association between soil and leaf concentrations was not established. However the association between soil pH and yield may operate through the availability of zinc. While pH was negatively associated with yield (Fig. 5) most of the variation in yield occurred at high pH. Indeed the data suggest a wide tolerance to pH by banana since high yields can be achieved over the range 4.7 to 8.0 (Fig. 5). However as pH increased there were a larger number of plantations which were yielding less than their potential. The answer to this in the field may lie in adding micronutrients, such as zinc, rather than changing soil pH.

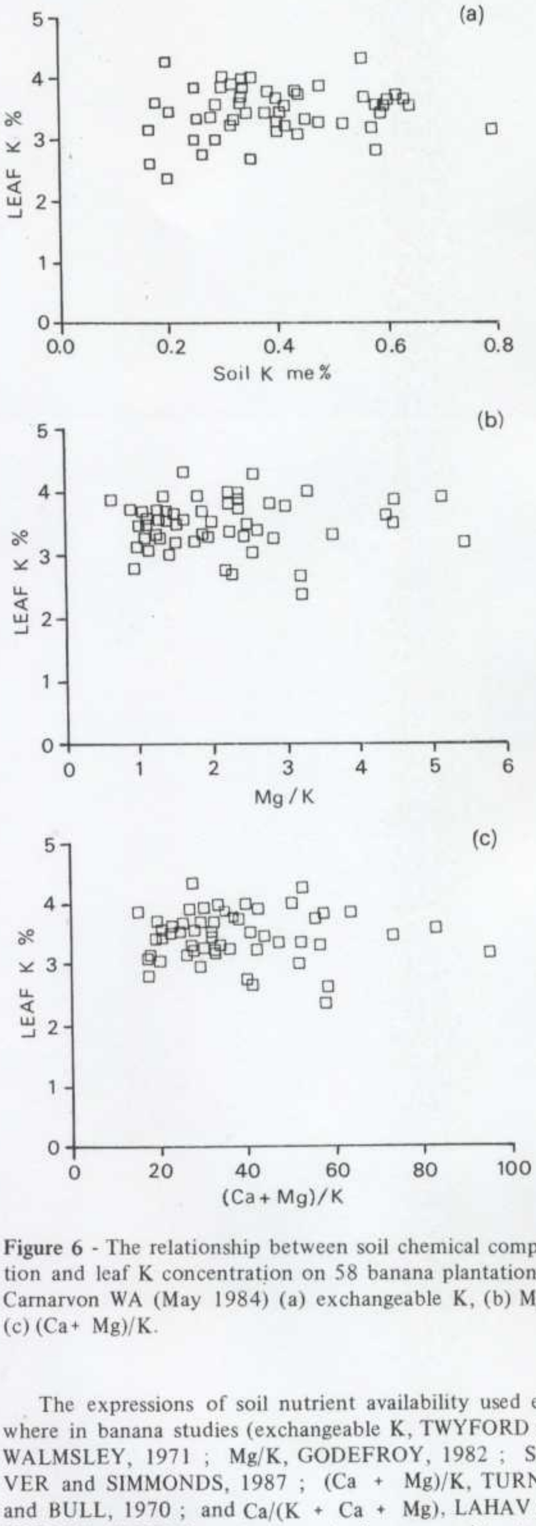

Figure 6 - The relationship between soil chemical composition and leaf K concentration on 58 banana plantations at Carnarvon WA (May 1984) (a) exchangeable K, (b) Mg/K (c) (Ca+ Mg)/K.

The expressions of soil nutrient availability used elsewhere in banana studies (exchangeable K, TWYFORD and WALMSLEY, 1971 ; Mg/K, GODEFROY, 1982 ; STOVER and SIMMONDS, 1987 ; (Ca + Mg)/K, TURNER and BULL, 1970 ; and Ca/(K + Ca + Mg), LAHAV and TURNER, 1973) do not appear to be appropriate to the soils of Carnarvon WA. Perhaps this is because the different indices used have been empirically shown to be associated with a particular response, be it nutrient uptake, yield response to added nutrient or to the occurrence of deficiency symptoms. They are therefore useful within the milieu in which they were established but do not have universal application.

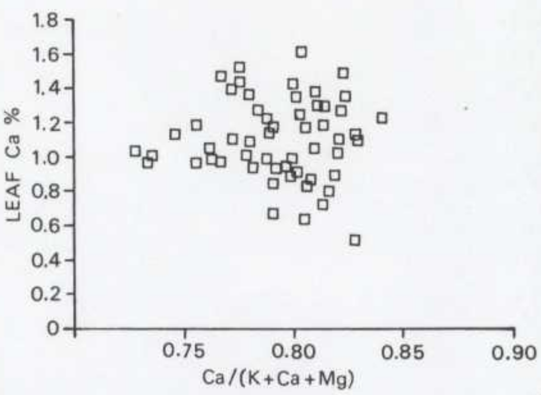

Figure 7 - The relationship between the proportion of Ca on the exchange complex in the soil and the concentration of Ca in the leaves among 58 banana plantations at Carnarvon WA.

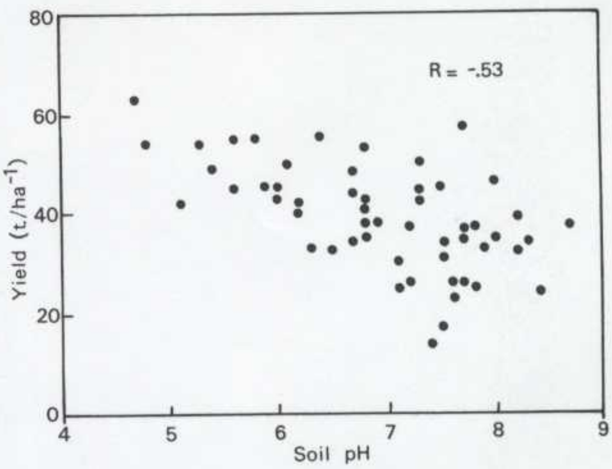

Figure 8 - Relationship between soil pH and yield of 58 banana plantations at Carnarvon, Western Australia.

TABLE 3 - Average yield of 58 banana plantations which were adequate or deficient in K, Fe, Cu, Zn, Cl and Na (From KORAWIS, 1986).

Plant nutrient	Critical concentration	Adequate[1] conc[3]	S.E.	Yield ($t\ ha^{-1} y^{-1}$)	Number of plantations	Deficient[2] conc	S.E.	Yield ($t\ ha^{-1} y^{-1}$)	Number of plantations
K%	3	3.6	0.04	39	52	2.6	0.06	41	6
Fe $\mu g\ g^{-1}$	80	124	3.21	40	57	78	-	14	1
Cu $\mu g\ g^{-1}$	9	10	0.25	42	28	6.8	0.24	38	30
Zn $\mu g\ g^{-1}$	18	18.3	0.33	49	3	15	10.2	39	55
Cl%	0.6	0.7	0.01	39	43	0.5	0.02	41	15

1 - Nutrient concentrations in leaves greater than critical concentrations

2 - Nutrient concentrations in leaves less than critical concentrations

3 - concentration

The poor associations between nutrient concentrations in soil and leaves is not unexpected since TWYFORD and WALMSLEY (1974) showed that leaf composition and total plant uptake are not necessarily associated. They found that the total plant uptake of K may vary twofold but the concentration of K in the laminae may not be different.

CONCLUSION

Soil analysis can be used to manage fertilizer application to banana plantations. While no reliable test for N has been established the cation balance can be diagnosed by looking at exchangeable K, Ca and Mg (GODEFROY and DORMOY, 1984). Cation exchange capacity is a good measure of the buffering capacity of the soil in supplying cations. The most widely studied soil nutrient is K, which is absorbed by the banana in greater quantity than all other nutrients put together. A range of indices and ratios have been used to assess the availability of soil K to bananas and while they appear to have some use in restricted locations they do not appear to have universal application.

To increase our understanding of the contribution of soil nutrient supply to banana nutrition there is a need to establish external nutrient requirements. This has been done for surphur (FOX *et al.*, 1979) and more recently for phosphorus (LIN and FOX, 1987). To complement this work adsorption isotherms and equilibrium soil solution concentrations need to be established. This should help us to estimate the mean nutrient concentration at the root surface (equation 1). But in equation 1 there are numerous other components of nutrient uptake which need to be considered, not the least of which are plant factors such as root length and in the case of nitrogen, plant growth.

REFERENCES

BURT (J.R.). 1988.
Carnarvon's horticultural industry.
Journal of Agriculture - Western Australia, 29, 27-31.

COLWELL (J.D.). 1983.
Fertilizer requirements.
In : *Soils an Australian Viewpoint. Division of Soils, CSIRO, CSIRO Melbourne/Academic Press, London*, p. 795-816.

CHALKER (F.C.) and TURNER (D.W.). 1969.
Magnesium deficiency in bananas.
Agricultural Gazette of New South Wales, 80, 474-476.

CHAPMAN (H.D.). 1966.
In : *CHAPMAN H.D. (Editor), Diagnostic criteria for plants and soils. Quality Printing Co., Albiene*, 793 p.

DREW (M.C.), NYE (P.H.) and VAIDYANATHAN (L.V.). 1969.
The supply of nutrient ions by diffusion to plant roots in soil.
1.- Absorption of potassium by cylindrical roots of onion and leek.
Plant and Soil, 30, 252-270.

FERNANDEZ-CALDAS (E.) and BORGES PEREZ (A.). 1971.
Les réserves de potassium dans les sols de bananeraies aux Canaries.
Fruits, 26, 651-656.

FOX (R.L.) and KANG (B.T.). 1977.
Some major fertility problems of tropical soils.
In : *Vincent J.M., Whitney A.S. and Bose J. (Editors). Exploiting the Legume - Rhizobium Symbiosis in Tropical Agriculture, CTA, University of Hawaii, Miscell Publication* No. 145, p. 183-210.

FOX (R.L.), KANG (B.T.) and WILSON (G.F.). 1979.
A comparative study of the sulphur nutrition of banana and plantain.
Fruits, 34, 525-534.

GARCIA (V.), BRAVO (J.J.), ROBLES (J.) and ALVAREZ (C.E.). 1979.
Etude de relation sol-plante sur les cultures de bananiers de l'île de la Palma (Canaries).
Fruits, 34, 393-397.

GODEFROY (J.) and LOSSOIS (P.). 1966.
Variations saisonnières des caractéristiques physico-chimiques d'un sol volcanique du Cameroun.
Fruits, 21, 535-542.

GODEFROY (J.). 1982.
Fertilisation minérale en culture bananière industrielle.
Diagnostic sol appliqué à la programmation de la fumure.
Fruits, 37, 225-227.

GODEFROY (J.) and DORMOY (Micheline). 1984.
Un exemple d'utilisation du diagnostic sol à la programmation de la fertilization en bananeraie.
Fruits, 39, 121-123.

GODEFROY (J.), ROOSE (E.J.) and MULLER (M.). 1975.
Estimation des pertes par les eaux de ruissellement et de drainage des éléments fertilisants dans un sol de bananeraie du sud de la Côte d'Ivoire.
Fruits, 30, 223-235.

KORAWIS (C.). 1986.
Assessment of the nutritional status of bananas at Carnarvon, Western Australia, with special emphasis on zinc nutrition.
MSc(Agric) Thesis, University of Western Australia, Nedlands, W.A., 180 p.

LAHAV (E.) and TURNER (D.W.). 1983.
Fertilizing for high yield - banana.
International Potash Institute, Bull. 7, 62 p.

LIN (M.L.) and FOX (R.L.). 1987.
External and internal P requirements of mycorrhizal and non-mycorrhizal banana plants.
Journal of Plant Nutrition, 10, 1341-1348.

LOPEZ (C.). 1983.
Diagnostico del estado nutricional de plantaciones bananeras Costa Rica.
ASBANA, 6 (19), 13-18.

MENGEL (K.). 1982.
Factors of plant nutrient availability relevant to soil testing.
Plant and Soil, 64, 129-138.

MESSING (J.H.L.). 1974.
Long term changes in potassium, magnesium and calcium content of banana plants and soils in the Windward Is.
Tropical Agriculture (Trinidad), 51, 154-160.

ROBINSON (J.C.) and NEL (D.J.). 1986.
The influence of banana plant density and canopy characteristics on ratoon cycle interval and yield.
Acta Horticulturae, 175, 227-232.

SMITH (A.N.). 1977.
Fertilization.
In : *Russell J.S. and Greacen E.L. (Editors). Soil factors in crop production in a semi-arid environment. University of Queensland Press, St. Lucia*, p. 262-278.

STOVER (R.H.) and SIMMONDS (N.W.). 1987.
Bananas.
3rd Edition, Longman, London, 468 p.

TURNER (D.W.) and BARKUS (B.). 1980 a.
An empirical relationship between climate, nutrition and nutrient concentrations in banana leaves.
Fruits, 35, 151-158.

TURNER (D.W.) and BARKUS (B.). 1980 b.
Plant growth and dry matter production of the 'Williams' banana in relation to supply of potassium, magnesium and manganese in sand culture.
Scientia Horticulturae, 12, 27-45.

TURNER (D.W.) and BARKUS (B.). 1981.
Some factors affecting the apparent root transfer coefficient of banana plants (cv 'Williams').
Fruits, 36, 607-613.

TURNER (D.W.) and BULL (J.H.). 1970.
Some fertilizer problems with bananas.
Agricultural Gazette of New South Wales, 81, 365-367.

TWYFORD (I.T.). 1967.
Banana nutrition : a review of principles and practice.
Journal of Science, Food and Agriculture, 18, 177-183.

TWYFORD (I.T.) and WALMSLEY (D.). 1974.
The mineral composition of the Robusta banana plant.
3.- Uptake and distribution of mineral constituents.
Plant and Soil, 41, 471-491.

WALMSLEY (D.), TWYFORD (I.T.) and CORNFORTH (I.S.). 1971.
An evaluation of soil analysis methods for nitrogen, phosphorus and potassium using banana.
Tropical Agriculture (Trinidad), 48, 141-155.

WARNER (R.M.) and FOX (R.L.). 1976.
Effect of nitrogen and climatic factors on seasonality of banana production in Hawaii.
Proceedings of the International Plant Propagators Society, 26, 38-47.

WARNER (R.M.) and FOX (R.L.). 1977.
Nitrogen and potassium nutrition of Giant Cavendish banana in Hawaii.
Journal of the American Society of Horticultural Science, 102, 739-743.

WARNER (R.M.), FOX (R.L.) and PRASOMSOOK (S.). 1974.
Nutritional guidelines for the 'Williams Hybrid' banana.
Hawaii Farm Science, 21/22, 4-6.

WECHSELWIRKUNGEN ZWISCHEN BODENANALYSE UND BLATTANALYSE SOWIE ERTRÄGEN BEI DER BANANENPFLANZE UNTER BESONDERER BERÜCKSICHTIGUNG EINER UNTERSUCHUNG AUS CARNARVON (WESTAUSTRALIEN).

D.W. TURNER, C. KORAWIS und A.D. ROBSON.

Fruits, Apr. 1989, vol. 44, n° 4, p. 193-203.

KURZFASSUNG - Der Stellenwert der Bodenanalyse im Rahmen des Düngungsprogramms für die Bananenpflanze ist durch die Akzentuierung der Blattanalyse in den Hintergrund getreten. Geprüft wird unter unterschiedlichen Voraussetzungen der Einsatz der Bodenanalyse zur Erfassung nutritionaler Karenzen auf Bananenplantagen. Untersucht wird ferner die Möglichkeit, mit Bezugsgrössen und in Vorschlag gebrachten, kritischen Konzentrationswerten zu arbeiten. Für 58 Plantagen in Carnarvon wurden folgende Daten erfasst : Boden, Blattwerk und Ertrag (14 bis 80 t/ha/Jahr). Die Bezugsverhältnisse zwischen den drei Paramatern wurden ausgewertet und die erhaltenen Daten gemäss den kritischen Werten der Fachliteratur interpretiert. Letztere - ausgedrückt als verwertbare Bodensubstanzen lassen sich nicht auf Carnarvon übertragen, da sie empirisch erarbeitet wurden und mit dem Ertrag bzw. dem Auftreten von Karenzerscheinungen in Zusammenhang gebracht werden. Die Konzentration von Substanzen an der Wurzeloberfläche ist nicht allein ausschlaggebend für ihre Absorption ; Wurzellänge und Wachstumsverlauf sind ebenfalls von Bedeutung für die Auswertung der Bodenanalyse.

EL ANALISIS DE SUELO Y SUS RELACIONES CON EL ANALISIS FOLIAR Y LOS RENDIMIENTOS EN EL BANANO CON REFERENCIA PARTICULAR A UN ESTUDIO REALIZADO EN CARNARVON (AUSTRALIA DEL OESTE).

D.W. TURNER, C. KORAWIS y A.D. ROBSON.

Fruits, Apr. 1989, vol. 44, n° 4, p. 193-203.

RESUMEN - La plaza del análisis de suelo en la programación de la fertilización del banano se ha visto reducida por el acento puesto sobre el análisis foliar. Se examina la manera de utilizar, en situaciones variadas, el análisis de suelo para detectar desequilibrios nutricionales en platanales ; se estudia la posibilidad de aplicar valor de referencias y concentraciones críticas propuestas de este modo.
Para 58 plantaciones de Carnarvon se han reagrupado datos : suelo, hojas y rendimiento (14 a 80 t/ha/año) ; se exploran las relaciones entre los tres y se interpretan los datos según los valores críticos indicados en la literatura ; estos últimos, en la expresión en elementos del suelo utilizables no convienen a Carnarvon ya que establecidos empiricamente y asociados al rendimiento o a la aparición de síntomas de carencia.
La concentración de elementos en la superficie de las raices no es el único factor que determina su absorción ; también intervienen longitud de las raíces e importancia del crecimiento y debe interpretarse el análisis de suelo a la luz de estos factores.