

SOIL FERTILITY DEGRADATION  
AND  
RESTORATION  
UNDER BANANA CULTIVATION

EKONA BANANA ESTATE OF CDC

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## INTRODUCTION

At the request of Mr. J.L. Robertson, the Banana Technical Adviser of CDC, the Soil Science Section of the Centre of Agronomic Research at Ekona carried out a soil fertility study in the Ekona Banana Estate of CDC, as a follow-up of the soil survey of the Estate summarized in Technical Report N° 11 "Soils and Soil Fertility Management of the Lands of the Ekona Banana Estate of CDC".

The purpose of this present study was to get further information on the following points:

- to try to find any common factor in the areas which have a tendency to produce "green ripe" fruits and also in fields with current potash deficiency symptoms;
- to establish a better fertilizer policy for the poorer soils of Mussaka Series.

The study was therefore conducted as follows:

- for each Soil Series as defined in Technical Report N° 11, banana fields were selected following field observations made by the Technical Adviser, i.e. fields with the presence or absence of green ripening and fields with potassium or magnesium deficiencies. Field plots L1, F2, F3 of Molyko Section, Q12, Q14, Q16 of Lysoka Section and B1, D1 of Moli Section were considered, at the time of the sampling, as "reference fields" where banana plants usually grow well with good recorded yields.
- Thereafter a simultaneous foliar and topsoil sampling was conducted in April 1981: topsoil samples were taken at a depth of 0-30 cm and banana leaves were sampled according to Martin-Prével's method (APFD).
- Topsoil and leaf samples were analyzed in the Soil and Plant Laboratory at Ekona.

Following technicians participated in the study:

- B. Delvaux, FAO Associate Expert
- A. Moukam, Soil Scientist
- J.N. Efite, Head of Laboratory
- T. Nyobe, Agric. Assistant.

The results of this study are presented in this report, taking into account comments and observations made by Mr. J. Champion, General Manager of IRFA, Messrs. H. Tezenas du Montcel and A. Lassoudière, Plantain and Banana Agronomists of IRFA who are here acknowledged for their helpful suggestions.

## 1. SOIL CONDITIONS

The soil conditions of the lands of the Ekona Banana Estate have been studied in detail in Technical Report N° 11 "Soils and Soil Fertility Management of the Lands of the Ekona Banana Estate of CDC".

The soils are developed in redeposited pyroclastic materials of basaltic origin (colluvial or mudflow deposits). The thickness of the deposit varies widely: some are very thin and underlain by lava flow that crops out locally; others are either gravelfree or gravelly and stony.

The deposits are of various ages and the soils are grouped into three soil series forming a chrono-toposequence. This sequence is characterized by the evolution of typical young loamy Andosols (Andepts) towards older and clayey soils (Humults).

The soil series are:

1.1. Molyko Series groups soils developed on young loamy mudflows (600-750m. alt. Their exchange complex is dominated by amorphous material. These soils have excellent physical properties: they are loamy, permeable, very porous with bulk densities lower than 0.85 gm/cc and have a fine granular topsoil structure. Stonefree profiles have no physical limitations for growing bananas.

Chemically, the soils of the Molyko Series belong to the most fertile soils of the area. Under natural vegetation they are rich in organic matter (8-13%) and only slightly acid (pH around 5.7-6.0), with high levels of nutrients, including phosphorus. They are classified as Udic Eutrandepts (Soil Taxonomy).

Under intensive banana cultivation and the prolonged application of Sulphate of Ammonia, the pH has dropped to 4.2-5.0, (pH water): the soils have still adequate levels of organic matter but the base saturation is lower. They are classified as Hydric Dystrandepts.

Potash deficiencies are observed only on very thin colluvial or mudflow deposits underlain by rocky lavaflows.

1.2. Ekona Series groups soils developed on somewhat older mudflows (alt. 400-600m.). These soils have lost many properties of the Andosols: the bulk densities are higher and the exchange complex is no longer dominated by amorphous material. They also have more clay and an argillic horizon. They have rather good physical properties: the topsoils are clayey and have a granular and fine blocky structure; the subsoil usually contains more clay and has a weak prismatic structure, without being dense. These soils are only slightly susceptible to compaction.

Chemically, they have good fertility levels under natural Vegetation: the topsoils are well supplied with organic matter (4-8%) and are slightly acid (pH 5.5-6.0) with good nutrient levels; The epipedon is often mollic and the soils are classified as Andic Argiudolls (Soil Taxonomy). Under intensive banana cultivation the pH has dropped to 4.4 - 5.0 but organic matter levels are still high (4-9%). Nutrient levels are adequate but the exchange complex is less saturated; the topsoil is often an umbric epipedon and the soils are classified as Andic Tropudalfs or Andic Tropohumults (Soil Taxonomy). Some Ekona soils have a cambic horizon and are classified as Andic Humitropepts.

1.3. Mussaka Series groups soils developed on older mudflows (alt. 300-400m.). These soils have a well developed argillic horizon.

The topsoils are clayey (50-70% clay) and have a medium granular and blocky structure. Under intensive banana cultivation, the structure tends to deteriorate into a coarse blocky structure, forming sometimes very hard blocks, when dry.

The subsoil is more clayey and dense, very difficult to penetrate by the root system of bananas. Moreover few mottles and fine concretions indicate an excess subsurface water during prolonged wet periods of the rainy season (mid-July to end of September).

These soils are thus susceptible to topsoil structure degradation, compaction and locally the formation of thin hardpans stopping the development of the rooting system.

Under natural vegetation, the soils have relatively high levels of organic matter (5-7%) and are slightly acid (pH 5.6-6.0) but under intensive banana cultivation the organic matter levels decreased to 2-4% and pH values dropped to 4.2-4.5. This is due to the much lower buffer capacity of the Mussaka soils in comparison to the Ekona and Molyko soils.

Under natural vegetation, the soils having a mollic epipedon are classified as Andic Argiudolls while those having an umbric epipedon are classified as Andic Tropudalfs and Tropohumults.

Under intensive banana cultivation, the topsoil is an umbric epipedon and most of the soils are classified as Andic Tropohumults, few of them as Orthoxic Tropohumults and Palehumults.

## 2. FOLIAR ANALYSIS (Table 1)

### 2.1. Leaf Nutrient Contents

Following observations can be made on the results of foliar analyses (Table 1):

- 2.1.1. There is a clear difference between the "reference fields" where Green Ripening was never observed, i.e. L1, F2, F3, Q12, Q14, Q16, B1, D1 and the other field plots. The reference fields have:
  - medium and lower levels of K (2.77 - 3.42%)
  - the highest contents of Ca (0.66 - 0.82%) and Mg (0.16 - 0.23%).
- 2.1.2. Leaf Ca and Mg contents seem to decrease progressively from Molyko Series to Mussaka Series; the same remark applies for leaf P content.
- 2.1.3. The worst field plots of Mussaka (D7, F7) and Bolifamba (A18, B18, B17) sections, where green ripening is currently observed and very low to catastrophic yields are regularly recorded, are characterized by:
  - the highest levels of leaf K (3.24 - 3.78%),
  - the lowest leaf P contents (0.163 - 0.175%),
  - very poor leaf Mg contents (0.10 - 0.13%),
  - relatively low Ca levels (0.54 - 0.68%).
- 2.1.4. The leaf N contents in all plots seem to be lower than optimum levels as compared with literature data.
- 2.1.5. Leaf K levels in field plots K7, L7, (Lysoka Section) and Blocks II and III (Ekona Section) were compared with those in field plots Q12, Q14, Q16, but no strict correlation between the probability of observing K deficiency symptoms and a critical K leaf content was found.
- 2.1.6. Although leaf Mg contents are often poor and far below adequate leaf levels proposed in the literature, the magnesium deficiency is seldom observed; symptoms were noted in field plot G12 of Mussaka Section where leaf Mg level is exceptionally low (0.08%) and leaf K content the highest observed (4.75%).

As a conclusion, bananas growing on the soils of Molyko and Ekona Series show a better foliar assimilation of P, Ca, Mg than bananas growing on the soils of Mussaka Series. On the latter lower Mg leaf contents (0.08 - 0.15%) may indicate that a Mg deficiency is probably latent in most of the banana fields. Higher leaf K contents likely correspond with a higher probability of observing the green ripening phenomena.

## 2.2. Leaf Nutrient Balances

When leaf cation contents are expressed in milli-equivalents per 100 g of leaf dry matter, it is possible to visualize the proportion of each cation relatively to the sum of cations (S) in a triangular graph (Fig. 1).

This graph shows that:

- 2.2.1. The probability of observing green ripening is very high when the proportion of K relatively to the sum  $K + Ca + Mg$  is over 64-65%;
- 2.2.2. When the relative proportion of K increases further (77.6%) magnesium deficiency symptoms are observed.
- 2.2.3. Potash deficiency does not seem to be related to a weaker relative proportion of potassium.
- 2.2.4. In field plots with current "green ripe" fruits, there is no particular antagonisms K/Mg and/or K/Ca: the relative excess of potassium (64-79%) occurs to the prejudice of calcium (26-23%) as well as magnesium (13-6%).

It seems therefore that green ripening could be related to an excess of potassium assimilation by the banana plant relatively to calcium and magnesium; a serious excess may induce a pronounced K/Mg imbalance hence Mg deficiency symptoms appear.

## 2.3. Minor Elements

In Lysoka area, a trace element trial showed no significant effect of application of zinc, manganese, boron and copper on vegetative growth characteristics. However no investigations were made on their effect on fruit quality (experiments RB/42 1967-68 and RB/43 1968-69 - CDC, IFAC Research Reports).

Recently, micro elements deficiency symptoms were noted by J. Champion and A. Lassoudière (January 1982).

In field plot G12 of Mussaka Section, zinc and boron deficiency symptoms appear on banana leaves, zinc deficiency being probably more important.

In the same field plot, toxicity symptoms were also widespread observed and were not attributed to any herbicide application: they consist of a blackening of the borders of the leaf extending towards its internal zone. A manganese toxicity could be suspected because of the strong acidity of the topsoil and a rather slow permeability. This should however be checked by foliar analysis.

### 3. THE ROOTING ENVIRONMENT OF THE BANANA PLANT

#### 3.1. Soil Physical Conditions

Trenches were dug in a few fields to examine the rooting system of the banana plant on one hand and the physical and morphological properties of the soil rooting environment of the plant on the other hand.

Such observations were made on soils of Molyko Series (field plot L1 of Molyko Section) and Mussaka Series (field plots G12 of Mussaka Section, D12 of Bolifamba Section and blocks II of Ekona Section).

##### 3.1.1. Molyko Section (L1)

Following observations were made in trenches parallel to the planting now:

Horizon depth (cm)	Texture; Consistency	Structure; porosity	Rooting System
Ap (00-17)	loam; slightly sticky, <del>non</del> plastic, loose to friable	fine loose to medium moderate granular aggregates; very high porosity	wide horizontal distribution of abundant long, medium (3-5mm) roots with many hair-roots;
A3 (17-40)	loam; slightly sticky, slightly plastic, friable	medium moderate granular and subangular blocks; many fine and medium pores	frequent medium roots, almost no hair-roots
B2 (40-60)	loam; slightly sticky, slightly plastic, friable	medium weak angular blocky structure; many fine pores	frequent medium roots; almost no hair-roots

The excellent physical properties of the soils of Molyko Series warrant an ample space for rooting system development and extension. The banana roots explore a large volume of soil (00-60 cm depth) and are thus able to extract the nutrients required by the plant.

##### 3.1.2. Mussaka (G12) and Ekona (Block II) Sections

The trenches were dug as follows:

- parallel to the planting row facing two banana plants,
- perpendicular to the planting row to see the effect of the ditching (prior to planting) on the roots distribution.

In the first case, following observations were made:

Horizon Depth (cm)	Texture; consistency	Structure porosity	Special Features	Rooting System
Ap (00-20)	clay; sticky, slightly plastic, friable (moist)	medium moderate granular and sub-angular blocky structure; many fine and medium pores	None	common medium but short roots; very few hair-roots
B1 (20-30)	heavy clay; sticky, plastic, friable (moist)	medium moderate subangular and angular blocky structure; many fine and very fine pores	few fine faint mottles	common medium but short roots; no hair-roots
(B21+ (30-50)	heavy clay, sticky, plastic, friable to firm (moist)	medium and coarse angular blocky structure with a tendency to form coarser prisms; common very fine pores	few fine faint mottles	no roots

When dug in a perpendicular way to the planting row, the cut shows that the banana roots only explore the soil volume that is disturbed by ditching and that the dense clayey subsoil is a serious obstacle to root penetration.

On the other hand roots although thick (4-6mm), are short, very little ramified and not abundant. These signs are known to be aluminium and/or manganese toxicity symptoms for several crops. Unfortunately no literature data exist on injuries to the rooting system of the banana plant as related to soil acidity. pH analysis however indicates values of 3.8-3.9 in the zone explored by the banana roots; these values are much lower than those given by the topsoils analysis (Table 2; Mussaka and Ekona Section) because in the latter case, the topsoils samples were taken in the planting row between two matts and at an equal distance between two plants that is in a zone which is less influenced by applications of Sulphate of Ammonia.

3.1.3. Bolifamba Section (D12)

The following observations were made:

Horizon Depth (cm)	Texture; Consistency	Structure; Porosity	Special Features	Rooting System
Ap (00-07) (00-11)	clay; sticky, slightly plastic, soft	fine and loose gra- nular structure; very porous	None	abundant medium roots; common hair- roots
hardpan (7-13) (11-15)	clay; sticky, plas- tic, very to extre- mely hard	continuous (locally discontinuous) pan with a strong platy structure; compact	few to common fine distinct Fe Mn mottles	no roots
B1 (15-30)	clay; sticky, plastic, friable	medium moderate angular blocky structure; many fine and very fine pores	None	no roots

This field has not been subsoiled for a very long time and the continuous use of Rome - plough (disc-harrowing) led to the formation of a plough pan that is 4-6 cm thick. This pan is impenetrable for roots; the soil volume explored by the banana roots is thus strongly reduced and this probably partly explains the very bad stand of the banana plant (5-7 leaves, very poor bunches) in this field.

Moreover, iron (orange) and particularly manganese (blue-black) mottles were found at the level of the pan which indicate an imperfect drainage with some excess water during the wettest period, hence a toxic environment for the roots within this 4-6 cm thick layer.

Therefore, correct tillage practices are very important on soils of Mussaka Series in order to ensure a larger soil volume to be explored by banana roots.

A double crossed subsoiling is imperative and should preferably be followed by a correct deep ploughing that tills and prepares the soil much better than a single crossing with the Rome-plough. The passage of the latter leaves very coarse and firm aggregates on the ground while the former breaks the clods into rather fine aggregates at approximately 30-40 cm depth. This was experienced in IRA plantain fields at Lysoka Antenna.

### 3.2. Soil Chemical Conditions (Table 2)

#### 3.2.1. Soil Acidity and Acid Soil Infertility

Generally the topsoils are acid to very **acid** (pH: 5.0-4.2) average pH value being around pH 4.5.

Comparing table 2 with the topsoil analysis carried out in 1976 (Technical Report N° 11), the average reduction of pH (as determined in water suspension) can be estimated around:

- 0.8 units for the soils of Molyko Series,
- 0.4 units for the soils of Ekona Series,
- 0.4 units for the soils of Mussaka Series.

"It is well known that pH per se has no direct effect on plant growth, except at pH values below 4.2, where the hydrogen ion concentration may stop or even reverse cation uptake by roots. Acid soil infertility is due to one or more of the following factors: aluminium toxicity, calcium or magnesium deficiency, and manganese toxicity" (Sanchez).

(a) Hydrogen ion concentration: no pH values were recorded below pH 4.2 as indicated in table 2 (topsoils are sampled in the planting row between two plants). Nevertheless, and as already pointed out in 3.1.2., samples taken in the root growth medium gave pH values of 3.8 and 3.9 in Ekona Section; although no literature data are available about the tolerance or sensitivity of the banana plant to soil acidity, it can be reasonably assumed that these values are extremely low and likely create an adverse chemical environment for the roots in their growth medium. This could probably explain the rather poor aspect of the banana roots in Ekona and Mussaka Section.

#### (b) Calcium and Magnesium Deficiencies

Foliar analysis does not indicate any calcium deficiency but only relatively lower levels in bananas growing on soils of Mussaka Series.

Magnesium deficiency is clear on field plot G12 and probably latent in most of the banana fields on soils of Mussaka Series.

Soil acidity clearly hampers both Ca and Mg assimilation (fig. 2D) whereas it does not affect K assimilation (fig. 2E and G). Besides fig. 2D shows a rather good grouping of the fields where current physiological troubles occur (green ripening, K and Mg deficiencies) below pH 4.6.

(c) Aluminium and Manganese Toxicities

No physiological mechanisms of the banana crops have been identified as associated with tolerance or sensitivity to aluminium.

In Columbia, the banana plantain "topocho" was tentatively proposed as a foodcrop suitable for acid soils in which Aluminium is the dominant exchangeable cation and with minimum lime requirements.

In Ivory Coast, banana crop is known to grow quite satisfactorily on acid peat soils, that should probably be low in available manganese.

In the studied case, an aluminium toxicity is probably not to be suspected: exchangeable Al levels, although expected to be higher at such pH values, range from 2.03 (pH = 4.2) and 0.10 (pH = 5.0); besides soil (Ca + Mg)/(Al + Ca + Mg) ratios are too high to suspect such a toxicity.

However a manganese toxicity can be suspected for the following reasons:

- manganese is very soluble at pH values lower than 5.5; its solubility also increases with soil reduction: therefore both acidity and imperfect drainage of the soils of Mussaka Series increase the availability of manganese; manganese toxicity can therefore occur if this element is present in sufficient amounts in the parent rock.
- the soil parent material is rich in manganese: blueish - black Mn mottles and/or concretions can be seen in soils found in depressions with poor drainage conditions and are much more abundant than iron mottles and/or concretions; this locally led to the formation of thick manganiferous hardpans (Pindi Valley, N'Sone Camp-Dibanda).

(d) Increasing soil acidity also reduced  $\Delta\text{pH}$  values:  $\Delta\text{pH}$  is the difference  $\text{pH}_{\text{KCl}} - \text{pH}_{\text{water}}$ ; in the studied Estate fields;  $\Delta\text{pH}$  actually varies between -0.2 and - 0.6. This is not a surprise on soils with a variable charge. Previous topsoil analysis (1976, Technical Report N° 11) indicated  $\Delta\text{pH}$  values ranging between - 0.8 and  $\rightarrow$  1.2 and higher pH values in water. Acidification has therefore strongly reduced the difference  $\text{pH}_{\text{KCl}} - \text{pH}_{\text{water}}$  and increasing further soil acidity may possibly lead to positive  $\Delta\text{pH}$  values.

Highly weathered and acid soils with positive  $\Delta\text{pH}$  are known to be the so-called "Multiple deficiency - soils" and this is related to low silica content.

The studied soils are not old enough to belong to that group of soils but increasing acidity may eventually lead to a comparable behaviour with the following characteristics:

- a poorer assimilation of cations, which is observed in this case on the most acid soils for Ca and Mg (fig. 2D);

- an increased fixation of phosphates by the oldest soils of Mussaka Series (Ekona, Bolifamba Sections), with available P mostly tied up with organic matter. The same remark applies for sulfate and molybdate anions; silicate applications can improve the availability of these anionic nutrients.
- Micro-elements deficiencies (except for Mn).

### 3.2.2. Organic Matter

Organic matter levels are generally adequate, particularly in soils of Molyko and Ekona Series. Lower levels are observed in the poorer soils of Mussaka Series. Besides, there is a correlation between leaf P content and organic matter level which confirms the remark made under 3.2.1. d.

### 3 2.3. Available Phosphorus

Very low soil P levels are observed in Lysoka Section (Ekona Series), Bolifamba, Ekona and Mussaka Sections (Mussaka Series) where they range between 3 and 8 ppm. Generally the critical level which is admitted with the Kurz-Bray II method is around 20 ppm of available P.

### 3 2.4. Exchangeable Bases

Total exchangeable Bases (TEB) levels are generally high on soils of Ekona and Molyko Series. Lower values are recorded on soils of Mussaka Series. Soil K level is generally much higher than 1 meq/100 grs. but K deficiencies are still observed (plots K7 and L7). This could be due either to high levels of actually non-exchangeable calcium and magnesium that can become readily available, or to physiological troubles in the banana plant.

The highest levels of magnesium are recorded in field plots where green ripening has never been observed. This element is highly variable in the studied soils (0.35-3.8 meq/100 gr. soil), but more than half of the values are below 2 meq/100 gr. soil. Calcium level is highly variable (1.21 - 12.11 meq/100 gr. soil) but the same tendency as for magnesium can be noted: field sections without "green ripe" fruits show higher values.

Soil cationic balances therefore widely vary as shown in the table below but there is a tendency showing that an excess of K relatively to Ca and Mg induces green ripening of the banana fruits:

Soil Series	Field Section	Plot N°	K/Ca + Mg	K/Ca	K/Mg	Field Observations
M O L Y K O	Molyko	L1	0.17	0.244	1.51	No Green Ripening
		F2	0.12	0.17	0.83	
		F3	0.21	0.35	1.07	
	Lysoka	K7	0.26	0.50	1.31	K deficiency
		L7	0.21	0.42	0.71	
E K O N A	Molyko	F10	0.25	0.40	1.80	Green Ripening
		F11	0.15	0.59	0.59	
	Lysoka	Q12	0.09	0.13	0.50	No Green Ripening
		Q14	0.09	0.13	0.50	
		Q16	0.11	0.15	0.59	
	Moli	B1	0.11	0.16	0.52	
D1		0.18	0.30	0.97		
M U S S A K A	Mussaka	D7	0.141	0.28	0.38	
		F7	0.26	0.50	1.13	
	Bolifamba	A18	0.22	0.37	1.18	Green Ripening
		B18	0.28	0.46	2.47	
		B17	0.27	0.45	2.03	
	Mussaka	F12	0.27	0.55	1.13	No Green Ripening
	Ekona	B1 II	0.24	0.40	1.42	K deficiency
B1 III		0.34	0.61	3.36		
Mussaka	G12	0.18	0.27	1.39	Mg deficiency	

### 2.5. Micro-elements

Although soil micro-elements levels were not determined, following remarks can be made, which are based on literature data and the available soil information.

Molybdenum is the only micro-element whose availability is affected by soil acidity: its concentration decreases 100-fold for each unit decrease in pH. Moreover the uptake of Mo by several plants is reduced by sulphate applications, this being due to a competition between  $\text{MoO}_4^{2-}$  and  $\text{SO}_4^{2-}$  anions. Molybdenum deficiency symptoms are unknown on the banana plant but yield responses to molybdate applications have been observed on very acid soils (pH 4.5) in Latin America.

Both soil acidity and an ample supply of sulphate anions through the use of Sulphate of Ammonia on the soils of the Estate may probably render Mo a limiting factor for intensive banana cultivation. This however should be tested: Ammonium Molybdate applications could best be tried out in field plot G12 (Mussaka Section) and will eventually indicate whether Mo is lacking or not in the soils of Mussaka Series.

Boron content is known to be lower in basalt rocks as compared to granitic or sedimentary rocks but its availability in soils usually increases with soil acidity. Its deficiency in Mussaka and Bolifamba fields is therefore most probably due to continuous exportations of this element in harvested bunches as well as a lower initial level in the soil parent rock. The lack of B could be easily corrected by Borax applications.

Zinc availability usually also increases with soil acidity whereas liming, high phosphate fertilization and liberal applications of Nitrogen often induce Zn deficiency.

Nevertheless zinc deficiencies were also reported on acid and imperfectly drained soils in Latin America (on rice); soil compaction may also be a factor inducing this deficiency. In some cases, it was observed that a proper Mg supply increases Zn availability.

It is possible that appropriate tillage practices could improve Zn assimilation by the banana plant but the quickest remedy would be to apply Zinc Sulphate.

Manganese solubility in soils strongly increases with soil acidity and in imperfect drainage conditions especially if the soil parent material is rich in this element, which is the case here.

Manganese reduces the availability of calcium, magnesium and often induces chlorosis symptoms due to iron deficiency. There is no indication in the literature that an excess of Mn could hamper Zn or B assimilation by the plants. Pronounced Mn-Mg antagonisms have already been reported in Cameroon (Tiko plain) and determined through leaf analysis to the prejudice of the second element.

In the Ekona Estate, Mn excess can be suspected in field plot G12 as continuous black and necrotic margins were noted on banana leaves (Martin Prével); moreover Mg deficiency symptoms (blue veining) have also been observed in this field hence a possible Mn-Mg antagonism could be suspected but this still has to be confirmed through leaf analysis.

Zn and B deficiencies were also noted in field G12, though one would expect a better assimilation of these nutrients in such acid conditions (pH 4.5).

On Lysoka Plantain field trials similar observations were made quite recently. Here plantain leaves often have black necrotic margins; moreover blue veining is often, but less frequently, noticeable: this could be attributed to respectively Mn toxicity and Mg deficiency, leaves suspected of Mn toxicity being often attacked by Deightonella. In addition chlorotic strips that could be attributed to Zn deficiency were noted on 2 or 3 plantains. These observations were made in fields characterized with pH values ranging from 4.4 to 4.8.

It may be of interest to mention that similar relationships have been noted in long-term fertilizer experiments on coffee on basaltic soils in Cameroon (Bouharmont, IFCC): higher doses of Sulphate of Ammonia have a strong depressive effect on zinc, boron, and copper levels in coffee leaves and on the other hand, a distinctly positive effect on manganese accumulation in the leaves, especially on the more acid soils (pH 4.4 - 4.6).

It seems therefore that these changes in the assimilation of Zn, B and Mn could be related to excessive use of Sulphate of Ammonia, this likely through increasing soil acidity.

In the Estate soil aeration by correct tillage practices but particularly liming reduce manganese activity in the soils.

#### 4. RELATIONSHIPS BETWEEN FOLIAR AND TOPSOIL ANALYSIS

The correlations between leaf nutrient contents and/or ratios and soil nutrient ratios and  $pH_{\text{water}}$  are shown in figure 2.

No appropriate correlation was found between leaf nutrient contents and soil nutrient levels hence a fertility scale could not be developed. Rather the assimilation of the cationic nutrients by the banana plant is greatly governed by soil cationic balances and soil acidity, with all its possible consequences (ref. 3.2.1.).

Graphs 2A, B and C indicate that the different fields can be grouped into two categories defined by the absence or presence of green ripening phenomenon. If the proportion of potassium relatively to calcium and magnesium is too high, either in the leaves or in the soils, or in both, the probability of observing green ripening considerably increases: the quality of the correlation seems to be better for K/Ca (fig. 2B) than for K/Mg ratios (fig. 2C). Moreover these graphs show there is no correlation between  $K/(Ca + Mg)$ , K/Ca, K/Mg ratios and the occurrence of potash deficiency; the latter even surprisingly appears when potassium seems to be in excess in the soil, as compared with calcium and magnesium. Potash deficiency has thus probably to be related to physiological disorders in the banana plant and/or to soil acidity since it appears only on fields with soil pH values under 4.6.

Graph 2D clearly establishes the depressive effect of soil acidity on the assimilation of Ca and Mg by the banana plant and its consequences on the probability of observing the green ripening phenomenon. Most of the "reference fields", except L1, are grouped in the graph above pH 4.6 and a leaf Ca + Mg value  $> 51$  meq/100 gr of dry matter.

The following information can be drawn out of graphs 2E, F, G, H :

- there is no correlation between leaf K content and soil pH; figure 2E also indicates that pH 4.6 seems to be a limit (1) above which the probability of observing either green ripe fruits or potassium or magnesium deficiencies does not exist and (2) below which K deficiency is noted if leaf K level is lower than 3.1%, green ripening phenomenon is observed if leaf K level ranges between 3.2-3.8% and eventually Mg deficiency appears if K leaf content is exceptionally high (4.75%);
- potash deficiency is not related to a relative excess of calcium and magnesium;
- soil acidity seems to have a more depressive effect on Ca assimilation than on Mg assimilation by the banana plant; moreover the grouping of the different fields is of better quality in figure 2F which could suggest a predominant role of calcium in the occurrence (absence-presence) of

## 5. CONCLUSIONS AND RECOMMENDATIONS

### 5.1. General

The ability of the natural environment of the Ekona Banana Estate to produce good quality bananas depends on several factors among which some can be modified through appropriate management practices. These practices are:

- the water supply to the banana crop during the dry season (25mm/week);
- the banana fertility management which is related to the fertility or the soil itself, which depends on both physical and chemical properties;
- the disease control (cercospora, nematodes, borers) is of chief importance in the Estate: banana plants which are not healthy cannot take all benefit from optimum irrigation and fertilization practices.

The ~~second~~ aspect only is treated in this report, but it should be born in mind that all three factors are inter-related: non-healthy plants do not take a maximum benefit from a proper fertilization; a plant which is not well fertilized is much less resistant to fungic diseases; banana roots which are attacked by nematodes or limited in their development and extension by any physical barrier are not able to explore an optimum soil volume and absorb all the nutrients available in it etc...

It is therefore felt that all the problems should be sequentially treated and fertility investigations should come at the last position hence if fertilizer trials have to be carried out, all the other factors should be kept at their optimum level: water supply should be ensured (irrigation in the dry season), disease control should be strictly applied and an ample soil volume should be at the disposal of the banana plant (tillage practices including subsoiling, locally drainage technics).

### 5.2. Soil Fertility Status

- 5.2.1. An excess of potash relatively to calcium and magnesium seems to favour the green ripening phenomenon as it is observed in the Ekona Banana Estate; moreover soil acidity also seems to play a role in the appearance of this physiological trouble probably because of its depressive effect on Ca and Mg assimilation by the plant.

- 5.2.2. The extension of the rooting system is locally restricted in a very small soil volume because of the formation of a thin hardpan; the development of the rooting system is locally very poor in the most acid fields on the heavier soils probably because of an adverse chemical environment for the banana roots.
- 5.2.3. This fertility survey gives a good indication on the evolution of the soil fertility status, by showing from where we come, that is field sections without green ripe fruits, and with a correct alimentation in P, Ca, Mg, K, and towards which situation we are going, that is field sections with very poor yields, green ripe fruits, excessive acidity, mineral deficiencies and possibly toxicities, poor development of the rooting system, etc.. if the same fertilization policy is followed.
- 5.2.4. Micro-nutrients problems have now to be added: Zn and B deficiencies were noted by IRFA Experts; Molybdenum could be suspected as a limiting factor while manganese is probably in excess in the most acid and clayey soils, where it locally reaches toxic levels.
- 5.2.5. The nutritional problems of the banana plant in the Estate are likely very complex, as many different deficiencies appear at the same time.

However the most common factor is a pronounced soil acidity ( $\text{pH} < 4.6$ ). Hence the first step of any soil fertility restoration programme should be the liming of the soils. Dolomite (31.9% CaO, 19.97% MgO) is periodically available in Cameroon and consists of a proper liming material in this case as Mg deficiency is most likely latent in many banana fields.

On the other hand Calcium Silicate could also be tested on the most acid fields as the soils have a variable charge.

### 5.3. Recommendations

#### 5.3.1. Tillage Practices

- a double-crossed subsoiling as well as a real and effective ploughing are recommended before planting; the plough depth should be around 30-35 cm;
- using heavy caterpillars on wet soils should be avoided;

- using heavy caterpillars should be limited as much as possible on the heavy clayey soils of Mussaka Series to a minimum number. These soils easily undergo structure degradation and topsoil compaction; lighter 4-wheel tractors could be used for operations such as ploughing and subsoiling.

### 5.3.2. Soil Fertility Trials

The ideal solution would be to carry out fertilizer trials at least on three pilot areas one on each soil series.

As already pointed out in 5.1, a strict disease control (cercospora, but especially borers and nematodes attacks) an adequate water supply during the dry season as well as an optimal soil preparation should be ensured and should proceed soil fertility investigations.

The latter mainly concern micro-element tests and liming experiments; in addition Phosphate trials can be installed on Mussaka Series soils while K applications could be tried out where a K deficiency is suspected.

Oligo-elements: separate Zn, B, and Mo tests should be carried out and if possible, compared with complete micro-element mixture applications. Doses could be 30 gm of Zinc Sulphate per plant, 20 gm of Borax per plant. Doses ranging from 200 to 400 gm of Ammonium Molybdate per ha. could be tested (foliar sprays).

### Liming Experiments

The following yearly doses were determined on the basis of pH values and Al contents:

pH <sub>water</sub>	Exch. Aluminium meq/100 gm	CaO kg/ha.	Dolomite kg/ha.	Dolomite gm/plant
4.2	2.0	2300	<b>7210</b>	3600
4.4	1.2	1400	4390	2200
4.6	0.85	1000	3140	1570
4.8	0.45	550	1725	865
5.0	0.10	115	360	180

Calculation is based on: (1) meq Ca/100 gm = 1.5 (Exch Al), bulk density = 1.1, (3) depth = 30 cm, (4) % CaO of Dolomite = 31.9.

In case of manganese toxicities liming should be aimed at neutralizing manganese rather than aluminium: in this case at least double doses could be tested.

If available, Calcium Silicate should also be tested; in this case, an analytical follow-up of the soil fertility should be carried out to see its effect.

P trials: Doses ranging from 75 to 150 kg P per ha. should be tested in selected fields in Bolifamba Section.

Set-up:

- Mussaka Series

+ Mussaka Section, field G12

- Nitrogen: on young plantings, 8-10 splits/cycle, starting 6 weeks after planting and then every month;  
first 2 doses : 100 gm Sulphate of Ammonia per plant,  
following doses : 50 gm Urea per plant;  
on mature plantings: 6 applications/year starting with  
100 gm SA/plant and then 5 applications of 50 gm Urea/plant;
- Oligo-elements : as mentioned above;
- Liming : 3 doses to be tested:
  - 1400 kg CaO/ha., i.e. 2200 gm dolomite/plant in 8 applications;
  - 2800 kg CaO/ha., i.e. 4400 gm Dolomite/plant in 8 applications (tentative dose neutralizing Mn).
  - 4750 kg CaO/ha., i.e. 7450 gm Dolomite/plant in 8 applications (tentative dose shifting the pH from 4.5 - 5.0).

+ Ekona Section, block II

- Nitrogen : as in Mussaka Section
- oligo-elements : as mentioned above
- liming : as mentioned above
- potash applications : 350 gm  $K_2O$ , that is 580 gm Potassium Chloride/plant
- P applications : 75-150 kg/ha.

+ Bolifamba Section, field to be selected : liming and P applications as above.

- Ekona Series : Nitrogen should be applied as in Mussaka Section; a liming experiment could be laid out in Molyko Section (fields F10, F11) to see the effect of dolomite application on the occurrence of green ripening phenomenon : dose could be 1000 (F11) and 1400 (F10) kg CaO/ha., that is 1570 and 2200 gm Dolomite/plant in 8 applications.
- Molyko Series (field L1)
  - Nitrogen : as in Mussaka Section;
  - Liming : 1 dose of 3600 gm dolomite/plant in 8 applications;
  - Potash : 580 gm KCl/plant in 4 or 5 applications.

Lay-out : the best would be to lay out the trials into block experiments (according to a given number of treatments and repetitions); For practical reasons this is not easily feasible in the Estate and the different treatments could be compared between different planting rows with a given number of banana plants (100-150).

Remark : KCl and N fertilizers could be applied at the same time; however in the case of urea, mixing should be done just before its application. Liming material and any of the N fertilizers should never be mixed.

### 5.3.3. Fertilizer Use in the Estate

It is time to change the fertilization policy in the Ekona Banana Estate in order to avoid the progressive sterilization of its soils.

#### NITROGEN

Sulphate of Ammonia should be replaced by Urea. Actually SA is applied on young plantings at the rate of 100 gm/plant with a frequency of 8-10 splits per cycle, starting 6-7 weeks after planting and then every month while on mature planting it is applied at the rate of 150 gm/plant with a frequency of 4 splits/year.

Replacing Sulphate of Ammonia by Urea can be done progressively: at the beginning 50% of the total N can be supplied in the 2 forms (SA : 21% N, Urea : 46% N) while eventually the first 2 applications on young plantings and only the first application on mature planting could be in the form of Sulphate of Ammonia in order to cover the sulphur requirements of the banana plant. In any case sulphur status should be watched as S deficiency could be possible on those soils (ref. 3.2.1. (d), p. 10).

100 gm SA corresponds to 45.6 (+ 50) gm Urea; 150 gm SA corresponds to 68.5 (70) gm Urea.

### POTASH

Potash applications should be systematically avoided in the Ekona Banana Estate, except in a few fields characterized by current deficiency symptoms. These fields are almost invariably the same for the past 3 years and therefore easy to locate : doses could be 500-700 gm Potassium Chloride/plant in 4 or 5 applications.

### LIMING

Before getting the results of field trials, it is advisable to **already start** applying liming material on soils of Mussaka Series (Mussaka, Ekona and Bolifamba Section). This practice should become systematic and would best be based on a dose of 150 gm Dolomite/plant, per month.

### OTHERS

- In case of quick responses to oligo-element tests micro-element fertilizer applications should be introduced in the general fertilizer policy of the Estate.

Liming experiments, particularly in field G12 of Mussaka Section, may also give a valuable indication of the effect of lime on micro-element assimilation by the banana plant.

- Responses to Phosphate applications would also indicate whether or not this element should be taken into consideration in the fertilizer policy.

#### 5.4. Soil Fertility Evolution with time under Banana Cultivation

Little is known on the effect of continuous cultivation of a single crop on soil physical and chemical properties in tropical areas and the lack of these essential data makes it difficult to make sound fertilizer recommendations. In the case of the Ekona Banana Estate and also the Mungo Banana Estates, a fertilization only based on the use of Sulphate of Ammonia and periodically Muriate of Potash was very likely the best one possible on the basis of the original soil fertility, especially in the case of the most recent volcanic ash soils of the Mungo area. This fertilization has progressively improved the assimilation of potassium through both a progressive acidification of the soils and the periodical supply of this element. This observation is not only valid for banana cultivation but also for tea and oil palm Estates in Mt. Cameroon area: it is often noted that (1) the more acid and the more clayey the soils, the better the assimilation of K by the plants (2) K deficiencies are often correlated with either young and loamy volcanic soils developed on recent pyroclastic materials deposits (Andepts) or somewhat older and clayey soils developed on stony and rocky lavaflows.

This is related to relatively low  $K/(Ca + Mg)$  ratios in the soil parent material which further increase with both weathering and soil acidity.

However the fertilization based on the supply of two elements only with in addition its effect on soil pH has induced the following consequences :

- soil acidification,
- locally, excessive assimilation of potash, hence the observation of green ripening phenomenon,
- reduction of Ca and Mg assimilation,
- occurrence of mineral deficiencies which could be due to both increasing soil acidity and also a non-compensation of nutrients exported with the harvested fruits,
- possible decrease of anionic nutrients such as phosphate and molybdate.

All these elements are most likely closely inter-related and the emergency of changing the actual fertilizer policy is more and more felt and should be established on the basis of soil survey data, foliar/topsoil analysis and well controlled field trials.

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## ANNEX

### ANALYTICAL LABORATORY METHODS, ANALYTICAL RESULTS, GRAPHS

Laboratory analysis included chemical determinations following methods and procedures in current use in most international soil laboratories as follows:

Soil samples are air dried and crushed with a rolling pin to pass through a 2 mm sieve.

- organic carbon: method of Walkley and Black (acid dichromatic digestion) and colorimetric determination of the chrominium ion with a Technicon Auto Analyzer.
- total nitrogen: digestion using a Tecator block digester, colorimetric determination of Nitrogen by the indo-phenol method on a Technicon Auto-Analyzer.
- soil pH: determined in  $H_2O$  (1:2,5) and in normal KCl (1:1) by means of a EIL pH-meter.
- exchangeable bases: displacement with a normal, neutral  $NH_4OAc$  solution; potassium and sodium are determined by flamephotometry on an Eppendorf 700 Flamephotometer, Calcium and Magnesium on a single beam Atomic Absorption Spectrophotometer model Perkin Elmer 272.
- cation exchange capacity ( $NH_4OAc$ ):  $NH_4$  saturation with normal, neutral  $NH_4OAc$  solution, the excess being washed by ethyl alcohol, followed by replacement of  $NH_4$  by using a normal KCl solution pH 2.5 Exchanged  $NH_4$  is determined colorimetrically by the indo-phenol blue method on a Technicon Auto-Analyzer.
- available phosphorus: extraction with 0.1N HCl and 0.03N  $NH_4F$  (Kurz-Bray II) and colorimetric determination with ammonium molybdate and ascorbic acid on a Technicon Auto-Analyzer (av. P. ppm).

Leaf Samples were analyzed as follows:

- total nitrogen: wet digestion in concentrated  $H_2SO_4$  using a Tecator block digester; nitrogen in the digest is determined colorimetrically using the indo-phenol blue method on a Technicon Auto-Analyzer.

An. 2

- phosphorus: dry ashing; ash dissolved in nitric acid; phosphorus is determined colorimetrically on a Technicon Auto-Analyzer using the yellow phosphovanadate complex.
- potassium: dry ashing; ash dissolved in nitric acid; potassium is determined on an Eppendorf 700 Flamephotometer.
- calcium and magnesium: dry ashing; ash dissolved in nitric acid; calcium and magnesium are determined on a single beam Atomic Absorption Spectrophotometer, Perkin Elmer 272.

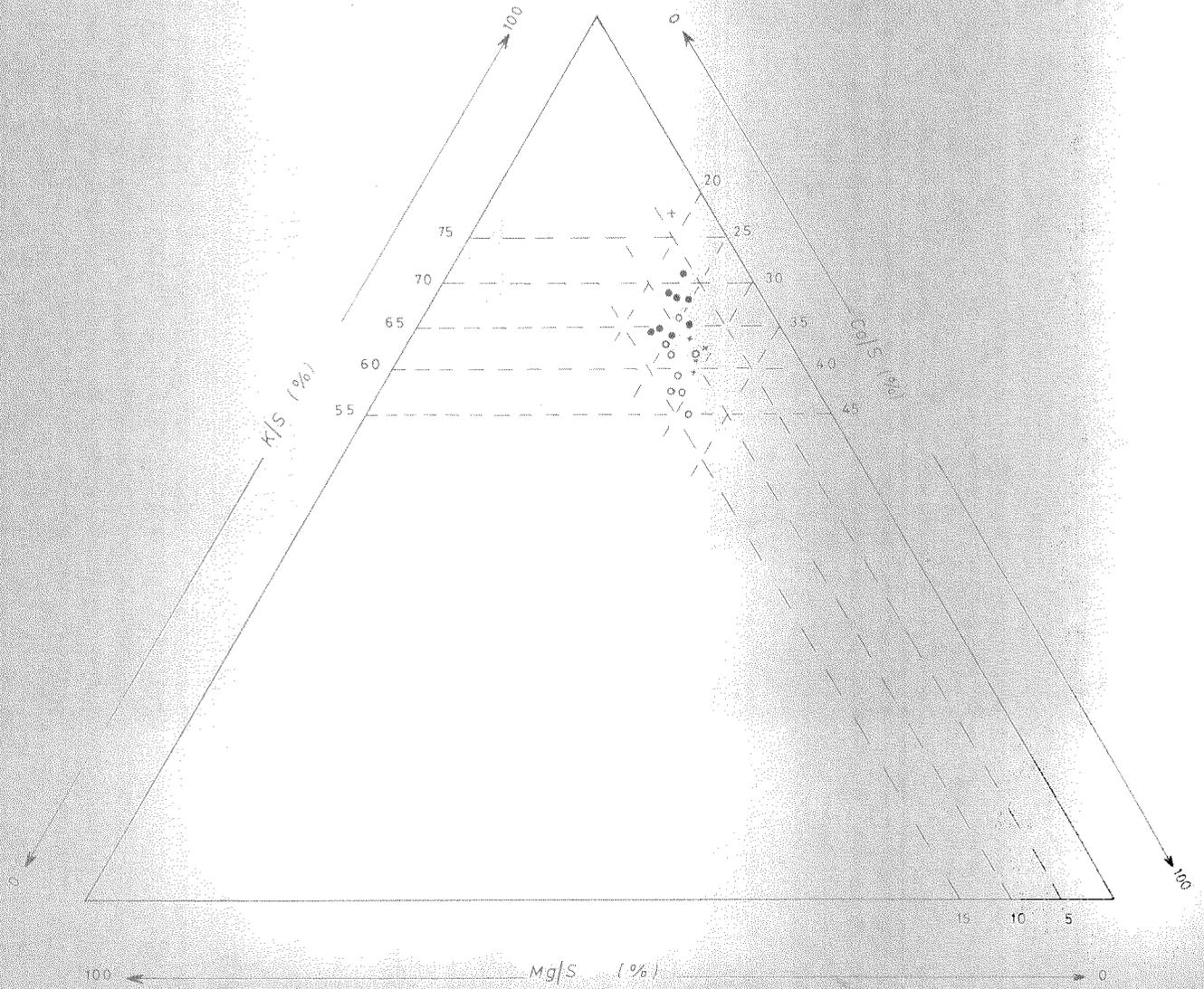
Soil Series	Field Section	Plot No	Foliar Analysis (Elements in % of Dry matter)						Field Observations
			N	P	K	Ca	Mg		
M O L Y K O	MOLYKO	L1	2.59	0.208	2.98	0.76	0.23	No Green Ripening	
		F2	2.65	0.210	3.16	0.76	0.16		
		F3	2.50	0.210	3.29	0.76	0.20		
K O	LYFOKA	K7	2.70	0.196	3.08	0.76	0.16	K deficiency	
		L7	2.95	0.194	2.80	0.68	0.12		
E K O N A	MOLYKO	F10	2.33	0.208	3.61	0.66	0.22	Green Ripening	
		F11	2.26	0.208	3.54	0.66	0.20		
	LYSCKA	Q12	2.58	0.187	2.82	0.82	0.22	No Green Ripening	
Q14		2.79	0.187	2.88	0.72	0.19			
Q16		2.76	0.214	2.77	0.74	0.20			
M O L I	MOLLI	B1	2.79	0.21	3.42	0.68	0.18	No Green Ripening	
		D1	2.70	0.173	3.24	0.66	0.19		
M U S S A K A	MUSSAKA	D7	2.79	0.175	3.78	0.64	0.10	Green Ripening	
		F7	2.55	0.17	3.27	0.54	0.13		
	BOLLWAMBA	A18	2.56	0.163	3.24	0.68	0.13		Green Ripening
B18		2.66	0.166	3.43	0.64	0.11			
B17		2.60	0.163	3.28	0.58	0.12			
M U S S A K A	MUSSAKA	F12	2.64	0.166	3.22	0.62	0.13	No Green Ripening	
		Bl. II	2.59	0.173	2.65	0.66	0.15	K deficiency	
E K O N A	EKONA	Bl. III	2.81	0.166	2.80	0.60	0.13		
M U S S A K A	MUSSAKA	G12	2.47	0.23	4.75	0.57	0.08	Mg deficiency Zn, B deficiencies	

TABLE 1. RESULTS OF FOLIAR ANALYSIS (1981 FOLIAR SAMPLING)

Soil Series	Field Section	Plot No	% O.M.	av. P ppm	pH		Exchange Complex meq/100g Soil				B.S. %	Field Observations		
					H <sub>2</sub> O	KCl	K	Na	Ca	Mg			TEB	CEC
M O L Y K O	MOLYKO	L1	9.84	121	4.2	4.0	0.53	0.0	2.17	0.35	3.05	32.05	9.52	No Green Ripening
		F2	9.5	79	4.6	4.1	1.42	0.0	8.40	1.7	11.52	38.2	30.10	
		F3	7.06	139	4.6	4.1	2.25	0.0	6.28	2.03	10.62	34.7	30.5	
E K O N A	LYSOKA	K7	4.33	-	4.5	4.0	2.59	0.15	5.12	1.97	9.83	33.14	29.66	K deficiency
		L7	4.59	34	4.4	4.0	1.56	0.15	3.69	2.17	7.57	12.24	34.04	
E K O N A	MOLYKO	F10	5.9	219	4.4	3.9	2.9	0.0	7.08	1.61	11.59	37.02	31.3	Green Ripening
		F11	4.9	148	4.6	3.9	1.5	0.14	5.86	2.51	10.01	31.7	31.5	
		Q12	7.17	130	4.8	4.3	1.14	0.02	8.45	2.24	11.85	37.0	32.0	
E K O N A	LYSOKA	Q14	8.84	5	4.8	4.4	1.50	0.02	11.28	2.99	15.8	42.27	37.18	No Green Ripening
		Q16	6.86	7	4.9	4.4	1.55	0.0	9.77	2.60	13.9	33.85	41.12	
		B1	7.1	146	5.0	4.5	1.98	0.0	12.11	3.8	17.9	35.9	49.8	
M U S S A K A	MOLLI	D1	5.4	140	4.8	4.2	2.22	0.02	7.24	2.27	11.7	29.5	39.8	
		D7	3.16	174	4.5	4.2	1.25	0.0	4.36	3.23	8.84	24.2	36.4	
		F7	2.97	79	4.2	3.9	1.16	0.01	2.29	1.02	4.48	22.2	20.3	
M U S S A K A	MUSSAKA	A18	4.14	3	4.4	4.0	1.86	0.01	4.94	1.57	8.38	26.5	31.6	Green Ripening
		B18	3.44	3	4.3	3.9	1.88	0.01	4.08	0.76	6.73	23.03	29.2	
		B17	3.30	5	4.5	4.0	2.09	0.01	4.62	1.03	7.75	25.4	30.5	
M U S S A K A	MUSSAKA	F12	3.52	77	4.3	3.9	0.94	0.01	1.69	0.83	3.47	21.7	15.9	No Green Ripening
		B1. II	2.97	8	4.4	4.0	0.97	0.02	2.38	0.68	4.05	17.8	22.7	
		B1. III	2.85	5	4.3	4.0	0.74	0.02	1.21	0.22	2.19	17.0	12.87	
M U S S A K A	MUSSAKA	G12	2.35	6	4.5	4.3	1.03	0.01	3.72	0.74	5.5	18.17	30.2	Mg, Zn, B deficiencies

TABLE 2. RESULTS OF TOPSOIL ANALYSIS (1981 Topsoil Sampling)

RELATIVE PROPORTION OF K, Ca, Mg (meq/100gr dry matter) IN BANANA LEAVES (SAMPLE A.P.F.D.)



LEGEND

S = K+Ca+Mg in meq/100gr dry matter

SYMBOL	FIELD OBSERVATIONS
o	NO Green Ripening
•	Green Ripening
x	Potash Deficiency
+	Magnesium Deficiency