INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
1560–8530/2005/07–5–824–831
http://www.ijab.org

Review

Plant Analysis as a Diagnostic Tool for Evaluating Nutritional Requirements of Bananas

N. MEMON, K.S. MEMON AND ZIA-UL-HASSAN†[1]
Sindh Agriculture University, Tandojam, Sindh, Pakistan
†*Rice Research Institute, Dokri, Larkana, Sindh; presently at ISES, University of Agriculture, Faisalabad, Pakistan*
[1]Corresponding author's e-mail: zhnshah@yahoo.com

ABSTRACT

Plant analysis has been considered a very promising tool to assess nutritional requirements of plants for cost effective and environment friendly agriculture. Diagnosing nutritional status of bananas through plant analysis not only provides the basis of correct fertilizer requirement of the crop but also guides towards the nutritional requirements of future crops. The total contents of nutrients in leaves, and plant parts, compared with Critical Nutrient Range (CNR), provide the basis for interpretation. The Diagnosis and Recommendation Integrated System (DRIS) is also used for interpreting plant analysis data, based on a comparison of calculated elemental ratio indices with established norms. The Plant Analysis with Standardized Scores (PASS), the most efficient diagnosis systems, has not been effectively utilized for bananas. The accurate plant sampling, handling, and analysis of the sample coupled with a thorough knowledge of cropping history, sampling techniques, soil test data, environmental influences, and nutrient concentrations favour efficient diagnosis and interpretation system. This, in turn, leads towards more efficient nutrient management and sustainable crop production. This paper reviews the research on various critical aspects of the use of plant analysis as a diagnostic tool for banana nutrition management.

Key Words: Banana nutrition; Plant Analysis Interpretation; Critical Nutrient Range; DRIS; PASS

INTRODUCTION

Plant analysis has been considered a very practical approach for diagnosing nutritional disorders and formulating fertilizer recommendations (Kelling *et al.*, 2000; Self, 2005). Plant analysis, in conjunction with soil testing, becomes a highly useful tool not only in diagnosing the nutritional status but also an aid in management decisions for improving the crop nutrition (Rashid, 2005). Plant analysis is the quantitative analysis of the total nutrient content in a plant tissue, based on the principle that the amount of a nutrient in diagnostic plant parts indicates the soil's ability to supply that nutrient and is directly related to the available nutrient status in the soil (Malavolta, 1994; Kelling *et al.*, 2000; Havlin *et al.*, 2004; Rashid, 2005). It is a very practical and useful technique for fruit trees and long duration crops (Rashid, 2005). Hence, it seems quite convenient and appealing for bananas also.

Bananas are heavy feeder of nutrients (Jones, 1998) and thus need balanced nutrition for optimum growth and fruit production, and in turn potential yields. A deficiency or excess of nutrients can cause substantial damage to the plant (Memon *et al*., 2001). The early (until the mid-1960s) researches on banana nutrition had concentrated on the description of symptoms of nutrient imbalance and the conduct of field experiments comparing response to rates of applied fertilizer on a range of soil types. During last three decades, scientists attempted to understand more clearly the role of nutrients in the growth and development of bananas. Field studies of fertilizer response are still being conducted, but attempts to relate nutrient concentrations in the soil and plant to yield have complemented this work. Analysis of plant parts for mineral elements and the attempt to set standards for interpreting leaf analysis data came to the fore in the late 1960s and early 1970s. However, each researcher approached the problem differently, probably reflecting a lack of unifying concepts in the understanding of the growth and nutrition of bananas, until Martin-Prevel (1974, 1977) initiated the formation of an International Group on Mineral Nutrition of the Banana that resulted in a suggested International Reference Method for sampling in banana fertilizer experiments. In this paper, the important aspects of banana nutrition management through plant analysis have been reviewed.

Use of Plant Analysis as a Nutritional Guide. Plant analysis, normally, is a laboratory analysis of collected plant tissue. Using established critical or standard values, or sufficiency range, a comparison is made between the laboratory analysis results with one or more of these known values or ranges in order to access the plant's nutritional status (Jones *et al.,* 1991; Kelling *et al*., 2000; Rashid, 2005). Hence, it can be successfully used to identify the hidden hungers of plants (PPI, 1997; Kelling *et al*., 2000; Tisdale *et al*., 2002; Rashid, 2005). The use of plant analysis as a diagnostic tool has a history dating back to studies of plant ash content in the early 1800's. While working on the

composition of plant ash, researchers recognized the existing relationships between yield and the nutrient concentrations in plant tissues. Quantitative methods for interpreting these relationships in a manner that could be used for assessing plant nutrient status arose from the work of Macy (1936). Since then, much effort has been directed towards plant analysis as diagnostic tool.

Plant analysis is carried out as a series of steps that include sampling and sample preparation followed by laboratory analysis and interpretation of analytical data. Each step is equally important to the success of the technique employed for diagnosing nutritional disorders. Since plant species, plant age, plant part, sampling time and applied fertilizer are all variables that affect the interpretation of the analytical data, careful sampling is highly important (Jones *et al.*, 1991). Surveys of nutrient concentrations in "deficient" and "adequate" plants have been used to establish standard nutrient concentrations for some species. This approach is primarily used for large perennial species such as trees and vines (Bevege, 1978; Leece, 1976), where it is costly and difficult to set up traditional experiments to measure nutrient responses. Later on, Smith (1986) came up with a method and proposed some important steps for developing standard nutrient concentrations for these crops. The first step is to select a plant part to sample, and define a sampling time during which nutrient levels are most stable. It is also necessary to define what constitutes a sample that will adequately represent a plantation being sampled. As a guide to sampling, preliminary studies are often done by frequent sampling of various tissues (usually leaves or petioles), over a number of years, from research station plantings. The second step is to conduct a district-wide survey of highly productive orchards to define mean concentrations for a number of nutrients in the defined sample tissue. The third step is to define a standard "range" for each nutrient that is adequate for high production, with a statistical analysis of the survey as a basis. Values outside this range are considered to be "high" or "low" unless they are known to be "deficient" or "toxic". Analytical values for deficiency and toxicity may be derived from a synthesis of data from sand culture experiments and field observations. Field fertilizer trials are used to refine the limits of the adequate range for each nutrient. For more detailed information, the way tissue analysis is used in orchard crop; readers may go through Leece (1968, 1976).

Plant analysis as a diagnostic technique, has a considerable history of application. It has been used to determine the combined soil and crop nutrient element status that forms the basis for prescribing fertilizer needs. A number of objectives for utilizing a plant analysis result have been proposed. Most importantly, plant analysis findings are used to determine if the soil fertility level and applied fertilizers are insufficient to meet the crop requirement (Jones *et al.*, 1991, Havlin *et al.*, 2004). Krantz *et al.* (1948) gave four principal objectives for the utilization of a plant analysis result. To aid in determining the nutrient supplying power of the soil, aid in determining the effect of treatment on the nutrient supply in the plant, study relationship between the nutrient status of the plant and crop performance as an aid in predicting fertilizer requirements, help lay the foundation for approaching new problems or for surveying unknown regions to determine where critical plant nutritional experimentation should be conducted. The succeeding research workers opined almost similarly about the uses of plant analysis (Smith, 1986, Jones, *et al.*, 1991, Kelling *et al.*, 2000; Havlin *et al.*, 2004; Rashid, 2005; Self, 2005).

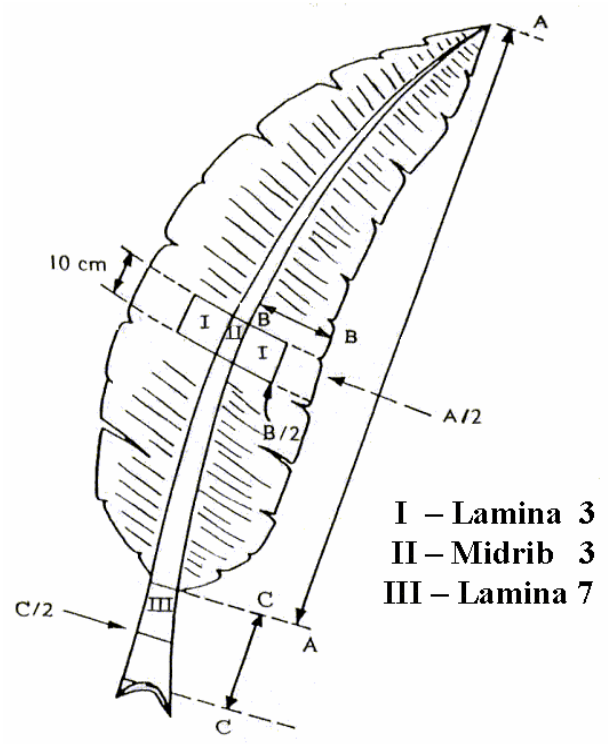
Sampling Bananas for Plant Analysis. For plant analysis, a specific plant part at a particular growth stage should be sampled because comparison of an assay result with established critical or standard values or sufficiency ranges is used to interpret analytical results (Rashid, 2005). It is important to follow the recommended sampling technique carefully, since criteria for elemental analysis interpretation have been established for specific plant sampling procedures. Therefore, for meaningful determinations of the elemental concentration, it is essential to adhere to the given sampling procedure designed for that plant species and the element(s) to be assayed (Jones, 1997).

Sampling procedures have been investigated by many researchers (Dumas, 1959; Twyford & Coulter, 1964; Martin-Prevel *et al.*, 1969; Lahav, 1970; Turner & Barkus, 1977). Earlier, researchers at the Jamaica Banana Board (Hewitt, 1953; Hewitt & Osborne, 1962) and IRFA, Guinea (Dumas & Martin-Prevel, 1958; Dumas, 1960a), used different approaches and defined some of the problems associated with sampling in banana. It was thus difficult to perceive indisputable overall advantage in either one method or the other and hence many workers preferred to establish a procedure well suited to their own special circumstances. In two decades, a variety of procedures were used. Later on, Martin-Prevel (1977) came up with a measure of uniformity to sampling methods by surveying the methods used in different countries.

Because of the internal variation in nutrient composition of banana, the results from these different techniques were, almost without exception, not strictly comparable. Lahav and Turner (1983) attributed the slow progress towards international standardization of sampling techniques "partly to the nature of the banana plant and partly to the absence of unifying concepts concerning its nutrition".

The interplay of growth and nutrition is more complex in the banana than most crops and best understood from detailed data on the nutrient flux in the plant as a whole. Realizing the need for uniformity of sampling method and to provide for comparison of results between experiments conducted in different countries, the International Working Group on Foliar Analysis in the Banana was established. The Working Group met for the first time in 1975 in the Canary Islands. There was a general realization of the

Fig.1. Sampling procedures for banana leaves (Martin-Prevel, 1977)



advantages of standardization of sampling methodology.

The first outcome was that each organization agreed to standardize procedures wherever this could be done without difficulty and to move towards an international reference sampling method (Method d'Echantillonnage Internationale de Reference - MEIR) (Martin-Prevel, 1974, 1976, 1977).

Area of sampling. According to MEIR samples are taken from three leaf parts at different positions on the plant (Fig. 1). The samples should normally be taken either just before or following floral emergence and when all female hands are visible (Martin-Prevel, 1974; 1976; 1977; Lopez & Espinosa, 2000). However, the age of the tissue to be sampled depends on the nutrient being diagnosed (Lopez & Espinosa, 2000). For instance, sulphur is better diagnosed if younger leaves are sampled before floral initiation (Fox *et al.*, 1979).

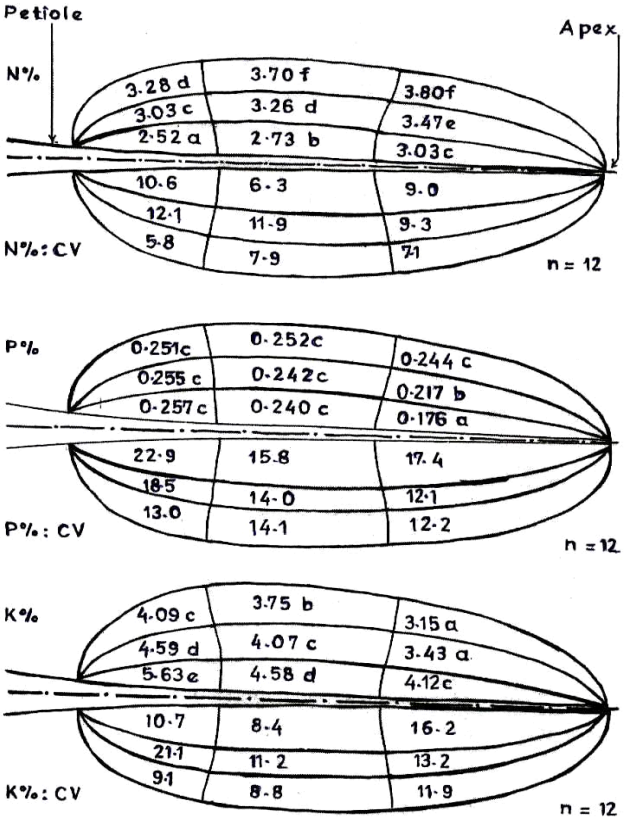
In most banana producing countries, the laminar structure of third leaf is sampled for tissue analysis. However, samples of the central vein of third leaf and the petiole of seventh leaf are also used. The laminar structure of third leaf is sampled by removing a strip of tissue 10 cm wide, on both sides of the central vein, and discarding everything but the tissue that extends from the central vein to the center of the lamina (Lopez & Espinosa, 2000). The MEIR method allows for comparison of results between experiments, but whether it is the best method for a diagnostic service still remains to be established (Memon *et al.*, 2001).

Further developments in sampling methods and some of the unresolved issues were reviewed in detail by Martin-Prevel (1980). He considered that the development of a uniform method of sampling was slow, especially when the benefits were considerable. Since the establishment of International Working Group and their first meeting in 1975, there have been two enlarged meetings on the "Nutrition of Banana Crop" in Australia in 1978 and on the "Agro-physiology of Bananas" in South Africa in 1982. Although considerable progress has been made in standardization, there is still much to be done to achieve complete uniformity. Almost all the information on assessment of nutrient status in the banana plant relates to leaf sampling – blade, midrib or petiole. There have been a number of investigations on other organs to quantify nutrient uptake or removal, only the leaf blade was considered in the first wave of investigations. In view of its size, it was not practicable to take the whole leaf as a sample. For that, Dumas (1960b) mapped the spatial variability in the mineral content of banana leaf blade, in an attempt to find areas of constant composition and reasonable size. The variations within each half of the blade were considerable, both transversely and longitudinally (Fig. 2).

As a result, whatever part of the blade was chosen it must be precisely defined, and the analyses interpreted only by reference to norms based on data for that part of the leaf. Lahav (1972a) pointed out that a 5 cm longitudinal displacement of the area sampled could give a difference in K content equivalent to that from an application of K fertilizer. Specifications such as "in the middle of the leaf" or about the first third of the leaf were inadequate. Variability between leaves is somewhat less in the central part of the leaf than it is in the basal and distal areas (Fig. 2). This is one reason why most authorities have chosen to sample parts of the central area rather than the extremities. Further work of Lahav (1972b, 1977) revealed that petiole analysis provided more information than the blade, at least for cations and phosphorus (P). Martin-Prevel *et al.* (1968) and Martin-Prevel (1970) also showed that the conductive tissues were useful indicators for cations. They found it best, however, to take the section of the midrib adjacent to the area of blade that was already being sampled (Martin-Prevel *et al.*, 1969). Langenegger and Du Plessis (1977) reached a similar conclusion and have since re-emphasized their preference for the midrib including its use to indicate plant nitrogen (N) status. Hewitt (1953) analyzed all odd numbered leaves and found that N content was highest at about position III. He, therefore, chose this as a standard and was followed in doing so by research groups in most countries. Position III has accordingly been adopted as the international standard.

For a diagnostic service, the appropriate sampling method is one that allows an empirical relation between the concentration of the nutrient and response to the application of that nutrient to be established. It may be that a single sampling method will not cater for all nutrients under all

Fig. 2. Spatial variability in the mineral content of leaf blade of banana cultivar Dwarf Cavendish. Figures in upper part of leaf are mean nutrient content of n leaves as % of DM and figures in the lower half are coefficient of variation of those means (Dumas, 1960b)



climatic and soil conditions (Lahav, 1972b; 1977). A full evaluation of the recommended sampling methods has yet to be completed but indications are that the petiole or midrib may be better than lamina for assessing P status.

Stage of sampling. A further requirement for a sampling method is that the variation from plant to plant within a tissue is as low as possible. Twyford and Walmsley (1974), who sampled 10 plants, found that the usual diagnostic tissue used in the West Indies (the fourth leaf lamina) was the least variable for all elements and all other plant parts, especially at the "large" stage of plant growth. It is also important that the diagnostic tissue, besides reflecting low plant-to-plant variability should indicate the nutrient status of the whole plant. For example, Twyford and Walmsley (1974) found that the concentration of potassium (K) in the leaves (3%) or petioles (3.2%) at the "large" stage was the same for two sites in Windward Islands but at one site the plant contained 210 g K and the other only 108 g K. Therefore, a quantitative estimate of plant height, if used in conjunction with the concentration data, may give an estimate of whole plant nutrient content. According the international standard, (Martin-Prevel, 1980) sampling stage in short banana plants is when all female hands are visible and up to 3 male or mixed hands have formed. The appearance of three of the latter takes about a week, so that the sampling period is a week long. The main advantage of this sampling stage is that most of the current growth cycle is over, so that its effects are reflected in the sample taken, yet there is opportunity to estimate yield and adequate time for interpretation before the next cycle begins. The sampler can obtain a yield estimate by counting the number of hands and of fingers per hand and also assess growth by measuring the circumference of the pseudostem at a standard height. Its disadvantage is a less information on a standard nutrient contents and repeatability of the results at this growth stage, which was little used before its adoption as an international standard (Martin-Prevel, 1980; Lahav & Turner, 1983).

When information is needed on banana plants before inflorescence emergence, the proposed standard is "at about inflorescence initiation" in the expectation that a better method of defining this stage will in due course become available. Lahav (1972a) studied the factors influencing the potassium content of the third leaf of the banana sucker. He reported that the K content of the 3rd leaf varied considerably along the length of the blade. Other factors that had a marked effect on the K content were leaf orientation, time of day, shade, irrigation and plant age. In another study, Lahav (1972b) grew bananas in sand culture with 5 levels of K and analysed all plant parts. The foliar sheaths, petiole and midrib were all good indicators of the K status of the plant. He recommended the sampling of the petiole of the 7th leaf as it also contained relatively high concentrations of Ca, Mg, Na and Cl. Langenegger and Plessis (1977) attempted to determine the nutritional status of Dwarf cavendish banana in South Africa. They analyzed various plant parts in fertilizer experiments and surveys of commercial plantings. The two most promising tissues for foliar analysis were a section of midrib (midrib 2/3) and also the corresponding lamina from the leaf in position III sampled after flowering at a stage when two hermaphrodite hands were visible. The midrib sample gave a rather better indication of N and K status as affected by fertilizer.

Taking representative sample. Besides the stage of sampling, it is important to obtain a sample that will represent the plantation. In an average crop, a representative sample can usually be obtained form 20 plants at a given stage of growth, though in some cases 10 are enough. In case of field experiments, it is better to sample 10-20 suitable plants per plot when the majority of the plants in the crop reach the defined growth stage. For example, for a post flowering sample, ignore the first 30% of plants that flower, sample the next 40% and ignore the final 30%.

Plant Analysis Interpretation. Once plant samples have been analysed for desired nutrients, the next question is usually whether the values found are sufficient to prevent the plant suffering from deficiency. For this purpose, it is necessary to interpret plant analysis data. For the interpretation of plant analysis data, various systems have

Fig. 3. Relationship between essential nutrient concentration and plant growth or yield (Havlin *et al*., 2004)

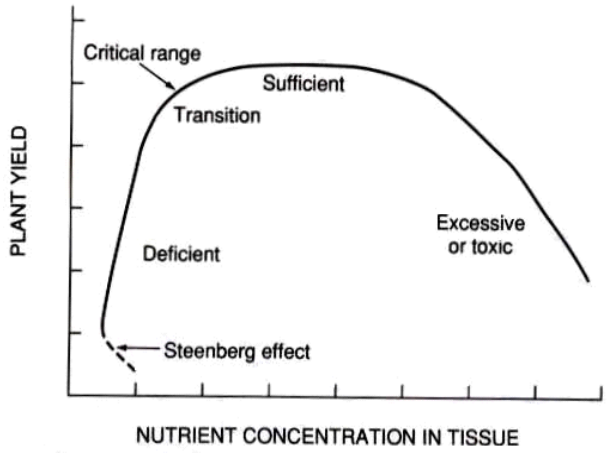
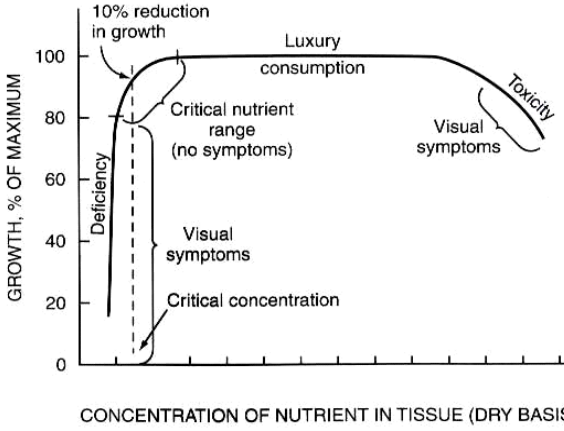


Fig. 4. Relationship between nutrient concentration in plant and crop yield. The critical nutrient range represents an economic loss in yield without visual deficiency symptoms (Havlin *et al*., 2004)



been proposed and used as follows.

The critical level concept. For correct interpretation of tissue analysis, the interpreter must be familiar with the relationship between dry matter accumulation and nutrient concentration. The general relationship between nutrient concentration in plant tissue and plant yield is shown in Fig. 3. Yield is severely affected when a nutrient is deficient, and when the nutrient deficiency is corrected, growth increases more rapidly than nutrient concentration (Havlin, *et al*., 2004).

Under severe deficiency, rapid increases in yield with added nutrient can cause a small decrease in nutrient concentration. This is called *Steenberg effect* and results from dilution of the nutrient in the plant by the rapid plant growth. When the concentration reaches the critical range, plant yield is generally maximized. Nutrient sufficiency occurs over a wide concentration range, wherein yield is unaffected. Increases in nutrient concentration above the critical range indicate that plant is absorbing nutrients above that needed for maximum yield. This *Luxury consumption* is common in most plants. Elements absorbed in excessive quantities can reduce plant yield directly through toxicity or indirectly by reducing concentrations of other nutrients below their critical ranges (Brady & Weil, 2004, Havlin *et al.,* 2004).

Plants that are severely deficient in an essential nutrient exhibit a visual deficiency symptom (Fig. 4). Plants that are moderately deficient exhibit no visual symptoms, although yield potential is reduced. Added nutrients will maximize yield potential and increase nutrient concentration in plant. The term luxury consumption means that plants continue to absorb a nutrient in excess of that required for optimum growth. This extra consumption results in an accumulation of the plant nutrient without corresponding increase in growth. However, with higher crop yields, a greater concentration of nutrients is required. When nutrient *toxicity* occurs plant growth and yield potential decrease, increasing the nutrient concentration in the plant (Havlin *et al.,* 2004).

The Critical Nutrient Concentration (CNC) is commonly used in interpreting plant analysis results and diagnosing nutritional problems (Fig. 3 and 4). The CNC is located in that portion of the curve where the plant-nutrient concentration changes from deficient to adequate; therefore, the CNC is the level of a nutrient below which crop yield, quality, or performance is unsatisfactory. However, considerable variation exists in the transition zone between deficient and adequate nutrient concentrations which makes it difficult to determine an exact CNC. Consequently, it is more realistic to use the Critical Nutrient Range (CNR), which is defined as that range of nutrient concentration at a specified growth stage above which the crop is amply supplied and below which the crop is deficient (Kelling *et al.,* 2000; Tisdale *et al.,* 2002; Brady & Weil, 2004; Havlin *et al.,* 2004; Rashid, 2005). This concentration range lies within the transition zone, a range in concentration in which a 0% to 10% reduction in yield occurs, with 10% reduction in yield point specified as critical value of the element (Havlin *et al.,* 2004). In an interpretative concept developed by Okhi (1987), the critical nutrient level is that nutrient concentration level at which a 10% reduction in yield occurs; this level is also defined as the Critical Deficient Level (CDL). Similarly, the Critical Toxic Level (CTL) is the concentration level at which toxicity occurs. Critical nutrient ranges have been developed for most of the essential nutrients in many crops.

Critical levels of NPK in Banana. Leaf analysis values in banana have been traditionally interpreted using the critical value approach, a diagnostic tool that considers each nutrient independently of one another.Many experiments on banana have established critical levels for all essential

nutrients. These levels are quite consistent despite being generated in different countries having a wide range of environmental conditions, and established from experiments involving various cultural treatments and practices. This information has helped determine the amount of fertilizer needed for correcting specific problems. Ramaswamy and Muthukrishnana (1974) reported that a critical level of 1.40% N was proved to be an optimal level in Robusta banana. Soil application of 150 g/plant was fixed as critical level for maximising the yield. The results obtained by Jambulingam *et al.* (1975) suggested that leaf K should be above 4.3% for optimum production. Later work by Arunachalam *et al.* (1976) showed that adequacy level of nutrients in banana leaf ranged from 3.18-3.43, 0.46-0.54, 3.36-3.76, 2.3-2.4 and 0.25-0.28% for N, P, K, Ca and Mg, respectively. Valsamma Mathew (1980) found that the nutrient status of third leaf at shooting ranged from 1.33 to 2.08% for N, from 0.14 to 0.17% for P and from 2.05 to 2.76% for K. In case of N, Kotur and Mustaffa (1984) reported that a rate of 210 g N/plant, corresponding to 3.51% leaf N, produced the highest yield of 44.8 t/ha. Fernandez-Falcon and Fox (1985) concluded that K level in the soil of less than 2.26 meq/100 g, and in the leaf of less than 3.2%, reduced banana yields. A nitrogen level in the leaf of less than 2.6% also limited yields. Adinarayana *et al.* (1986) observed that the mean potassium concentration (3.25%) in normal banana leaves was much higher than that observed in potassium deficient leaves (1.25%). According to Ray *et al.* (1988), a leaf content of 2.8% N, 0.52% P and 3.8% K at shooting was a good indicator of satisfactory subsequent productivity of Robusta banana. Lahav & Turner (1992) forwarded a summary of proposed critical levels in different banana tissues (Table I). However, this concept has limitations. Stage of growth greatly influences nutrient concentrations and unless the crop sample is taken at proper time, the analytical results will be of little significance. Coupled with this, considerable skill on the part of the analyst is needed to interpret the crop analysis results in terms of the overall production conditions (Tisdale *et al.,* 2002). Dumas and Martin-Prevel (1958) pointed out that if nutrients are considered individually, values equal to or higher than the critical level are not always associated with high yield or values lower than the critical levels are not always related to low yield. In this case, they proposed the use of ratio instead of concentrations as diagnostic norms.

Use of DRIS (Diagnosis & Recommendation Integrated System) norms. The actual application of nutrient ratios has not been realized until the use of Diagnosis and Recommendation Integrated System (DRIS) was proposed. Beaufils at the University of Natal, South Africa developed this approach for the interpretation of leaf or plant analysis (Beaufils, 1973). It is a comprehensive system that identifies all the nutritional factors limiting crop production and, hence, increases the chances of obtaining high crop yields by improving fertililzer recommendations. Index values that measure how far particular nutrients in the leaf or plant are from the optimum are used in the calibration to classify yield factors in order of limiting importance (Tisdale *et al.*, 2002). The DRIS techniques of interpretation determine the order on nutrient requirements in plants by measuring the deviation of leaf analysis values from the standard norms. It is based on the interrelationships among nutrients. Walworth and Sumner (1987) addressed the principles of this innovative technique. The DRIS approach to interpreting the results of plant analysis involves creating a database from the analysis of thousands of samples of a specific crop (Kelling *et al.,* 2000). Angeles *et al.* (1993) determined the DRIS norms for banana by using the procedures of Beaufils (1973). They assembled 915 observations from 26 published and un-published sources. The DRIS norms were established from the high yielding population with a yield >70 t/ha. About 16% of the total observations fell within the high-yielding population. They calculated the means of N, P and K concentrations, their ratios, products, and their respective coefficients of variation from the high yielding population to serve as norms. They compared the DRIS norms with critical values obtained from published sources (Table II). The critical values were compiled and averaged. Except for K and its ratios and products with other nutrients, DRIS norms were very

Table I. Suggested critical levels of nutrients in different tissue of completely developed banana plants

Nutrient	Lamina (Leaf 3)	Central vein (Leaf 3)	Petiole (Leaf 7)
		(%)	
N	2.6	0.65	0.4
P	0.2	0.08	0.07
K	3.0	3.0	2.1
Ca	0.5	0.5	0.5
Mg	0.3	0.3	0.3
Na	0.005	0.005	0.005
Cl	0.6	0.65	0.7
S	0.23	-	0.35
		(mg/kg)	
Mn	25.0	80.0	70.0
Fe	80.0	50.0	30.0
Zn	18.0	12.0	08.0
B	11.0	10.0	08.0
Cu	9.0	7.0	05.0
Mo	1.5-3.2	-	-

Source: Lahav and Turner, 1992
Data mainly based on the variety Dwarf Cavendish. Sometimes values differ in other cultivars

Table II. DRIS norms and critical nutrient levels in the 3rd lamina of banana established from published sources

Nutrient expression (%)	DRIS	Critical value range	Av. of published critical values
N	3.04	1.81-4.00	3.03
P	0.23	0.12-0.41	0.22
K	4.49	1.66-5.40	3.40

Source: Angeles *et al.*, 1993

similar to the average critical values.

The DRIS norms were validated in two fertilizer experiments, and their efficacy in making diagnosis was compared with critical values. The validity of DRIS norms and their superiority over the critical value in making correct diagnosis were partly confirmed in a single fertilizer experiment but further testing in field factorial experiment is needed.

Use of PASS (The Plant Analysis with Standardized Scores). The PASS system was developed at the University of Wisconsin, USA to combine the strengths of the Sufficiency Range (SR) and DRIS methods. The SR provides easily interpreted, categorical, independent nutrient indices. The DRIS gives difficult to calculate, easily interpreted, numerical, dependent nutrient indices, and a ranking of the relative deficiencies. The strengths of the SR are the weaknesses of the DRIS and vice versa. The PASS system combines an independent nutrient section and a dependent nutrient section. Both types of indices are expressed as Standardized Score and can be combined to make more effective interpretations. Research has demonstrated that PASS results in more correct diagnosis than any other systems. To date, however, the PASS system has not been effectively utilized for bananas (Kelling *et al*., 2000).

CONCLUSIONS AND RECOMMENDATIONS

Plant analysis is an authoritative tool for evaluating nutrient deficiencies, toxicities and imbalances, identifying hidden hunger, deciding fertilization plans, studying nutrient interactions, and determining the availability of elements for which reliable soil tests have not been developed. However, the results can be confusing if initial plant sampling, handling, and analysis of the sample are inaccurate. Experience with interpreting the overall plant analysis report is essential because of the many interacting factors that affect nutrient concentration in plant tissue. After assessing the status of each nutrient by interpretative methods, it is imperative to review possible causes of the effects observed. For that, cropping history, sampling techniques, soil test data, environmental influences, and a knowledge of nutrient concentrations all need to be considered in the final diagnosis. The efficient and accurate plant analysis results in more efficient nutrient management and sustainable crop production.

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(Received 11 May 2005; Accepted 12 July 2005)