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Banana Nutrition Management Through Plant Analysis

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Abstract: Banana is an important fruit crop of tropical and sub-tropical regions of the world. It requires high quantity of nutrients that must be supplied through fertilization to obtain optimum yields. To diagnose nutrient deficiencies and excesses using plant analysis is appealing. The nutrient content of plants provides reliable information on their nutritional status at the date of sampling, thus giving a guide not only to any supplementary fertilizer needs of the current crop but also to the probable requirements of future crops. Although it is more costly than soil testing and needs more care in the handling of samples, this method is growing in importance. Interpretation is usually based on the total contents of nutrients in leaves, or other suitable plant parts, in comparison with critical nutrient concentrations or "critical values". Another different and fairly new system of plant analysis interpretation is the Diagnosis and Recommendation Integrated System (DRIS) in which interpretation is based on a comparison of calculated elemental ratio indices with established norms. Since bananas are grown from between latitudes 33° north and south and on a wide range of soils, the mineral nutrition of the crop has attracted much attention. The overall requirements of nutrients can be estimated from analysis of the whole plant and estimated plant growth. The grower needs to know the ability of the soil to meet these requirements and whether supplementary fertilizer is needed. Two approaches have been adopted to solve this problem viz. field experiments and the analysis of plant and soil with the aim of estimating the amount of fertilizer required to optimize yields. Lots of researches have been done regarding banana nutrition management and on its related aspects. This paper encompasses the reviews on the use of plant analysis as a diagnostic tool for banana nutrition management, banana sampling for plant analysis, utilization of plant analysis data, plant analysis interpretation using critical level concept and DRIS norms, and most importantly banana nutrition management with special reference to Pakistan.

Keywords: Banana, Nutrition Management, Plant Analysis

Introduction

Low soil fertility is one of the major constraints to optimum crop growth and yield. The fertility of soils can be managed by fertilization, but the farmer must be aware of the nature and severity of the nutrient problem (s) in his field in order to arrive at decisions regarding the kind and dose of fertilizers to be applied. Numerous diagnostic techniques used in evaluating soil nutrient status and determining fertilizer requirement of the crop viz. Nutrient deficiency symptoms, Field experimentation, Greenhouse pot experimentation, Soil testing, and Plant analysis. Each technique has advantages as well as limitations (Rashid, 1996). For example, in the field nutrient deficiency symptoms may often be confused with the symptoms of disease or insect damage. In addition, it is often too late to adopt corrective measures after observing deficiency symptoms (Rashid, 1996; Tisdale *et al.,* 1990). Normally, plants can suffer from a lack of a particular nutrient without showing any visual evidence, a condition known as " hidden hunger" (Potash and Phosphate Institute, 1997). By the time a plant has shown deficiency symptoms a considerable reduction in the potential yield (to the extent of 70%) will already have occurred and the grower will have lost money (Lopez and Espinosa, 2000; Tisdale *et al.,* 1990). Moreover, there may be no foliar symptoms for some deficiencies but seed production fails completely as in case of copper deficiency in wheat (Robson and Snowball, 1986). Field experimentation is extremely expansive and time consuming, and it is impractical to carry out experiments on each and every field. In case of pot experiments results cannot be extrapolated immediately to field situations. Hence, soil testing and plant analysis remain the only practical approaches for diagnosing nutritional disorders and formulating fertilizer recommendations (Rashid, 1996). However, soil testing only informs about the amount of a nutrient available at a given moment that may not correlate with the amount actually taken up by the plants. When plant analysis is used in conjunction with soil testing, it becomes a highly useful tool not only in diagnosing the nutritional status but also an aid in management decisions for improving the crop nutrition. Plant analysis, also referred to as foliar/leaf/tissue analysis, is the quantitative analysis of the total nutrient content in plant tissue, based on the premise 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; Rashid, 1996; Tisdale *et al.,* 1990). It is a very practical and useful technique for fruit trees and long duration crops (Rashid, 1996). Hence, it seems quite convenient and appealing for banana also. Banana, having a root system spread in the top 60 cm soil (Shanmugavelu *et al.,* 1992), is a heavy feeder of nutrients. Being an exhaustive crop, its growth and fruit production need proper manuring and fertilizer application for potential yields. Deficiency or excess of nutrients can cause considerable damage to the plant. Almost all the approaches discussed above, coupled with diagnostic surveys on the basis of management history, are used to evaluate the nutritional status of bananas. Until the mid-1960s, researches on bananas' 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 the last twenty-five years, there has been an attempt by numerous workers to understand more clearly the role of nutrients in the growth and development of the plant. Field studies of fertilizer response are still being conducted, but attempts

to relate nutrient concentrations in the soil and the 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 the banana, 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. This paper reviews the available researches on banana nutrition management through plant analysis.

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 ranges, 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). Hence, it can be successfully used to identify the hidden hungers of plants (Potash and Phosphate Institute, 1997). 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. A 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, age, plant part, time sampled and fertilizer applied 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 following steps for developing standard nutrient concentrations for these crops.

1. 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.
2. Conduct a district-wide survey of highly productive orchards to define mean concentrations for a number of nutrients in the defined sample tissue.
3. With a statistical analysis of the survey as a basis, define for each nutrient a standard "range" that is adequate for high production. 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, the most frequent being either verification of deficiency symptoms or crop logging (Jones *et al.,* 1991). Krantz *et al.* (1948) gave four principal objectives for the utilization of a plant analysis result:

1. To aid in determining the nutrient supplying power of the soil
2. To aid in determining the effect of treatment on the nutrient supply in the plant
3. To study relationship between the nutrient status of the plant and crop performance as an aid in predicting fertilizer requirements
4. To help lay the foundation for approaching new problems or for surveying unknown regions to determine where critical plant nutritional experimentation should be conducted

The commercial uses of plant analysis data as given by Smith (1986) include:

1. Diagnosis of nutrient deficiencies, toxicities, or mineral imbalances
2. Prediction of nutrient deficiencies in current or succeeding crops
3. Establishment of fertilizer recommendations
4. Monitoring of the effectiveness of current fertilizer practices
5. Assessment of the amounts of key minerals removed in crop residues with a view to replacing them and thus maintaining soil fertility
6. Estimation of the overall nutritional status of regions, districts, or soil types
7. Prediction of crop yields
8. Estimation of nutrient levels in diets available to livestock

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).

Banana Sampling 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, 1996). Sampling procedures have been investigated by many researchers (Dumas, 1959; Lahav, 1970; Martin-Prevel *et al.,* 1969; Turner and Barkus, 1977; Twyford and Coulter, 1964). Earlier, researchers at the Jamaica Banana Board (Hewitt, 1953; 1955; Hewitt and Osborne, 1962) and IRFA, Guinea (Dumas, 1952; 1960a; Dumas and Martin-Prevel, 1958), 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, variety of procedures were proposed and used. Later on, Martin-Prevel (1974; 1980) came up with a measure of uniformity to sampling methods by surveying the methods used in different countries (Fig.1). 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 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. 2). The samples should normally be taken either just before or following floral emergence and when all female hands are visible. (Lopez and Espinosa, 2000; Martin-Prevel, 1974; 1976; 1977). However, the age of the tissue to be sampled depends on the nutrient being diagnosed (Lopez and Espinosa, 2000). For example, 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 leaf 3 is sampled for tissue analysis. However, samples of the central vein of leaf 3 and the petiole of leaf 7 are also used. The laminar structure of leaf 3 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 and 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, 1996). Recent development in sampling methods and some of the unresolved issues was reviewed in detail by Martin-Prevel (1980), who 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 its mineral content, 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.3). 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, as shown in Fig. 3 is somewhat less in the central part of the leaf than it is in the basal and distal areas. 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. Martin-Prevel and his co-workers (1968 and 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 N status. It is, however, easier to define and locate a petiole sample than a midrib sample. Hewitt (1953 and 1955) 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 climatic and soil conditions (Lahav, 1972b and 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 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 shot 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 finders per hand and also assess growth by measuring the circumference of the pseudostem at a standard height. A disadvantage is there 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 and 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 Du Plessis (1977) attempted to determine the nutritional status of Dwarf cavendish banana in South Africa. They analyzed various plant parts in fertilizer experiment 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 from 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 (treatment) 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 been proposed and used as follows.

The Critical level Concept: Tissue analysis is based on the understanding that direct relationship exist among nutrient supply and yield, nutrient supply and tissue nutrient concentration, and tissue nutrient concentration and yield (Malavolta, 1994). This relationship is illustrated in Fig.4. Incorrect interpretation of tissue analysis can easily occur when the interpreter is not familiar with the relationship between dry matter accumulation and nutrient concentration. In the diagram, section A, known as the Steenbjerg effect, is the result of a small amount of dry matter relative to tissue nutrient concentration or, in other words, small plants with an apparently high nutrient content. Section B of the curve represents better plant growth that is severely nutrient deficient, and this progresses into section C where moderate nutrient deficiency exists, followed by section D that depicts luxury consumption. The critical level is found at the transition point between section C and D. Tissue concentrations greater than this critical level have no further benefit on growth and yield. Alternatively, plant with tissue concentrations lower than the critical level have a high probability for a growth or yield response to application of the limiting nutrient. Section E of the curve represents toxic nutrient levels that reduce crop growth and yield (Lopez and Espinosa, 2000). The concept of critical nutrient concentration is most widely used for assessing plant nutrient status. Ulrich (1952) gave three formal definitions of the critical nutrient concentration: the nutrient concentration that is just deficient for maximum growth, or that which is just adequate for maximum growth, or the concentration separating the zone of deficiency from the zone of adequacy. According to Jones *et al.* (1991), a critical value is that concentration below which deficiency occurs. A single value is difficult to use when plant analysis result is interpreted for concentrations above or below the critical value. Some authorities have suggested that the twin transition zone be used to designate that range in elemental concentration that exists between deficiency and sufficiency. Others have termed this range in concentration as critical nutrient range (CNR). 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. 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. 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.

Critical Levels of NPK in Banana: 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. Hewitt (1955) identified the critical N, P and K levels as 2.6, 0.19 and 2.74%, respectively. Ramaswamy and Muthukrishnana (1974) reported that a critical level of N = 1.40% 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

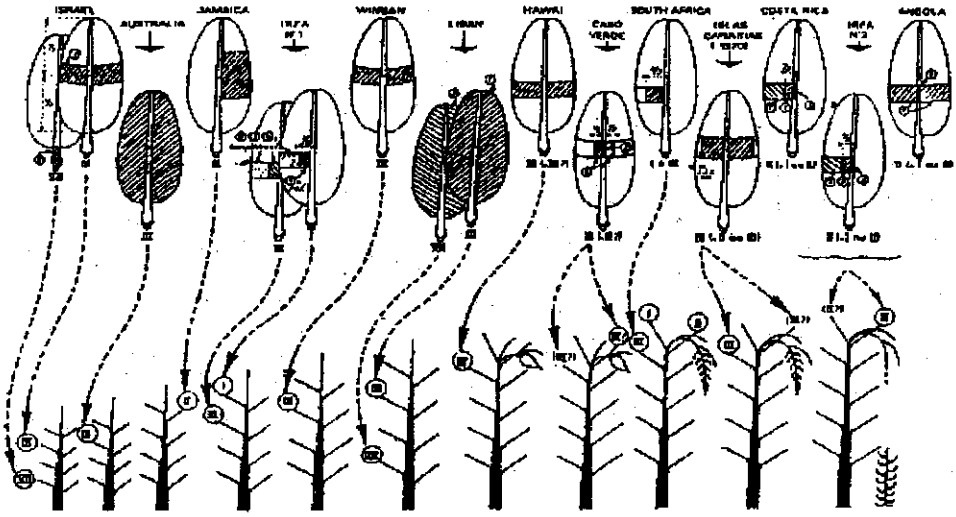

Fig.1 Sampling methods used in different countries (Martin-Prevel, 1977).

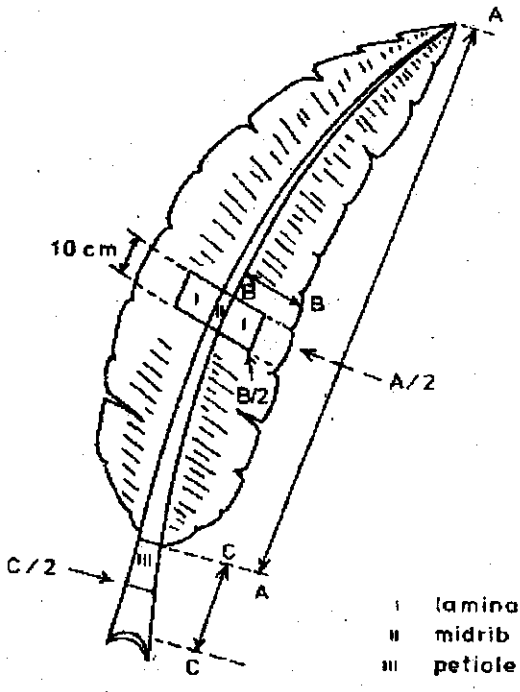

Fig.2 Sampling procedure for banana leaves (Martin-Prevel, 1977).

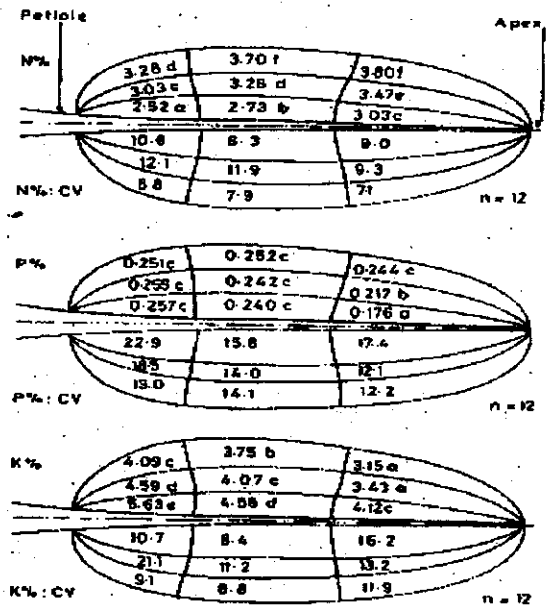

Fig.3 Nutrient contents of different parts of the leaf blade of banana cv. Dwarf Cavendish. Figures in upper half of leaf are mean nutrient content of n leaves as % of DM and figures in the lower half are coefficients of variation of those means (Dumas, 1960b).

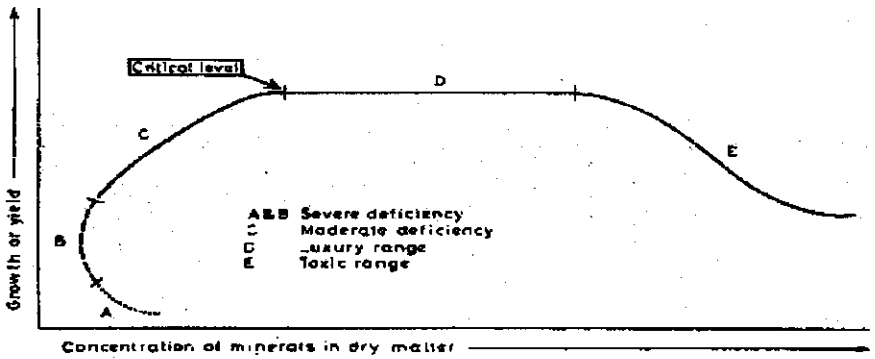

Fig.4 General relationship between plant growth or yield and elemental content of the plant (Smith, 1962).

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 percent for N, P, K, Ca and Mg respectively. The study by Valsamma Mathew (1980) revealed 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 and Turner (1992) forwarded a summary of proposed critical levels in different banana tissues (Table 1). 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 diagnostician is needed to interpret the crop analysis results in terms of the overall production conditions (Tisdale *et al.*, 1990). 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 and 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 fertilizer 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.*, 1990). 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. DRIS is based on the interrelationships among nutrients. Walworth and Sumner (1987) addressed the principles of this innovative technique. 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. 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. The critical values were compiled and averaged. Except for K and its ratios and products with other nutrients, DRIS norms were very 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.

Some important considerations in plant Analysis Interpretation: It is more reliable to define nutrient concentrations in ranges wherein maximum economic yield can be obtained (Potash and Phosphate Institute, 1997). The condition of the crop (i.e., growth and development) at the time of sampling is important for interpreting tissue analysis data (Lopez and Espinosa, 2000). One successful strategy involved estimating plant growth condition by measuring plant size or by counting the number of hands per bunch. This information combined with nutrient tissue concentrations provides an estimate of total nutrient content of the plant, and thereby helps avoid incorrect tissue analysis interpretations (Lahav and Turner, 1992). Both tissue nutrient concentration and rate of biomass production at sampling time be considered. With this approach, the intensity of a nutrient demand as well as the quantity of the nutrient in the whole plant is determined (Martin-Prevel, 1987).

Research on Banana Nutrition with Special Reference to Pakistan: Banana requires high quantity of nutrients and gives excellent response to applied fertilizers. The amount and type of fertilizer applied to banana plantations depend upon the available nutrient status of their soils. A specific combination of chemical and physical characteristics in the soil profile will identify distinct, yet manageable areas on the farm. Therefore, fertilizer management should be practiced in accordance with the particular characteristics of each defined area (Lopez and Espinosa, 2000). Researches conducted all over the world to study various aspects of banana nutrition. Following is an overview.

Banana Response to Applied Fertilizers: Researchers attempted to study the response of banana to applied fertilizers. Ramaswamy and Muthukrishnana (1974) studied on the effect of nitrogen on newly planted Robusta banana, using N at 0-255 g/plant, and constant levels of P_2O_5 and K_2O (85 and 285 g/plant, respectively). Several months after planting, leaf N rose to a maximum of 3.29% with N applied at 170 g/plant. At this N level, inflorescence emergence was accelerated and the period until harvest was shortened by 29 days, compared with plants receiving no N. The maximum cropping response in terms of hand and fruit numbers per bunch and bunch and fruit weight was also obtained with N at 170 g/plant. Singh *et al.* (1975) reported that when N (at 168 g/plant) + K (at 336 g/plant) were applied (with adequate P at 84 g/plant), an increased yield of 5.75 kg/plant was obtained, whereas N and K individually showed an increase of 3.25 kg and 1.00 kg/plant respectively. The number of hands and fingers were increased by the application of N, while the response to K was due to increased weight, volume and density of the fruit. The fruit quality of Robusta banana was appreciably improved by treatment having K combinations. Jambulingam *et al.* (1975) worked on the effect of potassium on Robusta banana and reported a significant increase in K content of leaves after soil application of 360 g K_2O per plant. Higher rates of K_2O significantly increased the pseudostem heights, girth, leaf area, sucker production and enhanced earlier flowering and maturity with good graded bunches. Potash also had a pronounced effect on fruit titratable acids and soluble solids. Lahav (1976) studied the effect of manure and fertilizer application on the nutrient content of William hybrid (banana sucker). He analyzed the third leaf blade and seventh leaf petiole for mineral analysis. The treatments of (a) three rates of chicken manure (3, 4.5 and 6 m^3/1000 m^2) and 3 rates of FYM (6, 9 and 12 m^3/1000 m^2) and (b) increased application of nitrogen and potassium fertilizers. All manures and fertilizers increased the K level and the N level (slightly) in the sucker while reducing the levels of Ca and Mg, the P level was affected by the manures only. Chicken manure was equal to F.Y.M as a source of N and K and preferable as a source of P. The K/Ca+Mg ratio was a much better criterion of the K nutritional status of the sucker than sample K analysis. The seventh leaf petiole

was preferable to the third leaf blade, under field conditions as a sampling organ for ascertaining K, Ca, Mg and P levels. Its use for N analysis needed further clarification. Singh *et al.* (1977) studied the effect of NPK fertilizers on growth, yield and quality of banana cv. Basrai. They recommended the application of 150: 90: 170 NPK supplemented with 20 kg compost/plant. Pillai *et al.* (1977) studied the response of Nendran banana to different levels of N, P and K. The results revealed that the optimum dose of N and K_2O corresponding to maximum yield of fruit was 191 and 301 g per plant respectively. Pillai and Khader (1980) conducted fertilizer studies on Robusta banana. The study revealed that the plants receiving 100:40:400 kg NPK/acre in three split doses produced significantly heavier bunches (26.6 kg). The number of hands and fingers recorded in this treatment were also largest. Valsamma Mathew (1980) studied the effects of nitrogen nutrition in rainfed banana cv. Palayankoda. The treatment levels were 0, 100, 200, 300 and 400 g of nitrogen per plant. The study revealed that at higher levels of nitrogen the total crop duration increases. The yield was maximum in plants receiving 200 g N/plant even though there was not significant variation between treatments. On an overall analysis of qualitative parameters it was found that the level of 200 g N/plant was superior to the rest. Hernandez *et al.* (1981a, 1981b) studied the effect of rates of nitrogen for banana (Musa paradisiaca and Musa sapientum). Rates of 0 to 300 g N/plant/yr and 50 and 300 g/plant/yr P_2O_5 and K_2O respectively, were tested on a ferrallitic soil of high P and K contents. Nitrogen significantly increased yield, hands and fruit number, but had no effect on fruit length, diameter and weight in both the species. No significant differences in the variables were obtained with rates of N higher than 150 g/plant/yr (Musa paradisiaca) and 100 g/plant/yr (Musa sapientum). Kohli (1984) studied the growth, dry matter production and yield of Robusta banana as influenced by different levels of nitrogen. Nitrogen was applied at 0-750 g/plant + PK basal dressing. Flowering was considerably delayed when no N was applied. Dry matter production was greatest in response to 150-300 g N/plant that also resulted in the highest yield. A significant correlation between yield and leaf N content was observed at the 16th leaf stage. Baruah and Mohan (1985) studied the effect of potassium on vegetative growth of banana (Musa cavendish) grown on an acid sandy loam soil. Suckers were planted at 1.8 X 1.8 m, and 130 g N and 13 g P were applied per plant. Potassium was applied at five different levels, viz. none (control), and 83, 166, 250 and 330 g per plant. Height and diameter of the pseudostem responded significantly to K with the highest effect at 250 g. On average, the number of leaves per plant increased with increasing K application, and leaf area index showed a significant difference after 6 months and at shooting. The number of suckers produced by each plant was highest at 330 g and lowest at zero K. Degade (1986) studied the effects of graded levels of nitrogen, phosphorus and potassium fertilization on growth, yield and nutrient status of basrai banana. Based on an investigation at the Banana Research Station, Yaval (India), he recommended fertilizer rates for bananas as 100 g N, 40 g P_2O_5 and 100 g K_2O per plant. Dave *et al.* (1990) studied the nutritional requirements of Banana cv. Basrai grown on deep black soils at two locations in South Gujrat. The fertilizer application rates for $N:P_2O_5:K_2O$ were: 45:45:45, 180:180:180 and 270:270:270 grams per plant. The leaf contents of N, P and K were closely related to the fruit yield, indicating that fruit yield can be increased by increasing the nutrient use efficiency of the plant. They recommended the application of 180:180:180 g of fertilizer per plant for the banana crop in South Gujrat. Sheela and Aravindakshan (1990) attempted to determine the production of dry matter and uptake of nutrients in rainfed banana Musa (AAB group) 'Palayankodan' as influenced by different levels of potassium. The crop received K_2O at 0, 300, 400 or 600 g/plant as muriate of potash, and N and P_2O_5 were each applied at 200 g/plant as basal dressing. All fertilizers were applied in 2 equal split doses at 90 and 150 days after planting. The plant material was sampled at 4 stages of crop growth. The total DM production increased with increasing K rates. The total N uptake increased between the early vegetative phase and the shoot development phase and then declined. K rate had no effect on N uptake whereas P and K uptake increased with rising K rate. Of the 3 nutrients, the uptake of K was the highest. Dave *et al.* (1991) worked on tissue analysis and nutrient requirement in banana. They conducted field experiments on Basrai variety of banana during 1982-83 at two locations. They planted rhizomes weighing 500 + 50 g in 30 x 30 x 30 cm pits filled with 5 kg well decomposed FYM at a spacing of 1.8 x 1.8 m. NPK at 45+45+45, 180+180+180 or 270+270+270 g/plant was applied in 3 equal split applications. Samples from the third leaf lamina were collected and analyzed for nutrient content at the sucker, large, pre-shooting and harvesting stages. A multiple regression analysis was performed to determine the relationship between leaf nutrient content and fruit yield and yield components. At one location, N and K showed a higher degree of association with yield, while at other only P showed this association. Fertilizer rate had no significant effect on fruit yield at either location. El-Khoreiby and Saleem (1991) determined the effect of potassium on the vegetative growth and the nutritional status of Dwarf Cavendish banana. They applied potassium at 100, 200, 300, 400 or 500 g K_2O/plant in 10 split applications from July 1988 to July 1989; no applications were made in Nov., Dec. or Jan. N and P fertilizers were also applied. The height and basal circumference of the pseudostem responded positively to the highest K application rate. At this rate, the plants were more vigorous, there was a greater leaf surface area, and the leaves contained balanced and adequate concentrations of macro-and micronutrients. It was concluded that an application rate of 400 g K_2O/plant was the most effective and economic. Gubbuk *et al.* (1991) worked on the effects of different application rates of nitrogen and farmyard manure on the nutrient concentrations in leaves of the banana cultivars Cavendish and Basrai grown in greenhouse. They applied nitrogen at 0, 80, 160 or 320 g/mat and FYM at 0, 75, 150 or 225 kg/mat, in various combinations. Data were tabulated on the leaf concentrations of N, P, K, and micronutrients. Increasing rates of N reduced the foliar concentrations of N and K; other nutrient concentrations were not markedly affected by N application. Increasing FYM rates significantly increased the foliar K in both cultivars, foliar N was highest with 225 kg/mat.

Split Fertilizer Application: Split application of fertilizers significantly increases fertilizer use efficiency, which ultimately translates into higher profits. Pacheco *et al.* (1986) recorded significant reductions in N losses when the total N rate was split into several applications.

Fertigation in Banana: Banana plants require permanent soil moisture for normal physiological functioning (Soto, 1992), making irrigation necessary in drier banana growing areas. In these cases, irrigation offers the possibility of applying nutrients along with water, a technique known as fertigation (i.e., fertilization + irrigation). Fertigation is often superior to conventional fertilization techniques because water is supplied with nutrients (Halevy and Bazelet, 1992). However, fertigation does require the use of high quality liquid or soluble dry fertilizers that are virtually free of impurities (Lopez and Espinosa, 2000).

Use of Organic materials alone or with chemical fertilizers: The use of organic materials together with inorganic fertilizers is a common practice in several banana zones in the world. Lahav and Turner (1992) report good results with the application of up to 500 t of organic materials/ha/year. Earlier, Lahav (1972c) found excellent results with a combined application of 80 t/ha/year of manure together with mineral fertilizers. The application of organic residues of up to 7 t/ha together

with 3 t/ha of $CaCO_3$ in small, hilly red soil areas of Costa Rica have produced excellent results (Lopez and Espinosa, 2000).

Banana Nutrition Management in Pakistan: Banana is cultivated in all four provinces of Pakistan. Sindh is the leading banana growing province. About 87% of the total banana area in Pakistan is planted in Sindh Province with a production of 89% of the total banana production in Pakistan (Bukhari and Arain, 1991). Since its introduction in Sindh, a number of experiments have been conducted, primarily at Horticulture Research Institute, Mirpurkhas, to determine NPK requirements for banana. Jagirdar (1961) reported that 250 kg N, 26 kg P, and 500 kg K are removed by one growth cycle of banana to produce 72 tonnes of fruit/ha. Ahmed (1979) reported that NPK at 450-225-450 kg/ha showed a significant trend in increasing height, bucnh weight, number of hands and fingers per bunch and total yield. Shaikh *et al.* (1986-87) attempted to determine the effect of different fertilizer doses and sources on growth and production of banana at village Rawat Leghari, Mirpurkhas during 1984-86. The William hybrid was planted for evaluating the two sources of complex fertilizers: NPK 17-17-17 (nitrate-based) and NPK 13-13-21 (sulphate-based) under three fertilizer doses of 400-150-400, 500-150-500 and 600-200-600 kg/ha. The total dose of fertilizer was applied in 10 equal splits - once every month from the month of February to November. They concluded that the number of hands per bunch, weight of bunch and yield of banana were highest at the fertilizer dose of 600-200-600 which was followed by 500-150-500 and 400-150-400. Sulphate-based fertilizer NPK 13-13-21 applied at the rate of 500-15-500 produced similar number of hands per bunch (8.87), weight of bunch (15.98 kg) and yield (47.35 tonnes/ha) to that of nitrate-based fertilizer NPK 17-17-17 applied at the rate of 600-200-600 which produced 9.15 hands per bunch, 16.5 kg/bunch and 48.88 tonnes/ha hands yield. Based on the experiments conducted at Sindh Horticulture Research Institute, Mirpukhas Memon and Leghari (1996) recommended application of 20 kg/plant or 200 mds/acre FYM, 8 bags of urea, 4 bags of T.S.P (triple super phosphate) or 10 bags of S.S.P. (single super phosphate) and 8 bags of SOP (sulphate of potash) per acre for obtaining highest banana yields. Bhatti *et al.* (1995) suggested same recommendation for optimum yield of banana in Sindh. Wiebel *et al.* (1994) attempted to determine the nutritional status of 12 Dwarf cavendish banana plantations (var. Basrai) in Kot Ghulam Mohammad region. Six sites each were under standard and progressive management, respectively, the latter with higher input of fertilizer and labour weeding. They collected leaf samples following the MEIR method and corresponding soil samples from the top layer (0-20 cm) and the sub-layer (20-50 cm). Banana plants were in 10th to 14th growth cycle. Fertilizer application (N, P and K) and weeding frequency were significantly higher under progressive management compared to standard management, resulting in more vigorous plants as indicated by height and circumference of the pseudostem, and higher yield. Average rate of N, P and K was at 169-68-21 kg/ha/year respectively under standard management, while under progressive management, NPK rate was at 492-156-325 kg/ha/year. Higher fertilizer application of nitrogen under progressive management was reflected by significantly higher N concentration in the leaf tissue (Table 2). However, P and K content of leaves were similar for bananas under progressive and standard management. Nitrogen concentrations in the leaf tissue under standard management (2.23%) were below the tentative critical value (2.60%) given by Lahav and Turner (1983). The occurrence of N deficiencies in such plants was already manifested in the chlorotic appearance of leaves and pseudostem. Potassium concentration in the leaf tissues of bananas under both management systems was also below the tentative critical value (Lahav and Turner, 1983), but typical symptoms were not observed (Table 3). Soil analysis (Wiebel *et al.*, 1994) revealed significantly higher P but lower K content in soils under progressive management. Lower Na and Cl, lower pH and EC indicated more favourable growing conditions on such sites. Simple calculations of major gains and losses of N, P and K showed the negative balance of potassium in the nutrient cycle (Table 4). Losses (especially of N and K) by the wasteful practice of flood irrigation were not even considered in this calculation. However, leaching might be responsible for N deficiencies occurring in bananas under standard management in spite of positive balance for nitrogen. Banana yield of orchards surveyed in this study may be limited by N, K and Zn (the latter under standard management only).

Table 1: Suggested nutrient critical levels in different tissue of completely developed banana plants

Nutrient	Lamina (Leaf 3)	Central vein (Leaf 3)(%)	Petiole (Leaf 7)
N	2.600	0.650	0.400
P	0.200	0.080	0.070
K	3.000	3.000	2.100
Ca	0.500	0.500	0.500
Mg	0.300	0.300	0.300
Na	0.005	0.005	0.005
Cl	0.600	0.650	0.700
S	0.230	-	0.350
		(mg/Kg)	
Mn	25	80	70
Fe	80	50	30
Zn	18	12	08
B	11	10	08
Cu	09	07	05
Mo	1.5-3.2	-	-

(%) Data mainly based on the variety Dwarf Cavendish. Sometimes values differ in other cultivars

Table 2: DRIS norms and critical nutrient levels in the 3rd lamina of banana established from published sources.

Nutrient (expression)	DRIS	Critial value range	Av.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

Table 3: Nitrogen, phosphorus and potassium (% DW) concentrations in leaves of banana under standard and progressive management and tentative critical concentration (Lahav and Turner, 1983).

Nutrient element	Management		L.S.D. at 5%	Critical concnetration
	Standard	Progressive		
Nitrogen	2.23	2.69	0.20	2.60
Phorphorus	0.21	0.23	0.03	0.20
Potassium	2.61	2.71	0.21	3.00

Table 4: Gains and losses of N,P, and K with application of fertilizer and removal by furits in banana plantation under standard and progressive management

	Standard management			Progressive management		
Yield (t/ha/Year)	10.6			26.7		
Element	N	P	K	N	P	K
Removed by fruits (kg/ha/year)	40	6	165	101	16	415
Applied fertilizer	169	68	21	492	156	325
Gains & losses	+129	+62	-144	+ 391	+140	-90

Memon (1996) conducted a study to evaluate the N, P and K nutritional status of banana through plant analysis. Twelve Dwarf Cavendish cv. basrai banana plantations were selected at random from the banana growing areas of district Hyderabad. The study also included two fertilizer trials at two locations involving farmers' practice

(FP, av. rate 381-227-93 kg N-P-K/ha/year) and improved practice of fertilization (IP, 544-227-494 kg N-P-K/ha/year). Plant and soil samples were secured from each site during the month of June, and additionally in March from fertilizer trials. Crop management information viz. fertilizer and manuring practices, yield levels etc. were noted for each site. Plant and soil samples were analyzed for their N, P and K contents. The data were compared with the established critical levels to diagnose N, P and K nutritional status of banana. Attempt was also made to determine the relationship between plant content of N, P, and K and their concentration in associated soils. The quantity of fertilizer nutrients used by banana growers ranged from 136 to 682 kg N, 0 to 455 kg P_2O_5, and 0 to 185 kg K_2O/ha/year with average of 427 kg N, 240 kg P_2O_5, and 27 kg K_2O/ha/year. The banana growers rarely used potassium fertilizers. Manure application was common and ranged from none to 20.8 t/ha. Banana yields ranged from 14.8 to 44.5 t/ha and averaged to 30.3 t/ha. Analytical data showed that leaf contents of N, P and K ranged from 1.74% to 4.32% (average = 3.00%), 0.17 to 0.29% (average = 0.24%), and 1.99 to 3.56% (average = 3.15%) respectively. Nutrient levels were below the critical level of 2.6% N, 0.20% P and 3.00% K at 4 sites for N, and two sites each for P and K. Correlation between N application rates and the leaf N status showed a highly significant "r" value of 0.83. In case of P, the value of "r" was 0.57. The values for the coefficient of correlation (r) between soil and plant contents of N, P and K were all non-significant. Fertilizer response experiments showed that (IP) was superior to FP in that it increased leaf N from 3.10 to 3.87%, leaf K from 2.53 to 3.26%, and banana yield from 51.2 to 60.8 t/ha. Leaf P contents were, however similar under both FP and IP treatments. Regression analysis of the composite data (general and experimental sites) showed that leaf N could be predicted by the equation $Y = 0.624 + 0.0127x$, $R^2 = 0.92$, and it required 385 kg N/ha/year to achieve critical level of 2.6% N. In case of P, the relationship was given by $Y = 0.20 + 0.0004x$ with $R^2 = 0.36$. The results revealed that leaf analysis (3rd leaf from top) for N and K can be used to indicate N and K nutritional status of banana. Leaf analysis for P was, however, less indicative of the P nutritional status of banana.

Memon (1996) conducted a preliminary study to evaluate the micronutrient (Cu, Fe, Mn and Zn) status of banana in which plant and soil samples were randomly collected from 12 banana plantations, and two NPK fertilizer experiments in district Hyderabad. Plant and soil samples were analysed for Cu, Fe, Mn and Zn along with physico-chemical properties of the soil. The quantity of various fertilizers, used by banana growers, ranged from 136-682 kg N, 0-455 kg P_2O_5 and 0-185 kg K_2O/ha/year with average of 427 kg N, 240 kg P_2O_5 and 27 kg K_2O/ha/year. Manure application rates ranged from none to 20.8 t/ha. The quantity of micronutrients added through the application of manure ranged from 0.0-0.33 kg Cu, 0.0-62.40 kg Fe, 0.0-3.22 kg Mn and 0.0-3.68 kg Zn/ha. On an average basis, the values were 0.21 kg Cu, 39.33 kg Fe, 2.03 kg Mn and 2.32 kg Zn/ha. Banana yields, ranged from 14.8 to 44.5 t/ha with average of 29.3 t/ha. Plant removal of micronutrients ranged from 0.10 to 0.32 kg Cu, 1.74 to 5.2 kg Fe, 3.20 to 11.11 kg Mn and 1.39 to 4.17 kg Zn/ha. On an average, the removal of micronutrient was 0.21 kg Cu, 3.45 kg Fe, 7.33 kg Mn and 2.75 kg Zn/ha. Analytical data showed that leaf content of Cu, Fe, Mn and Zn ranged from 9 to 26 mg/kg (average = 18 mg/kg), 183 to 559 mg/kg (average =289 mg/kg), 199 to 538 mg/kg (average = 403 mg/kg) and 11 to 35 mg/kg (avarage = 21 mg/kg) respectively. Quantity of Cu, Fe and Mn was adequate in all the plant and soil samples. Zinc was the only micronutrient that was below the critical limits for banana nutrition. The values for the coefficient of correlation (r) between soil and plant content of Cu, Fe, Mn and Zn were all non-significant. Fertilizer response experiments showed that improved practice (IP, 544-227-494 kg N-P-K-/ha/year) was superior to farmer's practice (FP, av. rate 381-227-93 kg N-P-K-/ha/year) in that it increased banana yield from 51.13 to 60.76 t/ha. Leaves content of micronutrients were higher than their critical levels for June sampling. March sampling data showed adequate nutrition of Cu, Fe and Mn but Zn was below the critical level. Soil status of micronutrients also reflected the same situation as observed for March sampling. The results of this study showed that Cu, Fe and Mn status of plants and soils from banana plantations of district Hyderabad was adequate for proper nutrition of banana. Zinc was the only nutrient that appeared to be in deficient supply in both the plants and associated soils. March sampling appeared to better reflect the nutritional status of banana than June sampling.

Later on Abro (1997) conducted a study to determine the NPK status of banana through soil and plant analysis. Twenty-four dwarf cavendish banana plantations (cv. basrai) were selected at random in banana growing areas of the district Hyderabad. Plant and soil samples were secured from each site during the months of May to August, 1996. Crop management information viz. fertilizer and managing practices, yield levels etc. was noted for each sampling site. The samples were analysed for their N, P and K contents. The data were compared with established critical levels to diagnose N, P and K nutritional status of banana. Attempt was also made to determine the relationship between plant content of N, P and K and their concentration in associated soils. The quantity of fertilizer nutrients used annually by banana farmers ranged from 80-783 kg N (av. = 427 kg N), 58 to 682 kg P_2O_5 (av. = 217 kg P_2O_5) and 0-308 kg K_2O (av. = 20 kg K_2O)/ha/year. Banana farmers rarely used potassium fertilizer. Manure application rates ranged from 0-33 t/ha (av. = 9 t/ha) and banana yields from 6 to 44 t/ha (av. = 26 t/ha). The soils supporting banana plantations were medium to heavy in texture, non-saline (EC = 0.17 to 0.86 dS/m) with pH 7.2 to 8.1. Organic matter, available P and NH_4OAc K contents of surface soil ranged from 0.50 to 1.30%, 2.9 to 40.3 mg/kg and 0.46 to 1.15 me/100 g respectively. Plant analytical data showed that leaf N, P and K contents ranged from 2.04 to 3.56% N, 0.096 to 0.267% P and 3.10 to 4.07% K. Nutrient levels were above the critical level of 2.6% N, and 3.00% K at all the sites except two sites, which were deficient in N only. In case of P, 45% of the sites were below the critical level of 0.2% P. The relationship between surface soil P and leaf P contents was highly significant (r = 0.52) and that of soil K and leaf K was significant at 6%. The results revealed that leaf analysis (3rd leaf from top) could be used to indicate N, P and K nutritional status of banana.

References

Abro, S. A. 1997. NPK fertilizer management and nutrition of Banana in District Hyderabad. Thesis Dept. Soil Sci., Sindh Agriculture University, Tando Jam. Sindh, Pakistan.

Adinarayana, V., D. Balagurvaiah, Y.N. Rao, P.N. Rao, I.V. Subb-Rao, and I.V.S. Rao.1986. Potassium and sodium disorders in banana. J. Potassium Research. Regional Agric. Res. Sta. Lam. Guntur, Andhra Pradesh. 2: 102-107.

Ahmed, M. 1979. Irrigation-cum-fertilizer trial on Basrai banana. M.Sc. Thesis, Sindh Agric. Univ. Tando Jam.

Angeles, D.E., M.E. Sumner, and E. Lahav. 1993. Preliminary DRIS norms for banana. J. Plant Nutrition. 16: 1059-1070.

Arunachalam, A., N. Ramaswamy, and C.R. Muthukrishnana. 1976. Studies on the concentration in leaf tissue and fruit yield with nitrogen level for Cavendish clones. Prog. Hort. Annamlai Univ., Annamalainagar, India. 8:13-22.

Baruah, P.J., and N.K. Mohan. 1985. Effect of potassium on vegetative growth of banana (Musa, AAA, Cavendish subgroup "Jahaji"). Banana Newletter. Assam Agri. Univ. Jorhat, Assam, India. 8:23-24.

Beaufils, E.R. 1973. Diagnosis and recommendation integrated system (DRIS). Soil Science Bull. University of Natal, South Africa.

Bevege, D.I. 1978. Foliar analysis as a guide to the nutrient status of tropical pines. In: Plant Nutrition. (Eds. A.R. Ferguson, R.L. Beileski, and I.B. Ferguson), Government Printer:Wellington. 1:53-60.

Bhatti, I.B.M., S.J.I. Bukhari, A. Hussain, and H.I. Majidano. 1995. Cultivation of banana. Sindh Horticulture Research Institute, Mirpurkhas. p. 1-8.

Bukhari, S.J.I., and S.A. Arain. 1991. Banana cultivation in Sindh. Paper presented at the National Seminar on Banana Disease Problem in Sindh, Present Status, and Future Control Strategies. Dept. Agri., Govt. Sindh.

Dave, S.K., J.S. Katrodia, and M.L. Patel. 1990. Nutrition and growth of banana cv. Basrai in deep to black soils of South Gujrat. Fertilizer News. Gujrat Agric. Univ. Navsari Campus, India. 35:19-26.

Dave, S.K., J.S. Katrodia, and M.L. Patel. 1991. Studies on tissue analysis and nutrient requirement in banana. Indian Journal of Horticulture, Gujrat Agric. Univ. Navsari, India. 48:305-308.

Degade, V.G. 1986. Effects of different levels of nitrogen, phosphorus and potassium fertilization on growth, yield and nutrient status of basrai banana. Indian J. Agri. Chem. Depat. Agric. Chem. and Soil Sci., College of Agric. Pune, India. 19 :1-7.

Dumas, J. 1952. Rapport Annul: Laboratoire de nutrition vegetale, R.A. IRFA Guinée. 6:1-5.Dumas, J., and P. Martin-Prevel. 1958. Controle de nutrition des bananeraies en Guinee (Premiers resultats), Fruits. 13: 375-386.

Dumas, J. 1959. Etude de la du bananier pour echantillonr dans less essais et les plantations. In: Nutrition minerale et Engrais (Ed. IFAC) Paris. p. 54-57.

Dumas, J. 1960a. Controle de nutrition de quelques bananeraies dans trois territoires africains, Fruits. 15:277-290.

Dumas, J. 1960b. Etude de la feuill du bananier pour echantillonner dans les essis et les plantations, In: Nutrition Minerale et Engrais, IRFA, Paris. p. 54-57.

Dumas, J., and P. Martin-Prevel. 1958. Controle de nutrition des bananaeraies en Guinee (Premicrs), Fruits 13:375-386.

El-Khoreiby, A.M.K., and A.T. Saleem. 1991. Effect of potassium on th vegetative growth and the nutritional status of Dwarf Cavendish banana. Bull. of Agri. Univ. Cairo. 42:247-258.

Fernandez-Falcon, M., and R.L. Fox. 1985. Effect of nitrogen and potassium fertilization on the yield of banana. Anales-de-Edafologia-Y-Agrobiologia. 44: 1439-1452.

Fox, R., B. King, and G.Wilson.1979. A comparative study of the sulfur nutrition of banana and plantation. Fruits 34:525-534.

Gubbuk, H., S. Paydas, and N. Kaska. 1991. The effects of different application rates of nitrogen and farmyard manure on the nutrient concentrations in leaves of the banana cultivars Cavendish and Basrai. Bahce. 20: 33-39.

Halvey, J. y M. Bazelet. 1992. Fertilization del algodon para rendimientos altos. IPI-INPOFOS. Quito, Ecuador.

Hernandez, T., F. Robaina, and T. Garcia. 1981a. Rates of nitrogen on banana (Musa Paradisiaca) var. "Hembra 3/4". Ciencia Y Tecnica en la Agriculture, Suclos Y Agroquimica. Estacion Experimental de Nutrition Vegetal "La Renee". La Habana, Cuba. 4:7-18.

Hernandez, T., F. Robaina, and T. Garcia. 1981b. Effect of different rates of nitrogen on banana (Musa sapintum) var. Giant Cavendish (Victoria). Ciencia Y Tecnica en la Agriculture, Suclos Y Agroquimica. Estacion Experimental de Nutrition Vegetal "La Renee". La Habana, Cuba. 4: 33-43.

Hewitt, C.W. 1953. Leaf analysis: bananas, Dept. Agric. Jamaica, Bull. No. 53:10.

Hewitt, C.W. 1955. Leaf analysis as a guide to the nutrition of bananas. Emp. J. Exp. Agri.23: 11-16.

Hewitt, C.W., and R.E. Osborne. 1962. Further field studies on leaf analysis of "Lacatan" bananas as a guide to the nutrition of the plant. Emp. J. Exp. Agric. 30:249-256.

Jambulingam, A.R., N. Ramaswamy, and C.R. Muthukrishnana. 1975. Studies on the effect of potassium on Robusta banana. Potash Review. 27:4-6.

Jagirdar, S.A.P. 1961. Banana culture in Pakistan. Punjab Fruit J. 14: 11-25.

Jones, Jr. J. B., B. Wolf, and H.A. Mills. 1991. Interpretation of results. In: Plant Analysis Handbook - a practical sampling, preparation, analysis, and interpretation guide. Micro-Macro Publishing Inc., Georgia, USA. p. 40-41.

Kohli, R.R., Y.T.N. Reddy, and B.R.V. Iyengar. 1984. Growth, dry matter production and yield in Robusta bananan as influenced by different levels of nitrogen. Indian J. Hort.. Indian Institute of Horticulture Research, Banglore, India. 41:194-198.

Kotur, S.C., and M.M. Mustaffa. 1984. Effect of spacing and nitrogen on the leaf nutrient status of Robusta banana. South Indian Horticulture. Central Horticultural Experiment, Karnataka.32: 324-326.

Krantz, B.A., W.L. Nelson, and L.F. Burkhart. 1948. Plant tissue tests as a tool in agronomic research. In: Diagnostic Techniques for Soils and Crops. (Ed. H.B. Kitchen) The American Potash Institute, Washington, D.C. p. 137-156.

Lahav, E. 1970. The role of plant analysis and metabolic indicators in the determination of potassium levels in the banana plant. Ph.D. thesis, Hebrew Univ. Jerusalem.

Lahav, E. 1972a. Factors influencing the potassium content of the third leaf of the banana sucker. Fruits. 27:585-590.

Lahav, E. 1972b. The role of plant analysis in determining the potassium level of th banana plant. Fruits. 27: 855-864.

Lahav, 1972c. Effect of different amounts of potassium on the growth of banana. Trop. Agric. Trin. 49:321-335.

Lahav, E. 1976. The effect of manure and fertilizer application on the nutrienet content of the (William hybrid) banana sucker. Agri. Res. Org. Israel. 65:123-130.

Lahav, E. 1977. The suitability of sampling the leaf petiole for determining the mineral content of the banana sucker. Fruits. 32:297-307.

Lahav, E., and D. Turner. 1983. Banana nutrition. Inter. Potash Institute, Berne. Bull No. 7, p. 1-62.

Lahav, E., and D. Turner. 1989. Banana nutriton, Int. Potash Inst., Berne. Bull. 7, 2nd ed., p. 5-55

Lahav, E. y D.W. Turner. 1992. Fertilizacion del banano para rendimentos altos. Segunda edicion. Boletin. 7. Insti. de la Potasa y el Fosforo. Quito, Ecuador. 71 p.

Langenegger, W., and S.F. Du Plessis. 1977. The determination of the nutritional status of "Dwarf Cavendish" bananas in South Africa. Fruits. 32:711-724.

Leece, D.R. 1968. The concept of leaf analysis for fruit trees. J. Aust. Inst. Agric. Sci. 34:146-153.

Leece, D.R. 1976. Diagnosis of nutritional disorders of fruit trees by leaf and soil analyses and biochemical indices. J. Aust. Inst. Agric. Sci. 42:3-19.

Lopez, A. and J. Espinosa. 2000. Manual on the Nutrition and Fertilization of Banana. PPI, Canada. 57 p.

Macy, P. 1936. The quantitative mineral nutrient requirements of plants. Plant Physiol. 2:749-764.

Malavolta, E. 1994. Diagnostico foliar. In : Silva, F. (ed) Fertilidad de Suelos: Diagnostico y control. Sociedad Colombia de la Ciencia del Suelo. Bogota, Colombia. p 59-98.

Martin-Prevel, P., J.J. Lacoeuilhe, and J. Marchal. 1968. Les elements mineraux dans le bananier "Gross Michel" au Cameroun. Fruits. 23:259-269.

Martin-Prevel, P., J.J. Lacoeuilhe, and J. Marchal. 1969. Orientations du diagnostic foliaire bananier. Fruits. 24:153-161.

Martin-Prevel, P. 1970. Aspects dynamiques des elements mineraux dans la production vegetale: travaux sur bananier. Potassium Symp. 9:295-316.

Martin-Prevel, P. 1974. Les methodes d'echantillonnage pour l'analyse foliaire du bananier: resultats d'une enquete internationale et propositions en vue d'une reference commune. Fruits. 29:583-588.

Martin-Prevel, P. 1976. Le groupe international sur l'analyse foliaire du bananier, 4th Coll. Intern. Contr. Nutr. Min. Gand. II:571-575.

Martin-Prevel, P. 1977. Echantillonnage du bananier pour l'analyse foliaire: consequences des differences de techniques. Fruits. 32:151-166.

Martin-Prevel, P. 1980. La nutritional minerale du bananier dans le monde. Fruits. 35:503-518, 583-593.

Martin-Prevel, P. 1987. Banana. In: Plant Analysis as a guide to the nutrient requirements of temperate and tropical crops. Lavoisier Public. New York. EEUU. p 637-670.

Memon, A. B., and N.H. Leghari. 1996. Fertilizer use in banana. Jadid Zaree Khojina (Banana number). 4:5.

Memon, N. 1996. Evaluation of macronutrient (N, P, & K) status in banana plantations of district Hyderabad through Plant Analysis. M.Sc.Thesis Dept. Hort., Sindh Agri. Uni. Tando Jam. Sindh, Pakistan.

Memon, S. A.1996. Evaluation of micronutrient (Cu, Fe, Mn & Zn) status in banana plantations of district Hyderabad through plant analysis. M.Sc.Thesis Deptt. Hort. Sindh Agriculture University, Tando Jam. Sindh, Pakistan.

Okhi, K. 1987. Critical nutrient levels related to plant growth and some phsiological processes. J. Plant Nutrition. 10:1583-1590.

Pacheco, R., M. Gonzalez, y J. Briceno. 1986. Efecto del fraccinomiento de la fertilizacion nitrogenada en la lixiviacion de nitrato, potasio, calico y magnesio en un Andept de Costa Rica. Agronomia Costarricense. 10 :129-138.

Pillai, G.R., S.B. Balakrishnan, P. Gverararaghavn, G. Santha Kumari, and R. Gopalakrishnan. 1977. Response of Nendran banana to different levels of NPK. Agric. Res. J. Kerala. 15:37-49.

Pillai, G.R., and J.B.M. Md. Abdul Khader. 1980. Studies on fertilizer requirement of Robusta banana. Proc. Nat. Seminar Banana Production Bananan. Vatika. 1:10-14.

Potash and Phosphate Institute. 1997. Manual Inyernacional de Fertilidad de Suelos. PPI, Atlanta, Georgia.

Ramaswamy, N., and C.R. Muthukrishnana. 1973. The effect of N on fruit development of Robusta banana. Prog. Hort. 5:31-36.

Ramaswamy N., and C.R. Muthukrishnana. 1974. Effect of leaf nitrogen on composition and quality of Robusta banana. Annamalai Univ. Agric. Res. Annual. 4:34-37.

Rashid, A. 1996. Soils: Basic concepts and principles. In: Bashir, E. and R. Bantel (eds). NBF, Islamabad.

Ray, D.P., G.N. Parida, and B.K. Chatterjee. 1988. Nutrient concentration in leaf tissue with differerent nutritional levels in Robusta banana. Indian Agriculturist, Department of Horticulture, OUAT, Bhubaneswar, India. 32: 249-256.

Robson, A.D., and K. Snowball. 1986. Nutrient deficiency and toxicity symptoms. In: Plant analysis - An Interpretation Manual. (Eds. D.J. Reuter and J.B. Robinson). Inkata Press, Melbourne and Sydney. p. 13-19.

Shaikh, A.A., M.H. Baloch, M.S. Baig, and I.B. Dehraj. 1986-87. Effect of diffrent fertilizer doses and sources on growth and production of banana. Sindh J. Agri. Res. 6: 40-46.

Shanmugavelu, K.G., K. Aravindakshan, and S. Sathiamoorthy. 1992. Banana (Taxonomy, Breeding and Production Technology). College of Hort., Tamil Nadu Agri. Univ., Coimbatore. 2nd ed. p. 1-459.

Sheela, V.L., and M. Aravindakshan. 1990. Production of dry matter and uptake of nutrients in rainfed banana Musa (ABB group) Palayankodan' as influenced by different levels of potassium. South Indian Horticulture. 38: 240-244.

Singh, S.S., P. Kalyanasundaram, and C.R. Muthukrishnan. 1975. Studies on the effect of N and K on physico-chemical characters of Robusta banana. Musa cavendishii (Lambert) Auara. 4:23-33.

Singh, U.R., A. Khan, and G. Singh. 1977. Effect of NPK fertilization on growth, yield and quality of banana cv. Basarai Dwarf. Punjab Hort. J. 17: 64-69.

Smith, F.W. 1986. Interpretation of plant analysis: Concepts and principles. In: Plant analysis - An Interpretation Manual (Eds. D.J. Reuter and J.B. Robinson). Inkata Press, Melbourne and Sydney. p. 1-12.

Soto, M. 1992. Bananos, Cultivo y Comercialization. Segunda edicion, Imprenta Lil. San Jore, Costa Rica. 674 p.

Tisdale, S.L., W.L. Nelson, and J.D. Beaton. 1990. Soil fertility and fertilizers. 4th ed. New York: Macmillan Publishing Co.

Turner, D.W., and B. Barkus. 1977. A comparison of leaf sampling methods in bananas. Fruits. 32:725-730.

Twyford, I.T., and J.K. Coulter. 1964. Foliar diagnosis in banana fertilizer trials. Plant Anal. & Fert. Problems. 4:357-370.

Twyford, I.T., and D. Walmsley. 1974. The mineral composition of the Robusta banana plant. 1. Methods and plant growth studies. 2. The concentration of mineral constituents. 3. Uptake and distribution of mineral constituents. 4. The application of fertilizers for high yields. Plant and Soil. 39:227-343 (1973); 41:459-470, 471-491, 493-508.

Ulrich, A. 1952. Physiological basis for assessing the nutrient requirements of plants. Annu. Rev. Plant Physiol. 3:207-228.

Valsamma Mathew. 1980. Nitrogen nutrition in rainfed banana cv. Palayankodan. M.Sc. (Hort.) Thesis. KAU, Vellanillara.

Walworth, J.L., and M.E. Sumner. 1987. The diagnosis and recommendation intergrated system (DRIS). In: Advances in Soil Science (Ed. B.A. Stewart), Springer - Verlag, New York, NY. 6:149-188.

Wiebel, J., P. Ludders, and A. Krauss. 1994. Nutrient status of banana plantations in the Indus Plains of Sindh, Pak. J. Potassium Research. 10: 134-139.