



/ Dr. Oded Achilea

A. Some botanical facts

Cultivated bananas and plantains are giant herbaceous monocot plants within the genus *Musa*, a member in the botanical family Musaceae. The center of origin of the group is in South-East Asia, where they occur from India to Polynesia. Other members of this genus are the following rather important crops: Plantains (*Musa paradisiaca*), Fe'i bananas, Manila hemp (*Musa textilis*) and Ensete (*Musa ensete*). Other crops belonging to the same botanical order are: ginger, cardamom, turmeric, galangal, fingerroot, myoga, Bird of Paradise flower, heliconias and prayer-plants.

The banana plant is a large perennial herb with leaf sheaths that form a trunk-like pseudostem. The plant has 8-12 leaves that are up to 270 cm long, and 60 cm wide. Root development may be extensive in loose soils, in some cases- up to 9 m laterally. Plant height, bunch size and various other characteristics depend on the variety, see following.

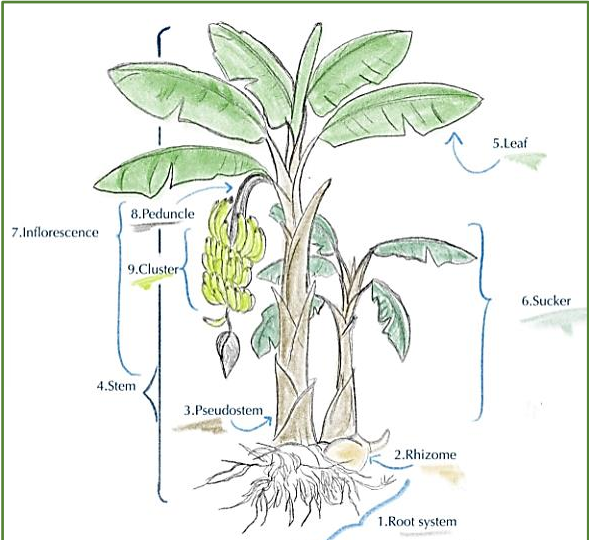
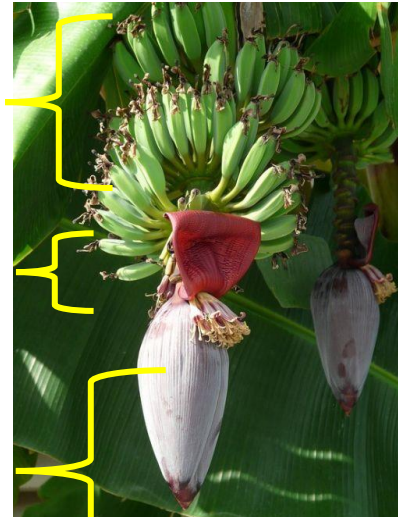
Flower development is initiated from the underground true stem (corm) 9-12 months after planting. The flower stalk grows through the center of the pseudostem, see figure 1. The flowers develop in clusters ("hands"), spirally around the flower stalk axis, see figure 2. The female flowers hands grow on the basis of the flower stalk, and in most cultivars, they are followed by a few hands of neuter flowers that have aborted ovaries and stamens. These neuter flowers are followed at the terminal ends of the flower stalk, by male flowers enclosed in bracts. These male flowers have aborted ovaries and functional stamens.

The fruits mature in about 60-90 days after the appearance of the flower stalk. Each bunch of fruits consists of variable numbers of "hands", along a central stem. Each "hand" consists of two transverse rows of fruits ("fingers").

A crop cycle takes 8–18 months, depending on genetics, nutrition, moisture, temperature, sunlight and health of the plant. In the tropics, a crop cycle may take only 7 months, so 1.2–1.5 harvests per year are possible.

August 2024

Mineral nutrition of BANANA plantations in East-Asia and in similar growth regions

<u>Figure 1. Structure of a mature banana plant</u> Ref: Banabiosa.	<u>Figure 2. Structure of a premature banana fruit bunch.</u>
	 Female flowers hands Neuter flowers hands Male flowers enclosed in bracts

A textual description of the phenological stages in the life cycle of a banana plant.

- ✓ Sucker: all young plant material before developing broad leaves.
- ✓ Small: early stage of vegetative growth, after appearance of 10 broad leaves, at about 1/3 of the size at flowering
- ✓ Large: plants in vegetative phase about two thirds grown to flowering, after appearance of some 20 broad leaves
- ✓ Shooting: first appearance of the flower
- ✓ Shot: immature fruits, about six weeks old
- ✓ Harvest: Reaping the bunch



Figure 3.: a visual description of some phenological stages in the life cycle of a banana plant

<u>Large</u>	<u>Shooting:</u> Inflorescence emergence	<u>Shot</u>	<u>Harvest</u>
			

B. A crop of continuously developing worldwide demand

Banana evolved in the humid tropical regions of S.E.A (Southeast Asia), with India as one of its centers of origin. Modern edible varieties have evolved from two species, namely, *Musa acuminata* and *Musa balbisiana*, and their natural hybrids, originally found in the rainforests of S.E.A. Its cultivation spread to Egypt and Africa during the seventh century AD. At present, bananas, along with plantains, are cultivated mainly in the regions, between 30°N and 30°S of the equator.

They feature the fourth most important staple crop worldwide, and are essential to maintaining food and nutritional security, among 400 million people, who rely on them for 15–27% of their daily calories in their producing countries. Global banana production is growing continuously, to respond to the developing demand for this staple food. The apparent reasons for this global trend are population growth, the increased awareness to the fruit's health values, and the growth of global sector of people that are ready to pay a premium for consuming it. The banana sector is a growing USD 25 billion industry, projected to expand at a compound annual growth rate (CAGR) of 4.5% between 2022 and 2027 (Mordor Intelligence, 2022).

Bananas, along with plantains, are essential to maintaining food and nutritional security among 400 million people in producing countries.

In year 2022 banana production has crossed the 135 million MT (metric ton) mark, (Figure 4), while Asia is, by far, the largest banana & plantain producer (Figure 5). The following countries are consistently the top producing ones, supplying in 2022 their domestic markets, and exporting their



produce in international ones: India (30.5 million MT), China (12.0), Indonesia (7.3), Brazil (6.8), Ecuador (6.6), Philippines (6.0), Guatemala (4.3), Angola (4.0), Tanzania (3.4) and Colombia (2.9).

Figure 4. Increasing global banana production
(million MT), 2000 – 2024. Ref: FAOSTAT

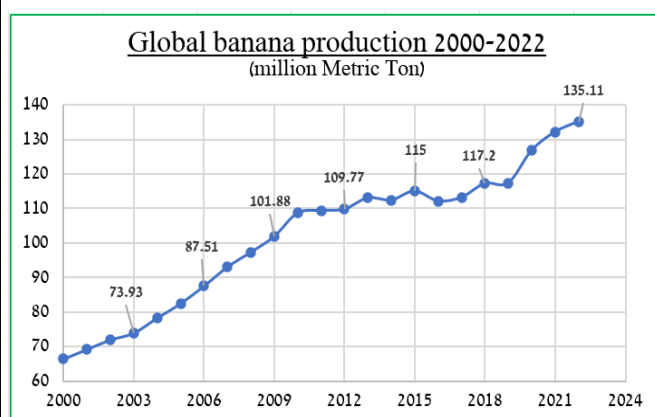
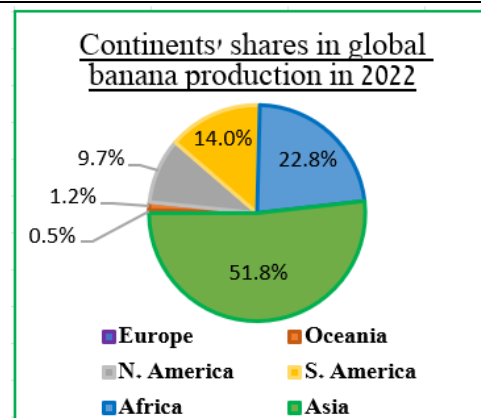


Figure 5. Continents' share in global banana production in 2022. Ref: ourworldindata.org



C. Bananas' genetic background and its horticultural implications

The global banana industry comprises of about one thousand cultivars. Most commercial fresh fruit banana and plantain types are triploid (3N), which implies that their flowers are sterile, so no sexual reproduction takes place. This, coupled with the fact that their fruits are parthenocarpic indicates that real seeds cannot be produced. Therefore, banana plants can be propagated only by planting vegetative parts, like roots, or corms, or suckers taken from existing plants.

Main types of commercially grown banana varieties were bred from the wild banana types *Musa acuminata* and *Musa balbisiana*. Variety names are followed by appendices A (representing *acuminata*) and/or B (representing *balbisiana*), depending on the origin of the genomes. The 'Cavendish' group type now accounts for almost half of all varieties grown worldwide, and nearly 100% of internationally traded fresh bananas. They originate from *Musa acuminata*, and are AAA genetically. Some typical instances are: 'Gros Michel', 'Dwarf Cavendish', 'Grand Nain' (which is a tall mutant of 'Dwarf cavendish') and 'Williams'. Meanwhile, the AAB genome group comprises many cultivars, each with its own unique characteristics. The genetic diversity within this group is high, indicating multiple origins from different wild hybrids.

Most plantains (cooking bananas), however, are breedings of *Musa acuminata* and *Musa balbisiana*, and feature **AAB** or **ABB** genomes.



Global focusing on one genetic composition, and absence of sexual reproduction results in very little, to no genetic diversity at worldwide banana plantations, make them highly vulnerable to pests and

diseases. (Reay, 2019). And, indeed, 'Gros Michel', the most popular banana variety until the 1950s, was devastated in Central and South America by the Fusarium wilt Tropical Race 1 (TR1), a deadly fungus found in soils. This catastrophic scenario gave way to the modern 'Cavendish' cultivars, which quickly replaced the 'Gros Michel' and is now facing similar threats from emerging pests and diseases, including Tropical Race 4 and Sigatoka fungi, which could wipe it out in the coming years. Scientists are racing to find resistant varieties to these diseases and to other challenges, such as climate change.

All the above-mentioned banana varieties are grown in ~150 countries, 30°North and south of the equator. They grow in tropical climates with average temperatures of 27°C and more than 200 cm of annual precipitation.

Figure 6. The fruits of some commercially important banana & plantain cultivars

<u>Dwarf Cavendish</u> AAA	<u>Grand Naine</u> (tall Cavendish AAA)	<u>Red banana</u> AAB	<u>AAB Group</u>	<u>Plantain</u> ABB
				

D. Banana's optimal horticultural growing conditions

A. Soil type

Bananas grow well over a wide range of soils. The ideal soil should be non-compact, and well drained, yet, it should have good water retention capacity. Soil pH should range 5.5– 7.5.

B. Climate

Banana plants do best at full sun exposure, and in wind-protected areas, because even moderate winds shear their leaves, thus reducing their light energy absorbance capacity. Average temperature of



27°C (81°F), and 90% relative humidity provide for optimum plant development and yields. Under such conditions the plant grows rapidly and expresses its best performance. When growing within the range

of 15–35°C, bananas can still grow, but exhibit suboptimal yield and quality. Below 15°C plant growth ceases, and temperatures below 12°C provoke serious chilling injury.

Water management

Banana plants have a large, constant requirement for water, due to their morphology and tissue hydration. Heaviest 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. However, it has shallow roots, which inhabit the top 30cm, and have weak penetration potential into the soil, poor ability to draw water from drying soil, and low resistance to drought. The plant displays rapid physiological response to soil water deficit. These factors determine banana plant's sensitivity to even slight variations in soil water content, and that irrigation scheduling is critical. Water is probably the most limiting a-biotic factor in banana production. The stringent water requirements of this crop can be evenly satisfied by effective rainfall and by irrigation. Irrigation is needed if rainfall is inadequate or irregular. The amount of water to apply is determined by water-holding capacity of the soil, effective rooting depth of the plant, and the depletion percentage of total available water, allowed before irrigation. While crop's evapotranspiration coefficient, determines the irrigation interval.

The fundamental importance of the water status of banana plants, banana production should be supported by an efficient irrigation system. Drip irrigation has multiple advantages over other irrigation methods in banana cultivation (Netafim):

- ✦ Drip irrigation has been proven to increase banana yields and improve the quality of the bananas.
- ✦ Drip irrigation allows for precise water application directly to the root zone, minimizing water wastage and maximizing efficiency. Compared to flood irrigation, drip irrigation can save more than 50% of the water.
- ✦ Drip irrigation allows for efficient delivery of water and nutrients directly to the roots of the bananas, letting them grow to their full potential. This method prevents leaching and delivers every drop of fertilizer directly to the root zone, with minimum labor involved.
- ✦ Drip irrigation can be used in various terrains, including undulating, saline, waterlogged, and hilly lands.



- ✦ Drip irrigation can be easily combined with remote control and automation to make your irrigation even more efficient.
- ✦ By applying water directly to the root zone and not wetting the entire field, drip irrigation can help reduce the prevalence of diseases and weeds.

E. Central role of the mineral nutrition of banana plantations

Banana is a crop with very high nutrient demand, which requires continuous high availability of nutrients to the plants. Bananas need to be constantly supplied with mineral nutrients, in order to maintain their vegetative and reproductive growth, as well as, to compensate for the high volume of nutrients exported from the soil, in the form of harvested fruit bunches. Naturally, soil fertility and properties strongly affect the availability of the applied nutrients to the crop.

Adequately applied fertilizers can markedly, positively affect the economic viability of the plantation. by:

- ✦ Increasing the total crop yield by enhancing the bunch weight.
- ✦ Improving the grading and external and internal qualities of the bunches, hands and fingers.
- ✦ Reducing the time needed for filling and maturation of the banana bunch, thus shortening the time to market of the plot, and increasing the number of growth cycles per year, hence, increasing growers' return from the plot.

Let's have a glance at the goal of the mineral nutrition of the banana plant, namely, bringing the required minerals to the plant organs, which need them mostly, see figure 7.



Figure 7: Main parts of a banana plant, where mineral nutrients are found at greatest concentrations.

Ref.: Lahav and Turner. 1989.

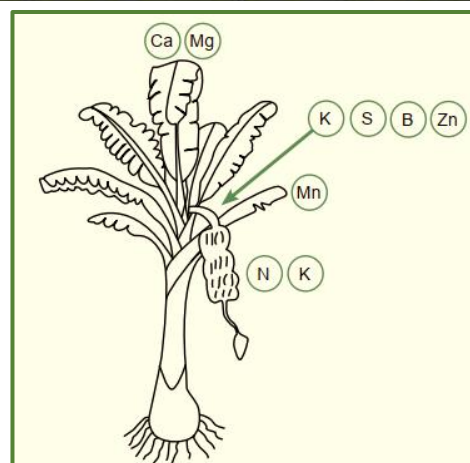


Figure 8 shows very clearly that banana is a crop with **very high K removal** in the produce, it is 4.9-fold higher than the N's removal rate.

Figure 8: Macro- & meso- nutrients removal by a yield of 50 MT/ha of 'Grand Naine' bananas.

Ref.: Lahav & Turner, 1989.

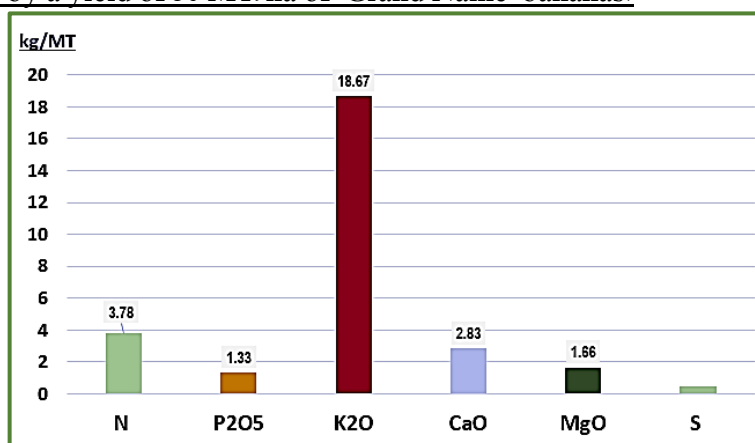
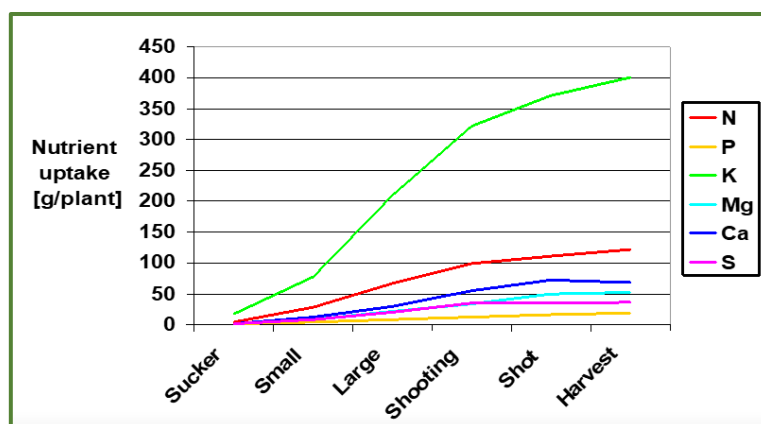


Figure 9 shows the remarkable continuous uptake rate of potassium comparatively to all other nutrients.



Figure 9: Nutrient uptake curves by growth stage, of banana (cv. Robusta) at 4th ratoon crop

Ref.: Lahav & Turner, 1989.



Nitrogen (N)

Nitrogen is one of the primary nutrients taken up by banana roots. Nitrogen is a constituent of amino acids, amides, proteins, enzymes, coenzymes, nucleic acids, chlorophyll, and many more. It is equally essential for proper cell division, growth and respiration.

- ♣ Nitrogen is the chief promoter of growth. It induces the vegetative growth of the pseudostem and leaves, contributing to their healthy green color. Adequate nitrogen status increases the bunch grade, and sucker production.
- ♣ A healthy robust vegetative 'skeleton' is an essential pre-requisite for high yields, and nitrogen is mainly responsible for this vegetative 'skeleton'. Lack of N produces thin, short and compressed leaf petioles, thin and profuse roots, and lesser number of suckers. framework
- ♣ N-deficient banana plants need 23 days for unfolding their leaves, versus 10 days needed for plants supplied with adequate N. Nitrogen deficiency is more severe on crop growth than any other nutrient deficiency. E.g. while N-sufficient plant will require 9.5 days between leaves' emergence, an N-deficient plant will require 22.6 days, under similar growth conditions, (ref.: Lahav and Turner. 1989.)
- ♣ Nitrogen deficiency negatively affects the longitudinal growth of leaf petioles. It also provokes paler leaves, reduced leaf area, and slower leaf production.
- ♣ Under tropical conditions, the required nitrogenous fertilizer produces best results, when applied as a mixture of different N sources, rather than if applied as a single source of N. It is reflected by improved growth, yield, physiological parameters, leaf nutrient contents, and quality characters. (ref. Keshavan et al. 2011).



- ♣ In tropical conditions, nitrification of ammonia and leaching of nitrate are rapid processes. Therefore, to ensure regular availability of nitrogen, throughout the growth period, and also to minimize the wastage of nitrogenous fertilizers, they should be applied in small split doses at short time intervals.

However, attention should be paid in avoiding excessive N application, as this may result in reduced firmness and breakage of the pseudostem, higher sensitivity to diseases, phosphorus deficiency, increased gaps between hands in the bunch, smaller fingers, poor finger filling, reduced resistance to transportation and storability. It will also delay shooting of new ratoons.

Nitrogen deficiency symptoms on banana plants

They appear rapidly, and simultaneously on the leaves and other parts of the plants, as follows:

- Leaves become smaller and pale green, see photo.
- Distance between successive leaves is reduced, producing a 'rosette' appearance, see photo.
- Mid-rib, petioles and leaf sheaths become reddish pink, see photo.
- Leaves' production rate is markedly decreasing.
- ☒ Poor growth is leading to a stunted plant.
- ☒ Fruit bunches are markedly smaller.
- ☒ Reduced number of suckers.

Figure 10: Nitrogen deficiency symptoms on banana plants. Ref.: <http://agritech.tnau.ac.in/>

Leaves: smaller and pale green	Leaves: a 'rosette' appearance'	Leaves' petioles: pink to violet
		

Phosphorus (P)

Phosphorus is a macronutrient, and is taken up by banana roots, mainly in the form of orthophosphate (H_2PO_4^-). It is necessary for many life processes such as photosynthesis, metabolism of



carbohydrates, and as a central component of ATP, it plays a key role in all energy- consuming reactions. It helps plants store and use energy from photosynthesis, develop roots, speed-up the maturity, and resist stresses. It helps to produce healthy rhizome and a strong root system. It also influences flower setting and general vegetative growth. It is a component of sugar-phosphates, nucleic acids, nucleotides, coenzymes, phospholipids, phytic acid, and more.

P deficiency symptoms

- The leaf margins of the oldest 4-5 leaves, become chlorotic.
- Under severe P deficiency leaves develop purple-brown flecks eventually producing 'saw-teeth' necrosis near leaf midrib and/or on the leaf edges.
- Affected leaves curl and the petioles break.
- Young leaves have a deep bluish-green color.
- ☒ Reduced vigor, stunted growth and poor root development.
- ☒ Delayed fruit maturity.

Figure 11: Phosphorus deficiency symptoms on banana plants. Ref.: <http://agritech.tnau.ac.in/>

Chlorotic leaves	'Saw-teeth' necrosis near leaf midrib and on leaf edges	Purple-brown flecks
		

Potassium (K)

Potassium is required as a cofactor for over 40 plant enzymes. It is the most prevalent cation in all plants' cells, thus, maintaining electro-neutrality in them. has a role in stomatal movements by plant cells. It is required for many physiological functions, such as: formation of sugars and starch, synthesis of proteins, normal cell division and growth, neutralization of organic acids, involvement in enzymatic reactions, regulating carbon dioxide supply, by controlling stomatal opening and closure. It improves sugar use efficiency, increases plant resistance to biotic and abiotic stresses,



such as: frost tolerance, by decreasing the osmotic potential of cell sap, due to higher ratio of unsaturated/saturated fatty acid, drought tolerance, regulation of internal water balance and turgidity, by regulating Na influx and/or efflux at the plasmalemma of root cells, chloride exclusion through selectivity of fibrous roots for K over Na, and imparting salt tolerance to cells by increasing K holding capacity in the vacuole against leakage, when Na incurs in external medium. Potassium does not play a direct role in the plant's cell structure, but it is fundamental, because it catalyzes important reactions such as respiration, photosynthesis, chlorophyll formation, and water regulation. The role of K in the transport and accumulation of sugars inside the plant is particularly important since these processes allow fruit fill, and, therefore- yield increase.

Due to the extremely high K contents in the banana fruit and leaves (see Figs. 8 and 9) K is considered the most important plant nutrient in banana production. The amount of K taken up from the soil and removed from the field in harvested bunches is very high, estimated annually at 400 kg/ha of elemental K (equivalent to 480 kg of K_2O) at production of 70 MT of fruit bunches. Therefore, banana plantations require a good K supply, even in soils where K levels are considered high.

The following tables impressively support the above claims.

Higher potassium application rate improves yield.

Table 1: The effect of K application on yield. Ref.: Saad & Atawia. 1999

<u>K₂O rate*</u> (g/plant)	<u>Bunch weight</u> (kg)	<u>Hands/bunch</u>	<u>Fingers/bunch</u>
400	25.0	12.4	217
600	26.7	12.8	220
800	29.0	13.2	225
1000	29.4	13.9	226

Table 2: The effect of K on yield

<u>K₂O rate*</u> (g/plant)	<u>Fruit weight</u> (g)	<u>Fruit length</u> (cm)	<u>Fruit diameter</u> (cm)	<u>Pulp</u> (%)
400	95.3	18.4	3.91	70.6
600	101.6	18.5	4.30	71.4
800	108.4	18.5	4.67	72.1

* Applied by fertigation



Potassium deficiency symptoms

Potassium deficiency symptoms normally appear at flowering time. They are:

- Rapid appearance of orange/yellow color on the older leaves, and subsequent drying and death.
- The mid-ribs of these leaves are very often bent or broken at two-thirds of its length making the leaf pointing downwards.
- Plants produce small leaves.
- Delayed flowering.
- Reduced bunch size, this symptom shows before the effect on plant growth

Figure 12. Potassium deficiency symptoms on banana plants.

Mild K deficiency: old leaves become yellow-orange	Moderate K deficiency: necrosis starts at leaf margins	Severe K deficiency: necrotic stripes reach leaf midrib	Extreme K deficiency: desiccation of most of leaf surface
			

Calcium (Ca)

Calcium is a secondary plant nutrient, taken up by plant roots as Ca^{2+} , while being part of the transpiration stream. Calcium is a constituent of the middle lamella of cell walls as Ca-pectate. It's required as a cofactor by some enzymes, involved in the hydrolysis of ATP and phospholipids. It is instrumental for root development and functioning; and required for chromosome flexibility and cell division.

Calcium deficiency is a widespread problem in banana crops, because it is significantly harmful for the plant and for fruit quality. Moisture stress is the major cause of calcium deficiency, as it interrupts the root uptake of calcium and leads to localized deficiencies in fruit. Calcium deficiencies are common in both acidic and alkaline soils, even when exchangeable soil calcium levels are high. This is largely due



to the low mobility of soil calcium and competition with other nutrients such as ammonium nitrogen, potassium and magnesium. Calcium deficiency is caused by:

- Low transpiration, e.g. at high humidity. Banana fruits are specifically vulnerable due to their low transpiration rate. Also, developing banana fruits may suffer from low transpiration rates, after being covered with plastic bags.
- A rapid consumption surge of Ca due to a new flush of growth, e.g. after spring flush.
- Cold winters in subtropics.
- Imbalances with K, Mg and NH_4^+ in the soil solution. Too high rates of K, Mg or NH_4^+ will reduce Ca availability. Optimum Ca uptake is optimal at soil solution composition $\text{Ca}/(\text{K}+\text{Ca}+\text{Mg}) > 0.7$.
- Boron deficiency and over-application of nitrogen fertilizers also increase calcium deficiencies.

Calcium deficiency symptoms in bananas:

On the leaves:

- ♣ Show always on the youngest leaves, their laminae are deformed, causing a 'spike leaf', or absent.
- ♣ Intervenial chlorosis near leaf margins.

Plant:

- ♣ Plant dwarfing, heart rot in newly planted tissue-culture plantlets.

Fruit:

- ♣ Peel splits when fruit ripe
- ♣ Fruit curling and bending up, resulting in mutual scratching within the bunch
- ♣ Reduced fruit size and weight
- ♣ The fruit quality is inferior and the peel splits during the ripening.



Figure 13: Calcium deficiency symptoms on banana plants. Ref.: <http://agritech.tnau.ac.in/>

Early foliar symptoms: yellow stripes parallel to leaf midrib	Chlorotic or necrotic heart leaf (left) Marginal chlorosis and necrosis (right)	Fruit curling and bending up
		

Magnesium (Mg)

Magnesium is a secondary plant nutrient, taken up as Mg^{2+} . It's a crucial constituent of the chlorophyll molecule. It is required, by a large number of enzymes and coenzymes, involved in phosphate uptake and transport, photosynthesis, carbohydrate metabolism, nucleic-acid synthesis, carbohydrates movement from leaves to upper parts. Mg deficiency takes place in old plantations, which have had little Mg applied, and/or where excessive potassium was applied. It results in yield reduction, poor plant growth, reduced uptake of K and Ca.

Magnesium deficiency symptoms in bananas:

On the leaves:

- Marginal leaf chlorosis
- Yellowish chlorosis of the central zone of the lamina, while leaf's margins and midrib area remain green. Also, purplish mottling of petioles ('blue sickness').
- Leaf sheath separation from the pseudostem.
- Malformation of the leaves.

Fruits:

Do not ripen properly, and become tasteless



Figure 14: Magnesium deficiency symptoms on banana plants. Ref.: various

Early deficiency stage: chlorotic areas on the leaves.	Chlorosis of the central zone of the lamina, while leaf's margins and midrib area remain green	Purplish mottling of leaf petiole and malformation of leaves
		

Sulphur (S)

Sulphur is a secondary plant nutrient, essential for protein formation, as it is a constituent of the three amino-acids cystine, cysteine and methionine. It is also required for the formation of chlorophyll and for the activity of ATP - sulfurylase. It is taken up by the roots, primarily as sulphate (SO_4^{2-}).

Sulphur deficiency symptoms in bananas:

Since S deficiency affects mainly protein synthesis, its deficiency symptoms are closely similar to those presented by nitrogen deficiency, but the chlorosis is uniform and general throughout the entire plant, including younger leaves. Heart leaf becomes white, and other leaf blades become very soft, and tear easily. They become yellowish-white chlorotic and reduced in size, with a thickening of secondary veins; rolling leaf edges; necrosis along edge of lower leaves. Bunches are small or choked. Yields are reduced. Plants with advanced deficiency are stunted.

Sulphur deficiency is aggravated on acidic soils, light, sandy soils, soils that are low in organic matter, and on poorly aerated soils, e.g. waterlogged soils.



Figure 15: Sulphur deficiency symptoms on banana plants, Ref.: Mane, R. 2014

A chlorotic new leaf	An S-severely chlorotic leaf
	

Micro-nutrients

The availability of micro-nutrients is markedly influenced by soil pH.

- ✦ Above pH 7 there is a clear reduction in the uptake of Fe, Mn and Zn
- ✦ Below pH 5 there is a clear reduction in the uptake of Mo and P and an increase in the uptake of Mn and Al.
- ✦ High Na and Mg contents in soil reduce uptake of micro-nutrients.

Figure 16: Micro-nutrients removal by a yield of 50 MT/ha of 'Grand Naine' bananas.

Ref.: Lahav & Turner, 1989.

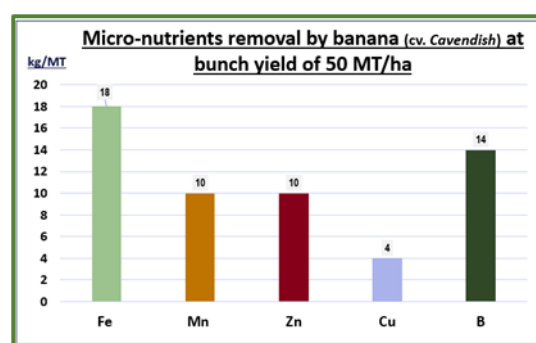




Figure 17: Micronutrients uptake curves by growth stage, of banana (cv *Robusta*) at 4th ratoon crop



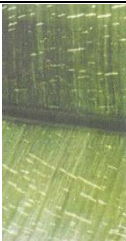
Boron (B)

B uptake rate in field is constant from sucker to harvest, at ~40 mg/plant/month

Boron deficiency is not common in bananas, except, in Latin American countries (e.g. Ecuador).

- ❖ Boron deficiency is common in acid soils.
- ❖ Boron deficiency symptoms:
 - Curling and deformation of leaves.
 - White strips perpendicular to veins on underside of the lamina.

Figure 18: deficiency symptoms of boron, copper and iron on banana leaves.

<u>B deficiency symptoms</u>		<u>Cu deficiency symptoms</u>	<u>Fe deficiency symptoms</u>
Whitish parallel streaking	Deformed foliage	Overall umbrella-like droopy appearance	Initial (left) & severe (right) leaf chlorosis
			



Copper (Cu)

Copper exists in biological systems in two oxidation states, the reduced Cu^+ state (cuprous) and the oxidized Cu^{2+} state (cupric). It also acts as a terminal electron acceptor of the mitochondrial oxidative pathway. In plants, copper plays an essential role in mitochondrial respiration, in the electron transport chain, photosynthesis, cell wall metabolism, and lignin synthesis. It also has a pivotal function in oxidative stress response and hormone signaling. One of the key roles of copper in plants is as a cofactor in various enzymes such as polyphenol oxidase, cytochrome-c-oxidase, laccase, and amino oxidase. Copper also performs critical functions in oxidative phosphorylation, transcription iron metabolism and protein trafficking. The interchange between Cu^+ and Cu^{2+} may result in generating toxic ROS, and other hydroxyl radicals. Therefore, plants have evolved mechanisms to precisely regulate copper uptake and accumulation, to avoid both deficiency and toxicity.

Deficiency Symptoms: Midrib and main veins bend backwards giving plant an umbrella appearance. Leaves turn a yellow bronze color. Cu toxicity may take place mainly where Bordeaux mixture is still in use for plant protection.

Iron (Fe)

Iron is a central constituent of cytochromes. Cytochromes contain an iron atom that is bound to a heme group. The iron atom can exist in either the ferrous (Fe^{2+}) or ferric (Fe^{3+}) state, and it switches between these states, as it accepts and donates electrons. This ability to shuttle electrons makes cytochromes crucial for processes such as cellular respiration and photosynthesis. Iron is also involved in the reduction in nitrates and sulfates, and in reduction processes by peroxidase and aldolase. Total amount of iron uptake by healthy plants is only about 1-3 g, 80% of which is taken up during the first half of plant's life. Iron is also crucial for N_2 fixation (which does not exist in banana plants).

Deficiency Symptoms:

General chlorosis of entire lamina, mainly of young leaves; Retarded plant growth; Small bunches. Leaf color becomes yellow-white.

Iron deficiency is mainly observed on: Calcareous soils; Soils with high water tables; High Mn soils.



Manganese (Mn)

Manganese is taken up by plant roots in the form of Mn^{2+} . It plays a crucial role in various physiological and biochemical processes. No less than 398 enzymes are predicted to contain Mn in the metal-binding site in Arabidopsis (Alejandro, 2020.) Manganese is an essential cofactor for the oxygen-evolving complex (OEC) of the photosynthetic machinery, catalyzing the water-splitting reaction in photosystem II. It also assists in photosynthesis by contributing to the chlorophyll synthesis and stability.

Manganese serves as a cofactor for a variety of enzymes, including those involved in lipid biosynthesis, and oxidative stress. It influences cell growth and division, promoting healthy cellular structures and overall plant development. It aids in maintaining proper cell functioning, ensuring optimal growth processes. Manganese is important for antioxidant enzyme activities, such as superoxide dismutase (SOD), which helps plants mitigate oxidative stress (Grandel, 2023). It contributes to stress tolerance by reducing the damage caused by reactive oxygen species (ROS) during adverse environmental conditions.

Manganese is necessary for root development, root elongation, and lateral root formation. It enhances nutrient uptake efficiency, by promoting a healthy root system, allowing plants to absorb essential nutrients from the soil.

Deficiency Symptoms: Young leaves appear lighter green, with numerous chlorotic spots between the parallel veins near the leaf margin. The spots later coalesce into large irregular necrotic spots. Chlorosis first appears on second or third youngest leaf.

Toxicity: Manganese toxicity is a common problem in acid soils. In severe cases, leaf Mn levels may reach 6000 ppm. High Mn levels reduce calcium uptake by 30%, magnesium uptake- by 40% and zinc- uptake by 20%, and may enhance the occurrence of disorder known as ‘mixed ripe’.



Figure 19: Deficiency symptoms of manganese and zinc on banana plants. Ref.: various

<u>Mn Deficiency symptoms</u>	<u>Zn Deficiency symptoms:</u> Smaller leaves (left); a cigar leaf (right)
	

Zinc (Zn)

Zinc is an essential micronutrient for plants, playing a crucial role in various physiological and biochemical processes as follows (Fariduddin, 2022):

- **Photosynthesis:** Zinc is an essential cofactor for the oxygen-evolving complex (OEC) of the photosynthetic machinery, catalyzing the water-splitting reaction in photosystem II (PSII).
- **Enzyme activation:** Zinc serves as a cofactor for a variety of enzymes, including those involved in photosynthesis, lipid biosynthesis, and oxidative stress. It is the only metal present in all six enzyme classes (oxidoreductase, transferase, hydrolases, lyases, isomerases and ligases).
- **Cell Growth and division:** Zinc influences cell growth and division, promoting healthy cellular structures and overall plant development. It aids in maintaining proper cell functioning, ensuring optimal growth processes.
- **Stress response:** Zinc-deficient plants exhibit inferior growth and yield, and are more susceptible to pathogens and damage at freezing temperatures.
- **Hormone regulation:** Zinc plays a role in the synthesis and regulation of plant hormones, including auxins, which are crucial for growth processes. It influences hormone transport, distribution, and signaling, impacting plant growth and development.
- **Protein degradation and recycling:** Zinc is involved in the degradation of proteins and the recycling of amino acids, aiding in nutrient mobilization within plants.

Zinc deficiency is a very common problem in bananas in all growth regions. It is more common on young plants with no mother plant to act as a nutrient reservoir. Symptoms may appear in one year



without affecting yield, but reduce fruit yield in second or third year. Zinc deficiency is found in bananas in sandy soils, and on high-pH soils, due to fixation, and on weathered acidic soils, where Zinc content is low. Under acidic conditions it maybe leached to deeper layers, where it would not be available to the root system. Also, zinc is inactivated at high concentrations of phosphorus in the soil.

Deficiency symptoms:

On leaves: Zn deficiency shows most clearly on young plants. A "cigar leaf" shows the first deficiency symptoms, with magenta-colored pigmentation, especially at the leaf base, see photo. As the leaf unfolds, the pigmentation only appears along the leaf margin undersurface. Leaves become narrow. Interveneal chlorosis stripes on the leaves. Oblong brown necrotic patches appear in the yellow stripes. It shows as narrow pointed and chlorotic young leaves, strap-shaped leaves, leaf chlorosis in strips or patches. Papery- textured leaf-laminae. Zinc deficient leaves are significantly smaller in size than a normal leaf and high concentration of anthocyanin pigmentation is developing on its lower side.

Suckers: become very thin.

Bunches have small twisted fingers.

Plant growth shows stunting and resetting.

F. Dynamics of nutrient requirements throughout the plantation's life

Figure 20: Nutrient uptake curves, comparison between 1st crop and ratoons, of banana (cv. 'Grand Naine'). Ref.: Irizarry et al. 1988.

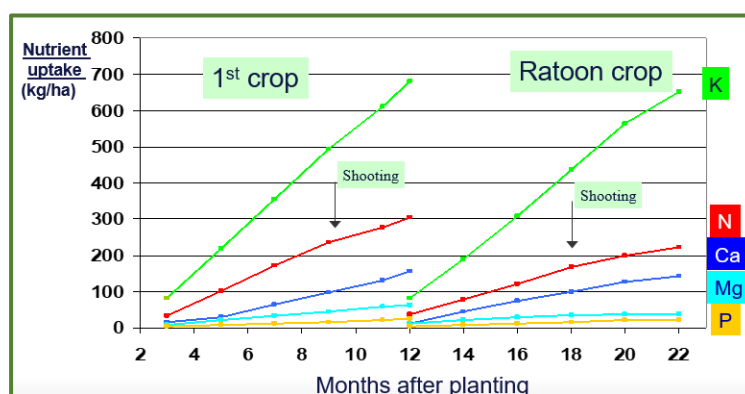


Figure 20 and common knowledge indicate that highest annual nutrient demand takes place on the first two years of the plantation's life. But marked decrease in the demand for N, P and Mg, but not for K and Ca takes place as of the 3rd plantation's life. The reason is that the next ratoons enjoy the minerals that are gradually recycled to the soil from the decaying cut leaves and pseudostems that are



left on the plantation's soil. This mineral recycling can be boosted by two methods, namely: A.) Avoiding cutting off the old pseudostems after harvest. B.) Cutting off the pseudostems, leaving them on the soil, and chopping them up. The practical advice stemming from the above, is that fertilizer application rates of N, P and Mg can be reduced by 25% for all ratoons, following the second one. But the rates of potassium and calcium should be kept throughout all the plantation's life.

G. Salinity issues

Banana plants are considered one of the highly sensitive plants to salinity. Salinity stress can adversely affect plant height, pseudostem circumference, leaf area, and can create nutrient imbalances, reducing uptake of other nutrients. Bananas can tolerate total soluble salts in the soil solution, at 100–500 ppm, but plants and fruits are visibly affected at 500–1,000 ppm; At >1,000 ppm plants become stunted or die. Salinity stress shows as marginal leaf chlorosis, stunted growth and deformed slim fruits. Dessert bananas of AAA type (e.g. *Cavendish* cultivars) are more sensitive than plantains (AAB/ABB types).

Apart from general salinity, banana plants are specifically sensitive to the chloride anion Cl^- , and to the sodium cation Na^+ . Bananas are more sensitive to sodium than to chloride. High chloride can cause severe damage to most parts of the plant, and, subsequently affect yields and fruit quality. It can lead to reduced chlorophyll content in leaves (chlorosis), and low sugar content in the fruit.

Sodium can be beneficial to plants, particularly under potassium deficiency. However, high external Na^+ concentration results in extreme tissue concentration of Na^+ , which may lead to toxicity. Na^+ toxicity symptoms often start with chlorotic discolorations that turns into necrotic lesions, and leaf-tip scorching.

The conclusion from the said above is that special care should be practiced by the grower, in avoiding application of high rates of fertilizers at once, and prefer applying low rates, continuously, throughout the year.



Figure 21: Banana plants irrigated with saline water, express necrotic symptoms in leaf margins. Ref.: Ravi & Vaganan. 2016.



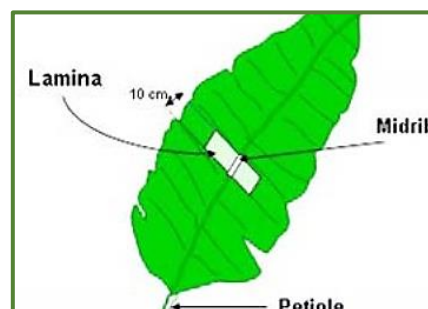
H. Avoiding nutritional deficiencies in bananas plantations

Leaf analysis is a highly efficient tool for diagnosing nutrient deficiencies in banana plants. Here is a general procedure for the 'Grand Naine' variety:

1. **Sampling time:** either just before flowering, or following floral emergence, when all female hands are visible.
2. **Sample Collection:** Collect leaf samples from some 12 plants across the relevant plot, to get a representative sample. The leaf to be sampled is the third fully expanded leaf, from the top of the pseudostem of a recently flowering (shot) plant.
3. **The leaf part** that should be used: generally (IRS method, 1975), a laminar structure of the said leaf is sampled, by cutting off a strip of tissue, ~10 cm wide, on both sides of the midrib, as shown in figure 22.
4. **Preparation:** Clean the sample with distilled water, to remove dust or any residues, rap it in towel paper and a paper bag and send it immediately to the closest expert lab.



Figure 22: The specific part of the plant leaf that should be sampled for chemical analysis.



5. **Interpretation:** The results from the laboratory are then compared to established nutrient sufficiency ranges for banana plants. If nutrient levels are below these ranges, it indicates a deficiency.
6. **Action:** Based on the results of the leaf analysis, appropriate fertilization strategies can be developed to correct any nutrient deficiencies.

Table 3: Leaf nutrient levels (in dry matter) for 'Grand-Naine' banana plantations.

Ref.: IFA manual, 1999.

<u>Status</u>	<u>Nutrient</u> (% in dry matter)						
	<u>N</u>	<u>P</u>	<u>K</u>	<u>Ca</u>	<u>Mg</u>	<u>S</u>	
Deficient	≤2.3	≤0.12	≤1.9	≤0.4	≤0.24	≤0.21	
Low	2.3-3.3	0.13	2.0-4.5	0.4-0.8	0.25-0.29	0.21-0.25	
Optimum	3.3-3.7	0.14	4.5-5.0	0.8-1.3	0.3-0.4	>0.25	
High	>3.7	0.15-0.3	>5.0	<1.3	<0.4		
<u>Nutrient</u> <u>Status</u>	<u>B</u> (ppm)	<u>Cu</u> (ppm)	<u>Fe</u> (ppm)	<u>Mn</u> (ppm)	<u>Zn</u> (ppm)	<u>Na</u> (ppm)	<u>Cl</u> (%)
Adequate	11	9	>100	160-2500	>20	100	1
Excess <u>Toxic</u>		25	300	>4,800		<u>≥300</u>	<u>≥3</u>

I. Nutrient management, general recommendation

♣ Removal of plant nutrients in the harvested banana fruit is one of the major considerations in formulating fertilizer recommendations. The quantities of plant nutrients contained in the whole plant and in the fresh fruit harvested and removed from the field, are the basis for scheduling the fertilization program.



- ♣ Nutrient requirements of the first crop after planting a new plot are considerably larger than those of the following ratoons. The reason is that the first crop requires the nutrients for producing the entire vegetative components of the mat, including the corm and the pseudostem. But ratoon crops enjoy the residues of the previous crops, e.g. leaf trash and cut pseudostems, that are left in the plot after harvests. While rotting they supply the soil with their recycled nutrient components, so less fertilizer is needed.
- ♣ Therefore, nutrients from applied fertilizers and trash leaves and pseudostems are contributing to soil fertility, and have to be considered for calculating fertilizer rates for ratoon crops.
- ♣ Plant nutrient requirements vary according to expected yield and plant growth, considering the contribution of recycled plant parts from the previous crop.
- ♣ Highly split application of fertilizers reduce nutrient losses, and contribute to constant and healthy growth of the plants.

Ref.: Irizarry et al. 1988; Twyford & Walmsley 1973/74/76; van der Vorm and van Diest. 1982.

Table 4: Nutrient removal by Cavendish Banana per MT of entire banana bunches. Ref. IFA, 1991

<u>Variety</u>	<u>Plant Nutrient</u> (kg/MT)					
	<u>N</u>	<u>P₂O₅</u>	<u>K₂O</u>	<u>CaO</u>	<u>MgO</u>	<u>S</u>
Cavendish group	4 - 7	0.9 - 1.6	18 - 30	3 - 7.5	1.2 - 3.6	0.4 - 0.8
Other	Up to 10	Up to 3.5	Up to 60	Up to 12	1.2 - 3.6	0.4 - 0.8



Table 5: Nutrient requirements for expected ratoon yield of 40-60 MT/ha.

Nutrients requirements (kg/ha)				
N	P ₂ O ₅	K ₂ O	CaO	MgO
<u>Uptake by whole plants</u>				
198 - 339	68 - 114	734 - 1268	165 - 273	92 - 155
<u>Removal by yield</u>				
57 - 114	15 - 30	240 - 480	24 - 48	21 - 42
<u>Available nutrients from recycled previous crop</u>				
48	12	280	16	16
<u>Recommended application rates</u>				
190 - 359	91 - 146	454 - 988	67 - 121	76 - 139

Practical nutrient-specific recommendations

- ❖ Nitrogen & phosphorus: continuous application throughout the growth period.
- ❖ Potassium: Continuous application throughout the growth period, but, smaller rates at early growth stages, increased rates at one month before and after flowering (from “large” to “shot”). 80% of annual rate should be applied before peak flowering.
- ❖ Calcium: Main application for fruit production should focus on periods before Shooting/Shot. Small rates after shooting.
- ❖ Magnesium: continuous application throughout the growth period.
- ❖ Sulfur: highest rate should be applied from “Sucker” to “Shooting” stages, then- low application rate.



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