2. Banana

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2.1. Introduction

The banana belongs to the family *Musa* and is grown in most tropical countries. It is an important food consumed world-wide and it can be eaten unripe or ripe, raw or processed (cooked, fried, roasted or processed). The fruit contains vitamins (A, B and C), minerals (calcium, potassium and iron) and has few calories (90 to 120 kcal/100 g). The fruit is approximately 70% water; the solid material is principally carbohydrates (23 to 32 g/100 g) with little protein (1.0 to 1.3 g/100 g) and fat (0.37 to 0.48/100 g).

In 2004, world banana production was approximately 73 million mt. The largest producer was India (23%), followed by Brazil (9%), then China and Ecuador (8% respectively). World production of plantains and bananas was 33 million mt. While the African continent, had the lowest production of plantains per unit area (5.72 mt/ha), it was nevertheless responsible for 70% of this total production. Major producing countries are Uganda (30% of the world production), Columbia (20%) and Rwanda (8%) (FAO, 2006).

In Brazil the banana is cultivated in the north and south on approximately 500,000 ha of land, ranging from the coastal region to the plateaus of the interior. In 2004, national production in Brazil was 6.5 mt, of which the south-eastern and north-eastern regions produced two-thirds. Ninety-nine percent of this production was for the internal market.

The banana tree is a herbaceous monocotyledon (after harvest the aboveground part is cut). It has a subterranean stem (rhizome) from which sprout the primary roots, in groups of three or four, to give a total of about 200 to 500 roots each about 5 to 8 mm wide. The roots are white and tender when young and healthy, turning gradually yellow and hard. The roots can grow horizontally up to 5 m, although more commonly 1 to 2 m, depending on the cultivar and the soil conditions, and about 40% are at a depth of 10 cm and 60 to 80% are concentrated in the top 30 cm layer of soil.

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The pseudostem is formed by overlapping leaf sheaths, closing around a cup of wide and long leaves, each leaf with a developed central vein. One plant may produce 30 to 70 leaves, with the appearance of a new leaf every 7 to 11 days. The inflorescence grows out from the centre of the cup, presenting reddish ovate bracts, from these axils appear the flowers. Each set of flowers becomes a cluster of fruit (usually 7 to 15 clusters), containing a variable number of fruits per cluster (40 to 220), depending on the cultivar.

Both internal and external factors influence growth and production. The internal factors are related to the genetic characteristics of the variety while the external factors include climate, soil, pests and diseases and human activity (Borges *et al.*, 2000).

2.2. Climate and soil

2.2.1. Climate

The best temperature for the normal development of commercial bananas is about 28ºC, but they can be grown within the range 15 to 35ºC provided that there is sufficient water and nutrients for maximum growth of the plant.

Below 15ºC plant growth ceases and below 12ºC there is a physiological disturbance called “Chilling”, which compromises the maturation process and damages the fruit, especially the peal. “Chilling” may occur in subtropical regions where minimum night temperatures reach 4.5 to 10ºC. This phenomenon occurs more commonly in banana plantations, but may also occur during transport of the fruit, in the acclimatization chambers or soon after the fruit turns yellow. Low temperatures also cause compaction of the flower rosette, making difficult the start of inflorescence or provoking its “choking”, which deforms the cluster, making it commercially unacceptable. At 0ºC, frosting occurs, causing serious damage, as much for the plant that will follow as for the current one.

In temperatures above 35°C, the development of the plant is inhibited, principally because of dehydration, especially the leaves (Borges *et al.*, 2000).

The banana is cultivated at altitudes varying from 0 to 1,000 m above sea level. The plant cycle changes with altitude. Bananas of the subgroup Cavendish, cultivated at low altitudes (0 to 300 m), have a growth cycle of 8 to 10 months, whereas above 900 m 18 months are required to complete the cycle. When the same cultivar is grown in the same soil and similar rain and humidity conditions, the production cycle increases by 30 to 34 days for every 100 m increase in altitude. Altitude influences temperature, rain, relative humidity and luminescence and this affects growth and production (Borges *et al.*, 2000). Low relative humidity results in drier leaves with a shorter life (Borges *et al.*, 2000).

The banana plant develops best in areas with an average annual humidity above 80%. At this humidity, the production of leaves is accelerated and their longevity increases. Also, the development of flowers and uniform fruit color is favored. However, when associated with rain and elevated temperatures, there is increased risk disease and fungal attack, especially yellow Sigatoka.

Wind damage is proportional to wind speed and ranges from minor effects to complete destruction of the plant. Effects range from “chilling”, due to cold winds; tissue dehydration as a result of intense evaporation; splitting of the secondary veins; cutting the leaves, diminishing of the leaf area; ripping out the roots; breaking the plants and causing them to fall over. Losses by wind have been estimated at between 20 and 30% of total production.

The majority of the cultivars can withstand winds of up to 40 km/h. Speeds between 40 and 55 km/h cause damage ranging from moderate to severe depending on the age of the plant, the variety, its development and its height. When wind speed exceeds 55 km/h, the destruction of the plant may be total. However, varieties with low stature, like Enano, may be able to withstand winds up to 70 km/h, compared to varieties of medium stature (Giant Enano and Grand Nain). In areas subject to wind it is recommended to use windbreaks: bamboo curtains of *Musa balbisiana*, *Musa textilis* or other plants.

The banana requires high light intensity, even though day length, apparently, does not influence its growth and fruit bearing. In regions with high light intensity the period required for the cluster to reach the point of commercial harvest is about 80 to 90 days after its emergence. In regions with low light intensity during part of the year, this period varies between 85 and 112 days. Where light intensity is medium, the harvest occurs between 90 and 100 days from the emergence of the cluster.

Photosynthetic activity accelerates quickly when light intensity, measured on the underside of the leaves where the stomata are more abundant, ranges from 2,000 to 10,000 lux, and then slows in the range 10,000 to 30,000 lux. Low values (less than 1,000 lux) are insufficient for the plant to develop well. At the other extreme, excessively high levels of sunlight may cause leaf burn, especially if this happens when the cluster has freshly opened or inflorescence has started (Borges *et al.,* 2000).

Banana has a large, constant requirement for water due to its morphology and tissue hydration. The largest yields are associated with total annual precipitation of 1,900 mm when it is well distributed throughout the year, *i.e.* 160 mm/month and 5 mm/day. The lack of water is most serious in the phases of flower differentiation (floral period) and at the commencement of fruit production. When water is severely deficient the leaf rosette tightens, inhibiting or even stopping the production of an inflorescence. Consequently, the cluster could lose its commercial value.

When irrigating, the amount of water applied is closely related to the ability of the soil to retain water. On deeper soils well able to retain moisture, adding 100 mm/month would be sufficient but on soils with a lower water retention, 180 mm/month would be required. It is therefore essential that the water source is sufficient to supply not less than 75% of the water retention capacity of the soil. On the other hand, soils should not become saturated because this inhibits aeration (Borges *et al*., 2000). Thus, the effective annual precipitation would be from 1,200 to 2,160 mm/yr.

2.2.2. Soil

In all areas of Brazil there are favorable soil conditions for growing bananas. However, the best soils are not always used and on the less suitable soils yields tend to be small and quality poor. Given that the banana has a superficial root system within the top 30 cm, it is important that the soil is deep, and at least the top 75 cm should be without any obstacles for root growth. Soils with a depth of less than 25 cm are considered unsuitable. In compact soils, the banana roots rarely reach a depth greater than 60 to 80 cm, and the plants are prone to falling over. On soils with a compacted layer at 30 to 35 cm, which the root system does not penetrate, subsoiling can be beneficial. Thus the nature of the whole soil profile, not just the superficial layers, is important. For good development of the plant, it is recommended that the soil does not contain an impermeable layer (rocky or compacted) and that the water table be less than one meter deep (Borges *et al*., 2000).

In general, when the climate is favorable, the plants may be established on hillsides as well as on flat ground. However, areas with gradients of less than 8% are recommended; soils with gradients between 8 and 30% being used with some restrictions; and gradients above 30% considered unsuitable. Ground with gently sloped hills (gradients less than 8%) is ideal, facilitating crop management, mechanization, maintenance operations, harvest and soil preservation.

On slopes with gradients in the range 8 to 30%, other than the need to control erosion, irrigation is more difficult. High-powered pumps with greater energy consumption and pressure compensated systems are required due to the topography. In the principal banana producing regions in the world, workable soils in the lowlands and depressions within the landscape, have been used successfully to grow bananas, especially those destined for export (Borges *et al.*, 2000).

The availability of an adequate oxygen supply in the soil is of fundamental importance for the good development of the root system. When oxygen is lacking, the roots lose their rigidity, acquire a pale blue-grey color and decompose quickly. Poor aeration may be the result of soil compaction or flooding. To improve soil aeration in areas with a tendency to flood, a good drainage system should be established. If the soil is water logged for more than three days there can be irreparable damage to the root system, with almost certain loss of yield. For this reason, soils used to grow bananas should be of a good depth and internal drainage, so that excess moisture drains away quickly and the water table can be maintained below 1.80 m (Borges *et al*., 2000).

2.3. Soil and crop management

The banana plant does little to induce soil degradation, but this does not dispense with the need to choose suitable sites for growing it. Other than this, it is important to ensure adequate soil preparation to promote root growth both in volume and depth. The use of organic mulches is recommended to keep the soil covered, reduce the effects of flash flooding and recycle nutrients (Souza and Borges, 2000).

In general, soil preparation aims to improve the physical condition of the soil for root growth, by increasing aeration and water infiltration and reducing the resistance of the soil to root expansion. The following precautions are recommended in soil preparation. Alternate the type of implement used and the depth of working to minimize the risk of forming compact layers and excessive disintegration of the soil. Invert the soil as little as possible, work the soil in conditions of adequate moisture, preserve maximum amounts of plant residues on the soil surface. Soil preparation for planting may be done manually or with machines.

Liming, when recommended, should preferably be done at least 30 days before planting using calcareous dolomite. This avoids an imbalance between potassium (K) and magnesium (Mg), which can lead to the physiological disorder called “blue banana” (deficiency of Mg induced by an excess of K). Liming should aim to achieve a base saturation of 70% with Mg^{2+} being 8 $cmol_c$ kg. With acidic soils (pH in water less than 6.0) add 300 g of lime in the planting pit (Borges *et al*., 2002).

Bananas are quite sensitive to weed competition during establishment, and require weeding at about monthly intervals to stimulate quick growth (Chambers, 1970), especially during the first five months after planting (Alves and Oliveira, 1997). After this period, the banana is less sensitive to weed competition (Belalcázar Carvajal, 1991). Weeds can be controlled mechanically or chemically. Manual weeding – using a hoe, taking care to avoid damaging the root system and mechanical weeding – using a discer or a rotary tiller between the rows of plants, can lead to soil compaction and damage the root system. Five months after planting it is recommended to do the weeding manually or with a mechanical mower rather than a rotary tiller to avoid turning the soil and cause damage to the root system. The choice of herbicide or mixture of herbicides for chemical weeding will depend on the types of weed in the orchard and the cultivar being grown (Carvalho, 2000).

Integrated control, using a mechanical method (mower between the rows) with a chemical method (post-emergence herbicide), is used in certain periods of the year, being combined with the planting of legumes between the rows, which are harvested in the dry season (Carvalho, 2000).

2.4. Mineral nutrition

Banana plants grow quickly and require, for their development and production, adequate quantities of available nutrients in the soil. Although part of the nutrients required can be supplied by the soil itself and by plant residues, it is usually necessary to apply lime and organic manures and/or chemical fertilizers to obtain economically viable yields. The amount of nutrients required depends on the cultivar, its yield potential, plant population density, the phyto-sanitary state and, principally, the balance of nutrients in the soil and the uptake by the roots. The amounts of mineral fertilizers required are usually large because large quantities are removed in the harvested produce (Borges *et al.,* 2002).

2.4.1. Uptake and export of nutrients

Banana requires a large quantity of nutrients to maintain good growth, large yields and profitability (López M., 1994; Robinson, 1996). Potassium (K) and nitrogen (N) are needed in the largest amounts followed, in order, by magnesium (Mg) and calcium (Ca) sulphur (S) and phosphorus (P) (Table 2.1).

Of the micro-nutrients, boron (B) and zinc (Zn) are taken up in the largest amounts, especially the by “Terra” variety, followed by Cu (Table 2.1). The variation between genotypes highlights the larger nutrient uptake by the “Terra” variety, undoubtedly because of the greater production of dry matter and the different climatic conditions under which it is grown (Table 2.1).

Besides knowledge of total nutrient requirement, it is important to quantify the total exported in the harvested crop, aiming to replenish the amounts by fertilization and by returning the plant residues to the soil. At harvest, the nutrients are exported through the bunch (fruits + stalk + female rachis + male rachis + heart). The vast majority of research has shown that the removal of macro-nutrients in the bunch occurs in the following order: K>N>Mg, and varying the order for the quantities of S, P and Ca (Table 2.1). Cultivars with the largest amount of dry matter in the bunch remove the largest quantities of macro-nutrients. The offtake of nutrients in the bunches of the subgroup Cavendish are, in kg/mt, 1.7 of N; 0.2 of P; 5.0 of K; 0.2 of S (IFA, 1992). In Sao Paulo, the amount of nutrients removed for the cultivar "Nanicão", is, in kg/mt, 2.1 of N; 0.3 of P; 5.0 of K and 0.1 of S (Raij *et al*., 1996). For "Prata Ana", grown in Reconcavo da Bahia, the amount removed, in kg/mt is: 2.3 of N; 0.24 of P; 5.5 of K; 0.28 of Ca; 0.35 of Mg and 0.12 of S (Faria, 1997).

The export of micro-nutrients in the bunch in relation to the quantity absorbed is approximately 28% for B, 49% for Cu and 42% for Zn (calculated from Table 2.1).

Although banana requires a large quantity of nutrients during growth, a considerable proportion is recycled in the pseudostem, leaves and rhizome, which are 66% of the vegetative growth at harvest and are returned to the soil. For example, for the cultivar "Terra" the quantities recycled in residues can be, in kg/ha, 170 of N; 9.6 of P; 311 of K; 126 of Ca; 187 of Mg and 21 of S (Borges *et al.,* 2002).

Nutrient losses by leaching, volatilization and erosion depend on the physical and chemical conditions of the soil and rainfall. To decrease these losses, the root system should be vigorous and the fertilizers applied in small quantities at a time (Borges *et al*., 2002).

2.4.2. Functions and importance of nutrients

Nitrogen (N): Nitrogen is important for vegetative growth, especially in the first three months, when the plant is developing. It favors the production and development of slips and increases the quantity of dry matter. Its deficiency reduces the number of leaves, increases the number of days for the emergence of a new leaf, and fruit bunches are stunted and less numerous. Compared to a treatment without N, adding 400 kg of N/ha/yr increased the number of leaves and bunches by 8% and 11%, respectively, (Oliveira *et al.,* 1998).

Nitrogen deficiency results in a generalized chlorosis of the leaves, reddish stems, stunted clusters and a smaller number of bunches. Deficiency normally occurs in soils with little organic matter, where there is a less mineralization of organic matter, and also in soils with considerable leaching and where there is a prolonged drought. Deficiency can be corrected by applying 50 to 300 kg N/ha, depending on the concentration of N in the leaves. Excessive N results in production of weak clusters with widely spaced bunches (Borges *et al.,* 2002).

Table 2.1. Quantities of macro- and micro-nutrients absorbed (AB), exported (EX) and recycled (RE) to the soil for different banana cultivars at harvest.

	Macro-nutrients (kg/ha)																	
Cultivar	N			P			K			Ca			Mg			S		
	AB	EX	RE	AB	EX	RE	AB	EX	RE	AB	EX	RE	AB	EX	RE	AB	EX	RE
Caipira	146.9	52.9	94.0	9.8	3.9	5.9	313.9	124.7	189.1	53.0	2.8	50.2	58.0	5.2	52.8	9.3	3.0	6.3
Prata Anã	136.5	44.4	92.1	10.1	4.6	5.5	418.5	107.1	311.4	71.6	5.5	66.1	61.6	6.9	54.7	5.8	2.4	3.4
Pioneer	116.7	29.7	87.0	8.5	3.2	5.3	371.1	100.0	271.1	73.2	3.6	69.6	70.8	5.0	65.8	5.3	1.1	4.2
FHIA-18	144.1	50.9	93.2	11.2	5.2	6.0	382.4	142.4	240.0	74.1	4.8	69.3	64.5	7.0	57.4	7.5	2.8	4.7
Terra	227.9	57.9	170.0	15.5	5.9	9.6	459.2	156.2	303.0	131.0	5.5	125.5	193.2	6.5	186.7	35.9	14.9	21.0
Average	154.4	47.2	107.3	11.0	4.6	6.5	389.0	126.1	262.9	80.6	4.4	76.1	89.6	6.1	83.5	12.8	4.8	7.9

	Micro-nutrients (g/ha)								
Cultivar	B			Cu			Zn		
	AB	EX	RE	AB	EX	RE	AB	EX	RE
Caipira	295.5	98.8	196.7	52.1	11.7	40.4	132.9	40.5	92.4
Prata Anã	309.5	70.1	239.4	26.9	5.4	21.5	148.1	52.4	95.7
Pioneer	222.3	50.3	172.0	30.1	4.9	25.2	120.5	33.2	87.3
FHIA-18	237.7	81.9	155.8	34.7	10.2	24.5	115.7	43.5	72.2
Terra	482.7	132.6	350.1	239.9	155.4	84.5	662.0	324.2	337.8
Average	309.5	86.7	222.8	76.7	37.5	39.2	235.8	98.8	137.1

Source: Borges *et al.*, 2002.

Phosphorus (P): With a deficiency of P, the plants are stunted and have poorly developed roots. Other than this, the oldest leaves show a marginal necrosis in the shape of saw teeth, with dark green coloration and stem breakage. The fruit may be smaller and with a lower sugar content. Deficiency is likely where there is little P in the soil, and especially on acid soils. Deficiency can be corrected by applying 40 to 100 kg of P_2O_5/ha, the actual amount depending on the composition of the soil and the leaves (Borges *et al.,* 2002).

Potassium (K): Potassium is the nutrient taken up in the largest quantity by the banana plant. Potassium plays several vital roles in plants. It is involved in translocating photosynthates within the plant, in the water balance of the plant, and the production and quality of the fruit by increasing total soluble solids and sugars and decreasing the acidity of the pulp. Rapid yellowing and withering of the oldest leaves characterize K deficiency; the lamina bends at the tip of the leaf, which appears cracked and dry (see appendix of chapter 2, Plate 2.1 - 2.3). The cluster is the part of the plant most affected by K deficiency, reducing the production of dry matter. When the supply of K is limited, the translocation of sugars from the leaf to the fruit decreases and, even when the sugars reach the fruit, their conversion into starch is restricted, producing small fruits and clusters, with irregular maturation and almost tasteless pulp which makes them unsuitable for sale. Potassium deficiency occurs in nutrient poor soils, especially where there is intense leaching, and also where excessive amounts of lime are applied, because of the antagonism between Ca and K decreases K uptake. Potassium deficiency can be corrected by applying 150 to 600 kg K_2O/ha, depending on the soil type, %K in the leaves and the yield expected. (Borges *et al*., 2002).

Calcium (Ca): The visual symptoms of Ca deficiency are seen principally in the newest leaves and are characterized by discontinuous chlorosis along the edges, thickening of the secondary veins and reduction in leaf size. The fruits can mature irregularly and rot and green fruits that form along with mature ones have no aroma or sugar. Deficiency occurs in soils with little Ca and also where there has been excessive amounts of K applied. Calcium deficiency is corrected by application of lime or gypsum. The quantity required is a function of the calcium content in the soil and leaves. (Borges *et al.,* 2002).

Magnesium (Mg): Deficiency of Mg occurs in acid soils low in fertility, and also following excessive K fertilization. This is an important aspect because banana is very demanding of K. The amount of Mg in the soil should be sufficient to prevent the occurrence of "blue banana", a deficiency of Mg induced by excess K and characterized by brownish-violet spots on the stems.

Deficiency occurs in the oldest leaves and is characterized by yellowing parallel to the edges of the leaf stem, by deformation and irregularities in the emergence of flowers. Rotting of the lamina leads to a bad smell and separation of the sheath from the pseudostem. The most common symptom in the field is chlorosis in the internal part of the lamina, also known as magnesia chlorosis, with the central vein and the edges remaining green. When the deficiency is severe and reaches the clusters they become stunted and deformed, the fruit and pulp mature irregularly, and the pulp becomes soft, viscous, tastes bad and rots quickly.

Deficiency can be corrected by applying calcareous dolomite or 50 to 100 kg/ha magnesium sulphate, depending on the level of Mg in the soil and the leaves. Excess Mg gives a bluish color to the stem and irregular chlorosis followed by death of the leaves (Borges *et al*., 2002).

Sulphur (S): Sulphur deficiency is characterized by a generalized chlorosis of the lamina of the newest leaves, which disappears with age, as the root system develops and exploits a greater volume of soil. When the deficiency persists the edges of the lamina die, there is a slight thickening of the veins, similar to that with Ca deficiency, and the clusters are small.

Sulphur is normally applied in ammonium sulphate and single superphosphate (Borges *et al*., 2002).

Boron (B): The first signs of boron (B) deficiency is seen in yellowish-white lines, which spread over the leaf's surface parallel to the main vein, followed by death of the tissue. The leaves may remain deformed and the lamina may be decreased. These symptoms are similar to those of S deficiency. In serious cases, a gum appears on the pseudostem, which reaches the flower and may even prevent its emergence, the inflorescence being retained within the pseudostem.

Copper (Cu): The deficiency of Cu is often confused with that of N, owing to the generalized chlorosis and reduced stature of the plant, which has an umbrella shape. The plant becomes very prone to attacks by trips, fungus and mosaic virus and the fruits contain rust stains (Cordeiro and Borges, 2000). According to Dechen *et al*. (1991), Cu is involved in the defence mechanism against fungal diseases, therefore in its absence the plants are less protected physically, which facilitates the penetration of the pathogen.

Iron (Fe): Plants deficient in iron have chlorosis along the edges of the lamina of the youngest leaves, quickly reaching the middle by way of the interveinal spaces, with the potential to become almost completely white.

Manganese (Mn): The deficiency of Mn normally occurs in the middle leaves, with the lamina displaying a chlorosis in a comb-like shape along the edges. Eventually the fungus *Deightoniella torulosa* develops on the leaf lamina and contaminates the fruit (Cordeiro and Borges, 2000).

Zinc (Zn): An essential element in the synthesis of tryptophan, a precursor of indoleacetic acid (IAA), which induces the production of tilose. The latter is involved in the plant's resistance to Panama Sickness, showing that there is a positive correlation between Zn deficiency and the incidence of Panama Sickness (Cordeiro, 1984).

Deficiency slows the growth and development of the plant. The leaves are small and lanceolate and have yellowish-white stripes between the secondary veins and red pigmentation on the under side of the leaves. Besides being small, the fruits may be curled, with light green tips and the apex in the shape of a nipple in bananas of the Cavendish subgroup. Such symptoms are often confused with a viral infection (Cordeiro and Borges, 2000).

Leaf analysis is an important technique in fruit growing but to be used successfully it is necessary to know the position of the leaves sampled and the characteristics of the growing season. For banana, it is recommended to sample the third leaf counting from the apex, with the inflorescence having all female rachises (without bracts) and no more than three male rachises of the male flowers (Fig. 2.1). Collect 10 to 25 cm in the inner middle of the lamina, eliminating the central vein. For this state of development there are standard nutrient compositions, which may be used as reference. The ranges of nutrients adequate for some cultivars are found in Table 2.3 (Borges *et al*., 2002).

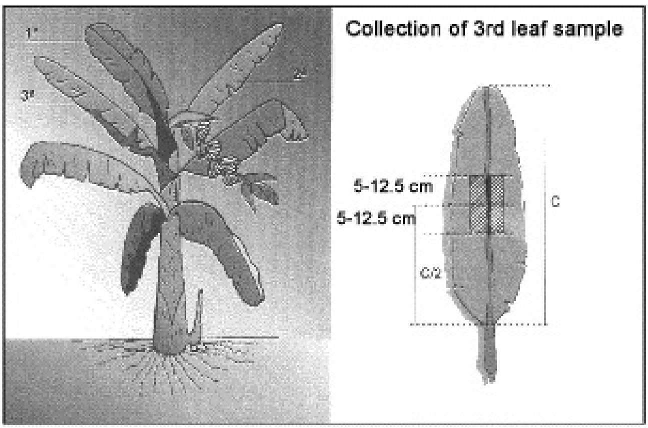

Fig. 2.1. Banana leaf sample for chemical analysis (Borges *et al*., 2002).

2.5. Fertilization

2.5.1. Organic fertilization

Organic manures are the best way of supplying N, especially when conventional seedlings are used because N losses are minimal and root growth is stimulated. Therefore, such manures should be applied in the plant pit: For example, bovine manure (10 to 15 L) or chicken manure (3 to 5 L) or castor bean pie (2 to 3 L) or other manures available in the region or on the property. It is worth noting that the organic manure, irrespective of the source, should be well composted. If available, add 20 m^3/ha of bovine manure annually. Covering the soil with banana plant residues (leaves and pseudostems) is a viable alternative for small producers. This practice increases the content of nutrients in the soil, principally K and Ca, besides improving the physical, chemical and biological characteristics of the soil (Borges *et al*., 2002).

2.5.2. Mineral fertilization

Nitrogen is very important for vegetative growth and it is recommended to apply 200 kg mineral N mineral/ha/yr in the development phase and 160 to 400 kg/ha/yr in the production phase of the banana, depending on the anticipated yield. The first application should be made around 30 to 45 days after planting. Ammonium sulphate, calcium nitrate and ammonium nitrate are recommended as N fertilizers.

Potassium is considered the most important nutrient for the production of superior quality fruits. The recommended quantity varies from 200 to 450 kg of K_2O/ha in the development phase and 100 to 750 kg of K_2O/ha in the production phase, depending on the K content of the soil. The first application should be made in the second or third month after planting. If the soil K content is less than 1.5 $mmol_c/dm^3$ the first application should be given at 30 days, along with the first application of N (Tables 2.2 and 2.3). Potassium can be applied as potassium chloride, potassium sulphate and potassium nitrate, although because of the price the chloride is almost always used. On soils with a K content above 6.0 $cmol_c$/dm it may be possible to dispense with applying K fertilizer (Borges *et al.,* 2002).

Although necessary, banana needs only small quantities of P but if P is not applied the development of the root system is compromised and consequently production is affected. The total quantity recommended after soil analysis (40 to 120 kg of P_2O_5/ha) should be put in the planting pit. The application should be repeated annually after soil sampling for analysis. If a soil contains more than 60 mg P/kg (resin extraction) there is no need to apply P fertilizer (Table 2.2) (Borges *et al*., 2002).

Table 2.2. Fertilizer recommendations for N, P and K at planting, and during the development and production phases of irrigated banana.

Development Phase	N	P-resin (mg/dm^3)				K-exchangeable (mmol$_c$/dm^3)			
		0-12	13-30	30-60	>60	0-0.15	0.16-0.30	0.31-0.60	>0.60
	kg/ha	---------------- P_2O_5 (kg/ha) -----------------				----------------- K_2O (kg/ha) -----------------			
Planting	70[1]	120	80	40	0	0	0	0	0
Days after planting									
30	20	0	0	0	0	20	0	0	0
60	20	0	0	0	0	30	30	0	0
90	30	0	0	0	0	40	30	20	0
120	30	0	0	0	0	60	40	30	0
120-180	100				0	300	250	150	0
Production									
Expected yield (mt/ha)									
<20	160	80	60	40	0	300	200	100	0
20-40	240	100	80	50	0	450	300	150	0
40-60	320	120	100	70	0	600	400	200	0
>60	400	160	120	80	0	750	500	250	0

[1]Nitrogen in organic form (bovine manure).

Source: Natale *et al.*, 1996a.

Table 2.3. Range of macro- and micro-nutrients from various sources considered adequate for banana (IFA, 1992) and irrigated banana (Silva *et al.*, 2002; Borges and Caldas, 2002).

Nutrient	Source		
	IFA, 1992.	Silva *et al.*, 2002. *cv. Prata Anã*	Borges and Caldas, 2002. *cv. Pocovan*
Macro-nutrient	----------	g/kg	----------
N	27-36	25-29	22-24
P	1.6-2.7	1.5-1.9	1.7-1.9
K	32-54	27-35	25-28
Ca	6.6-12	4.5-7.5	6.3-7.3
Mg	2.7-6.0	2.4-4.0	3.1-3.5
S	1.6-3.0	1.7-2.0	1.7-1.9
Micro-nutrient	----------	mg/kg	----------
B	10-25	25-32	13-16
Cu	6-30	2.6-8.8	6-7
Fe	80-360	72-157	71-86
Mn	200-1,800	173-630	315-398
Zn	20-50	14-25	12-14

Boron and zinc are the micro-nutrients most commonly deficient in banana. As a source, apply 50g of F.T.E. Br-12 (see composition of F.T.E. Br-12 in footnote of Table 2.4) or similar material to the plant's base. If the soil B content is less than 0.21 mg/kg (hot water extract) 2.0 kg of B/ha should be applied; for soil Zn content of less than 0.6 mg/kg (DTPA extract) 6.0 kg Zn/ha is recommended (Table 2.4) (Borges *et al.,* 2002).

Whether or not to split fertilizer applications will depend on soil texture and the cation exchange capacity (CEC) of the soil, as well as on the rain pattern and management adopted. In sandy soils with low CEC, fertilizers should be applied weekly or bi-weekly. In soils with a larger clay content, fertilizer applications may be made monthly or bi-monthly, especially when applied to the soil (Borges *et al.,* 2002).

Table 2.4. Quantities of boron (B) and zinc (Zn) applied at the plant base of irrigated banana, based on soil analysis.

Nutrient	Soil test (mg/kg)	Fertilization (kg/ha)
	Hot water[1]	
B	0-0.21	2.0
	>0.21	0
	DTPA[1]	
Zn	0-0.60	6.0
	>0.60	0

[1]Determine annually the availability of boron and zinc in the soil, and if necessary, apply fertilizers containing B and Zn, according to the table above, or add 50 g/plant of F.T.E. Br-12 (9% Zn, 1.8% B, 0.8% Cu, 3.0% Fe, 2.0% Mn and 0.1% Mo).

Source: Borges *et al*., 2002.

When applying fertilizers under the leaf canopy they should be put in a circular band 10 to 20 cm wide and 20 to 40 cm from the base of the plant, increasing the distance with the age of the plant. In an adult banana plantation, the fertilizers are distributed in a half moon in front of the plant's sucker and secondary sucker (Fig. 2.2). On sloping land, the application should be made in a half moon on the upper side of the planting hole and then lightly incorporated into the soil. In dense plantations and on flat lands, the fertilizer can be thrown from the paths (Borges *et al.,* 2002).

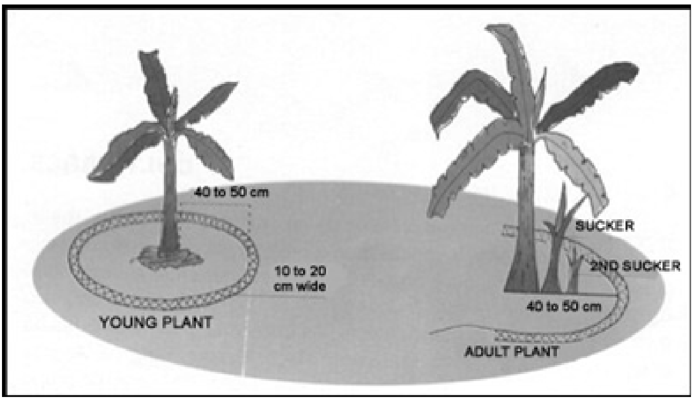

Fig. 2.2. Banana leaf sample for chemical analysis (Borges *et al*., 2002).

For the first cycle of the cultivar 'Grand Nain', Borges *et al.* (2002) reported that the fruits did not meet export requirements (22 to 26 cm long and 32 to 36 mm in diameter), but the application of 300 kg of N and 550 kg of K_2O/ha/yr resulted in a larger yield (81 mt/ha), heavier (251.8 g) and longer (20.4 cm) fruits. For the first cycle of the cultivar for 'Prata Anã' grown on a Red-Yellow Agrisol, with a K content of 19.5 mg/kg, Sousa *et al.* (2003) found no effect of N and K other than increased production (24.3 mt/ha) with 570 kg N and 770 kg K_2O/ha/yr.

2.6. Irrigation

Banana requires a large quantity of water, because it has a large leaf area and 87.5% of the total weight of the plant is water. Water deficiency can affect the production and quality of the fruits. The water requirements of the plant depend on its age. It has been estimated that on sunny days with low relative humidity of the air and for a foliar area of approximately 14 m^2, the plant consumes about 26 L/day, 17 L/day on partly cloudy days, and 10 L/day on completely cloudy days.

2.6.1. Irrigation methods

There are no restrictions on the method of irrigation for the majority of banana varieties. The chosen method will depend on the local conditions including soil type and its topography, the cost of installation, maintenance and operation, as well as the quantity and quality of the water and the labour available. The preference is for methods that promote:

(i) Uniform distribution of water in the soil, that is, a high coefficient of water distribution;

(ii) Greatest efficiency in water use;

(iii) Maintenance of a stable average relative humidity under the canopy (Oliveira *et al.*, 2000).

Localized irrigation, with a greater efficiency and a lower consumption of water and energy, is generally recommended, especially in regions where water is limiting. Between the systems of jet and drip, the former generates a larger wet area, permitting greater development of the roots. In spraying the nozzles used should have spray rates greater than 45 L/h, and have one jet per four plants to get the largest wet area. In dripping, attention should be given to the number and position of the drippers, establishing a wet area adequate for the development of the roots. The drippers may be installed in one or two lateral rows per row of plants, making a continuous long wet line along the lateral row. This reduces the problem of possible incompatibilities of localization of the drippers in relation to the pseudostems, which change for every cycle. The irrigation interval for spray and drip systems can vary from one day for medium texture and sandy soils to every third day for medium to clayey textured soils (Coelho *et al.*, 2000).

2.6.2. Water requirements

The response of banana to different levels of irrigation depends on the local meteorological conditions, which result in different evapo-transpiration conditions, and heat constant, associated with the characteristics of the cultivar, such as: ruggedness, plant height and foliar area, which directly influence aerodynamic resistance. Other factors include cultivar spacing, irrigation method and management practices like mulching.

2.6.3. Fertigation

In irrigated plantations, nutrients may be applied with the irrigation water, fertigation. This practice, employed in irrigated agriculture, is a more efficient way of applying nutrients. This practice is adapted more for localized irrigation systems (spray and drip), in order to take advantage of the characteristics of the method, like low pressure, high frequency of irrigation and possibility of application of the solution to the root area, making more efficient use of the nutrients. The frequency of fertigation could be every two weeks on soils with high clay content; on more sandy soils a weekly frequency is recommended. For monitoring fertigation, chemical analysis of the soil is recommended, including the electrical conductivity of the saturated soil, every six months (Borges and Coelho, 2002).

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