NUTRITION AND FERTILIZATION IN MANGO. LITERATURE REVIEW

Víctor Galán Saúco. Tropical Fruit Consultant
email: vgalan46@gmail.com Telephone: 34- 660331460

Table of contents

Executive Summary

The main objective of this report consists in providing assistance to mango growers in establishing an adequate fertilization program. To accomplish this objective a thorough literature review was complemented with a survey on mango nutrition and sent to mango producers and researchers all over the world, as well as information collected from different important fertilizers companies.

The establishment of a correct fertilization program must begin with conducting a soil analysis performed before planting. This will indicate the physicochemical characteristics of the soil where mango is going to be cultivated, a necessary step in order to setup the initial basal dressing and correction measures. Appropriates values for a soil to be cultivated with mangos are discussed, and general recommendations are given in the **Soil analysis** paragraph**.** Examples of general fertilizer programs that have been recommended in different countries for mango cultivation for the first year have been provided, and also for adult trees in smaller farms with no access to laboratories (**General recommendations for fertilizing mangos** paragraph)**.**

As indicated in this report, despite its limitations, foliar analysis is the most useful tool for a correct establishment of a mango fertilizer program. A complete review of the values recommended by different authors as well as a discussion about sampling and interpretations techniques, both based on individual values and on the relations between nutrients, is reported in the **Foliar analysis** paragraph**.** As indicated in the **Nutrient extractions** section, the reposition of macro and micronutrient losses due to crop load, dropped fruits, leaves and branches removed by pruning, as well as those removed by lixiviation, volatilization, soil fixation and runoff is essential for an appropriate mango fertilizer program. It is clear from our review that fertilizer programs differ depending on cultivars and locations (soil and climatic conditions, particularly temperature), cultural practices and age of the tree and, as a consequence, nutrient extraction should be determined for each mango farm and cultivar. An example of using crop removal to establish a mango fertilization program is given in Annex 4.

The role of macro and micronutrients, their effect in the plant at different moment of the growth cycle and the most appropriate moment for their application was also reviewed. In conclusion, most macronutrients, and particularly nitrogen, should be applied directly to the soils or through fertigation immediately after harvest, except for foliar applications of nitrates to induce flowering. Micronutrients, however, should be applied by foliar sprays mostly during flowering, with the exception of iron that should preferably be applied regularly as chelates through fertigation.

It is also indicated that experiments done in mango comparing organic and inorganic sources of fertilizers have not shown clear differences regarding nutrient absorption and yield; and that organic fertilizers are applied directly to the soil or, in some cases, through fertigation.

The final conclusion of the report is that the many variables involved in mango nutrition and fertilization makes it impossible to draw general recommendation for a mango fertilizing program that have to be established by each particular farm. This is true even for each cultivar inside the farm, based in the sound interpretation of soil and foliar analysis and forecasted nutrient extraction. However, guidelines for a correct interpretation of these tools have been given in this report that can serve mango growers for obtaining the maximum productivity for this crop through an adequate fertilizer program.

Introduction

Fertilization and Nutrition are not identical concepts. The first consist in giving to the plant the type of fertilizers previously selected, while by nutrition it is understood as the process by which a plant absorbs the nutrients present in the applied fertilizers from the media in which it thrives in order to its development and growth. Because of this, for a correct planification of a fertilizer program it is not so important to think which fertilizer product to apply, but which nutrients we need to apply. As a consequence, in order to achieve a good nutrition of our crop it is necessary to know its nutrient demand, the right moment to apply our fertilizers and the nutrient content of the fertilizer, but also the factors influencing the correct assimilation of those nutrients like climatic considerations, soil type, quality of irrigation water or the irrigation system. Because of all these considerations no general fertilizer formula can be given for designing a mango fertilizer program. However, I hope that this literature review, complemented with a survey on mango nutrition sent to mango producers and researchers all over the world, as well as information collected from different fertilizers companies around the world may help mango growers to establish a correct fertilizer program Several relatively recent books on mangos (Carvalho Genú and de Queiroz Pinto, 2002; Litz, 2009; Galán Saúco, 2008; Galán Saúco and Lu, 2017) have dedicated chapters to the subject of fertilization of mango and will serve as main initial steps for this review.

As in many other crops, the nutrients demand of mango is dependent on genotype (rootstock and cultivar), soil, climate, lixiviation losses, irrigation system, water quality, plant health, phenological stages and expected crop load. The study of the effects of different nutrients on mango production and fruit quality is rather complicated because of the interaction of the different parameters (soil type, soil pH, cultivar, water quality, climate,) involved in the final result of any experiment dealing with mango nutrition (Levin, 2017). Its response to fertilizer application depends also on many factors such as type and dosage of fertilizer, environmental and soil conditions, cultivar and rootstock (Whiley, 1984; Cull, 1991 *et passim*). This is the reason why fertilizer recommendations have to be made for each particular orchard. Although the importance of fertilizing mango has been stressed by many authors, no clear recommendations have been made in the scientific literature for a general fertilizer strategy for mango under different growing conditions. In consequence, the assessment of the nutrient needs of mango trees to obtain profitable yields results is a significant and difficult challenge.

Summary of interviews about fertilization in mango

To obtain updated information about the actual practice of fertilizing mangos in different countries, 47 individuals, including researchers, and producers or producer associations from 30 of the most important mango producing countries (Annex 1) where interviewed. The procedure for getting information was as follows: first sending them through email a survey about the subject (Annex 2) and later, when necessary, by phone or personal contacts. The selection of the contacts was based mainly on a previous work done for the National Mango Board on the influence of rootstocks in quantitative and qualitative aspects of mango production and about the role of magnesium in mango (Galán Saúco, 2016, 2018a). The main findings of the different sections of these interviews are summarised in Annexes 3-11.

An email was also sent to the 11 biggest fertilizer companies in the world (Roy, 2015) asking for any relevant information they may have about fertilization in mango. Only Yara, K+S and Haifa contribute with valuable information for this report which is commented along this review.

Soil analysis

It is common in many places to apply different quantities of fertilizers to mango orchards without a prior soil analysis. In fact, many of the countries that answer the mango nutrition survey did not report any soil analysis used for their fertilizing programs (see Annex 3). Although this analysis only indicates the presence of a nutrient in the soil and not the quantity that can be absorbed by the plant, the establishment of a fertilizer program for a mango orchard should begin with a soil analysis made before planting which will indicate the biological and physicochemical characteristics of the soil where mango is going to be cultivated. Soil analysis can be used to provide basic information especially for knowing soil pH, the organic matter level and the content of nutrients., The content of elements like N and K which are easily lost by lixiviation are not of great value.

Because of the commented points, an analysis of soil is necessary, particularly in order to realise the initial basal dressing and correction measures, which will allow to prepare the soil for planting. Regular soil analysis during the production phase and foliar analysis will serve as the base for establishing a rational mango fertilising program.

The mango is well adapted to different types of soils (Majunder and Sharma, 1985; Kostermans and Bompard, 1993 *et passim*) and can be cultivated without problems in soils with pH values of 5.5 to 7.0 or even in very sandy soils with low organic content (0.3%), low cation exchange capacity (7-13 mmol/100g of soil), low capacity of water retention as well as in calcareous soils (>38% $CaCO_3$) with pH of 8.7 (Whiley and Schaffers, 1997)**,** provided corrections of iron and zinc deficiencies are made and appropriate rootstocks are used (Gazit, 1970; Kadman and Gazit, 1984). As an example of an appropriate soil for mango cultivation in South Africa it is recommended a value of pH between 6.0 and 7.2, a minimum Ca content of 200 ppm, a value of 2.5 to 5.0 for the relation Ca+Mg:K, a content of potassium between 80 and 120 ppm and a minimum content of Phosphorous of 20 ppm (Mostert and Abercrombie, 1998).

Values for mango soil analysis reported from the mango nutrition survey, differs much amongst countries with different values accordingly to soil types, cultivars and possibly methods of extraction (see Annex 3). An indicative of the values considered appropriate for a soil to be planted with mangos can be seen in table 1, given by the Queensland Department of Agriculture and Fisheries (QDAF, 2015).

Table 1. Appropriate values for a soil to be cultivated with mangos (QDAF, 2015)

pH	5.5-7.0
Organic C	1-2%
CE	<0.2 (dSm)
N	<10 mg/kg
P	60-80 mg/kg
K	0.25-0.40 meq/100g
Ca	3-5 meq/100g
Mg	0.75-1.25 meq/100g
S	>12 mg/kg
Na	<1.0 meq/100g
Cl	<2.50 mg/kg
B	1-2 mg/kg
Zn	2-15 mg/kg
Mn	4-50 mg/kg
Fe	4-100 mg/kg
Cu	0.3-10 mg/kg
Cation Exchange	≈5
% Na	>1%
% K	5 %
% Ca	65-80 %
% Mg	15-20 %

Soil analysis should not be limited to the pre-planting moment. It is very convenient to conduct soil analysis once each year in order to determine the potential reservoir of nutrients and, as indicated before, together with foliar analysis orientate about fertilizer rates to be applied.

General recommendations for fertilising mangos

During the first years of a plantation it is useful and common to fertilize accordingly to general fertilizer programs based in previous experience in the area or in other countries. However, the plant enters in production, the most rational way for fertilizing mangos is through a foliar analysis which compares the leaf content for different nutrients with standards previously decided. The knowledge of the figures for nutrient extractions per kg of production obtained will also be of great help for determining a fertilizer program that allows to obtain the best yields from a mango farm.

The following examples of general fertilizer programs that have been recommended in different countries for mango cultivation can be useful for the first couple of years and also for adult trees in smaller farms with no access to foliar analysis.

1. Florida, sandy and calcareous soils. Quantities recommended for its application to the soil may be reduced or even suppressed if foliar levels are adequate. Quantities should be gradually increased as tree grows (Crane, 2019).

- Young trees:
  Nitrogen: 113-227 g/tree of a 6 to 10% nitrogen source (better with a fertilizer mixture containing 25 to 50% of the nitrogen in organic form) per tree every 8 weeks during the growing season. Quantities to be reduced in muck soils.
  Phosphorous: Fertilize regularly with phosphorus fertilizers containing 3 to 10% phosphate during the first 4 years. Periodic soil applications may be made along with nitrogen applications
  Potassium: 113-227 g/tree of K_2O/ha (from a 6 to 10% potassium source) every 4 to 8 weeks during the growing season.
  Magnesium: Apply it in a fertilizer mix along with N and P and Potassium at 25-50% the rate of K_2O.
  Calcium: Not recommended, except if leaf analysis indicates calcium deficiency.
- Adult trees:
  Nitrogen: 22-35 kg of nitrogen /ha and year/ha split into 2 to 4 soil application with same type of fertilizer as for young trees.
  Phosphorous: May not be necessary.
  Potassium: 57-113 kg of K_2O//ha and year split into 2 to 4 soil applications.
  Magnesium: Apply it in a granular form along with nitrogen, phosphorus, and potassium in a fertilizer mix (e.g., 6-6-6-3) or better foliar application at a dosage of 1.4-2.3 kg of the magnesium nitrate or sulphate are mixed in 380-950 litres of water.

2. South Africa

General program (Anon., 1975):

Tree age (years)	Calcium Ammonium Nitrate (kg/tree and year)	Ca superphosphate (kg/tree and year)	Potassium Chloride (kg/tree and year)
1	0.25	0.50	—
2-3	0.50	1.00	—
4-5	1.00	2.00	0.50
6-7	1.50	2.25	0.75
8-9	2.00	2.25	1.25
>10	2.50	2.25	1.50

Specific recommendation for cultivar Sensation (Stassen and Janse van Vauren, 1997a): N, K and Ca dosage can be calculated as 6g of the element per kg of yield or as 11g/cm of trunk circumference (measured at 80 mm above the grafting point).
P and Mg dosage can be calculated as 0,8 g of the element/or 1,5 g/cm of trunk circumference

Microelement spray recommendations (Tomlinsom and Smith, 1998):

— Boron.- 300 g Solubor /100 l water

— Copper.- 200 g Copper Oxyclorure /100 l water

— Manganese.- 200 g Manganese sulphate/100 l water

— Zinc.- 200 g Zinc Oxyde or 150 ml Nitrozinc in 100 l water.

3. Australia, southern hemisphere (Anon., 1999)

Young trees:

Years from planting	Timing	Amount of fertilizer per tree (NPK 15-4-11)
1	Every 6 weeks	30-60g
2	Every 6 weeks	30-60g
3	December (*) or after crop removal March	500g plus 500g gypsum Idem
4	December or after crop removal March	750g plus 1,000g gypsum Idem

Adult trees:

	1-3 m canopy ∅ 'Keitt'	2-6 m canopy ∅ 'Kent', 'Keitt', 'Palmer','KP', 'R2E2'	4-8 m canopy ∅ 'KP', 'Haden', 'R2E2'
After harvest NPK mixture 12-2-13	350-650 g (*)	650-2,000 g	2,000-2,700g
Four weeks later Gypsum Magnesium sulphate Solubor	 1-2 Kg 500g	 2-3 kg 500g	 3-4 kg 500g
Before flowering NPK mixture 12-2-13 Gypsum Foliar boron	 100-350g 2-3 kg 1%	 350-1,000g 3-4 kg 1%	 1,000-1,300 g 4-5 kg 1%
At bud break Foliar potassium nitrate Solubor Potassium sulphate	 1% 10g 500g	 1% 20g 1kg	 1% 40g 2kg

∅ = diameter; KP = Kensington Pride.
(*) Apply the lower rates for trees with a light crop or in fertile soils and the higher figures after a heavy crop or in sandy soils or after a heavy rain that removes nutrients

- Microelement recommendations:

  1% Zinc sulphate foliar spray (Littlemore *et al.*, 1991)

  25 g/tree Borax to the soil after flowering and fruit set (Campbell and Mohr, 1991).

4. Israel (Crane *et al.,* 1997)

Adult trees:

Year application (kg/ha)

N	K_2O	P_2O_5	Observations
150-200	100-120	20-30	Stop or reduction of these applications 3 months before harvesting

Young trees:

Continuous applications through the irrigation system during the whole year of N-P-K with the same proportion that for the adult trees (12-2-8). The recommended dosage of N is 20-40 ppm, with proportional quantities of P and K

- Microelement applications to avoid deficiency stages in alkaline soils:
  Spring applications of 100-200 g/tree (light to heavy soils) of Sequestrene through the drip system and one spray of 1% Zinc sulphate or foliar sprays of iron sulphate (0,2%), iron nitrate (0,3%) or Wuxal (2%) plus the adherent Titron X-100 at 0,025% (Gazit, 1970). Four applications during summer at the moment of the onset of new flushes after harvest are recommended (Kadman and Gazit, 1984).

5. México (Crane *et al.,* 1997)

Tree age (years)	Fertilizer	Dosage (kg/tree and year	Geographic zone
1-4	N-P-K	0,2/0,1/0,1	Mexican Gulf
5-10	N-P-K	0,4/0,2/0,4	Mexican Gulf
11-15	N-P-K	0,6/0,3/0,6	Mexican Gulf
16-20	N-P-K	0,8/0,4/0,8	Mexican Gulf
>20	N-P-K	1,0/0,5/1,0	Mexican Gulf
1-5	N-P-K	0,4/0,2/0,2	South Pacific
>5	N-P-K	0,7/0,7/0,7	South Pacific
1-4	N-P-K	0,4/0,2/0,4	North Pacific
5-10	N-P-K	1,3/0,55/0,85	North Pacific
10-15	N-P-K	2,8/0,9/1,8	North Pacific

6. Brazil (Alburquerque et al. (1998) cited by Coelho and Borges, 2004)

Recommended amounts of N, P_2O_5 and K_2O:

As indicated below during the juvenile phase (planting till 2 years of age) it is recommended to apply up to. 500 g de N, 40-160 g de P_2O_5 and 20-100 g de K_2O per plant depending in the soil content of K and P. During the productive phase the quantities to apply varies in function of the foliar content of N and the soil content of K and P.

Valores recomendados de N, P_2O_5 and K_2O en función del análisis s desuelo de P and K

Phase	N (g/plant)	P in soil (mg/dm^3)	P_2O_5 (g/plant)	K in soil (cmol$_c$/dm$^{3)}$	K_2O (g/plant)
Planting	--	<10	150	<0.16	100
Planting	--	10-20	120	0.16-0.30	80
Planting	--	21-40	90	0.31-0.45	40
Planting	--	>40	60	>0.45	20
Growing	500	<10	160	<0.16	100
Growing	500	10-20	120	0.16-0.30	80
Growing	500	21-40	80	0.31-0.45	40
Growing	500	>40	40	>0.45	20

7. Pakistan (Bibi, 2018)

Fertilizer needs for big productive trees (7.7 x 9.6 m width.height)

Element or fertilizer	Quanrtity/ (tree and year)	Momento of application
Nitrogen	2 kg	Inmediately after harvest (1.5 kg) At flowering (500g)
Phosphorous	3 kg	Inmediately after harvest (3 kg)
Potassium	2 kg	Inmediately after harvest (1 kg) Durante el desarrollo del fruto (1 kg)
Farm manure	100 kg	Inmediately after harvest (100 kg)
Zinc sulphate	250 g	At flowering (total amount)
Copper sulphate	75 g	At flowering (total amount)
Ferrous sulphate	250 g	At flowering (total amount)
Mnaganese sulphate	150 g	At flowering (total amount)
Boric Acid	75 g	At flowering (total amount)

Note.- Macronutrients and farm manure to the soil, Micronutrients by foliar sprays

8. Philippines (Mango Production Guide, undated)

Young Mango trees:

One year old - 100 g urea (split application at start and end of rainy season) or 200 g manure +100 g urea/plant. Fertilizer should be placed few inches from the trunk in a shallow canal constructed around.

Two years old - 200 g urea (split application) or 500 g manure + 200 g urea/plant.

Three years old - 300 g triple 14 (split application) or 1-2 kg manure + 300 g triple 14/plant.

Four years old – 400 - 500 g triple 14 (split application) or 2-3 kg manure + 400 - 500g urea/plant.

Adult trees:

In the absence of soil and tissue analysis, the following recommendation for bearing trees could be observed.

Tree Age (years)	Amount of fertilizer/plant
5-6	0.5-1 kg Triple 14 or 3-4 kg manure + 0.5-1kg Triple14
7-8	2 kg Triple 14 or 4-5 kg manure +plus 2 kg of Triple 14
9-10	3 kg Triple 14 or 5-6 kg manure + 3 kg Triple 14
11-15	5 kg Triple 14 or 5-6 kg manure +10 kg Triple14
16-20	6-7 kg Triple 14 +12 kg manure
20 and above	10 kg Triple 14 +10 kg manure

Time of application: Apply whole amount at the start of the rainy season or split application with the first half given at the start of rainy days and the remaining before the end of the rainy season.

Foliar fertilizer is also recommended at flowering as supplement for optimum growth. Foliar fertilizers with major elements (NPK) as well as others such as Calcium, Magnesium, Boron and Zinc are used.

9. Corrections of soil deficiencies in different countries

Iron and zinc deficiencies occurring in alkaline soils are common in some subtropical climates like Israel or the Canary Islands (Galán Saúco, 2008) and are usually corrected with iron chelates applications or zinc sulphate following the recommendation indicated above for Israel. According to the nutrition survey from Puerto Rico, to avoid these deficiencies it is desirable to have a foliar content of 200 ppm of Fe and 75 ppm of Zn. Other frequent deficiencies also common in alkaline soils are those of manganese and boron. This last one is better corrected through a foliar spray of boric acid at 0,2 – 0,3 % applied slightly before flowering which also favour the apparition of a higher percentage of hermaphrodite flowering, usually associated to this element (Silva *et al.*, 2002).

Foliar analysis

General review

Foliar analysis is the most useful tool for a correct establishment of a mango fertilizer program. However, since leaf nutrient content varies not only between cultivars but also depending on different factors related with the leaf itself (age, leaf position, orientation) and phenological stages. Some differences are shown in the different levels indicated by different authors as appropriate for mango (see table 2). In consequence, they should be taken only as indicative values since they vary between locations, soil type and cultivars. In fact, in South Africa as an example (see table 3), recommendations values for some cultivars are lower or higher than the indicated values and the same is shown in recommendations from Australia for N leaf content (see table 4). Different recommendations about optimum leaf levels depending on soil type has also been published (see table 5). However, as a general rule the values published by Quaggio (1996) summarising different bibliographic references recommendations for different cultivars and locations (see table 6) with the range of adequate values for leaf nutrient content in mango can allow us to derive general recommendations for a fertilizer program for the mango based in leaf analysis.

Despite the great value of foliar analysis, results from the nutrition survey show that important mango producing countries like India, Israel, Philippines or Thailand do not report the use of foliar analysis as principal tool to establishing their mango fertilizing programs, preferring instead soil analysis, crop removal and traditional recommendations to establish them (see Annex 4). With a few exceptions, most of the countries that are using foliar analysis as the main tool for establishing their fertilizer programs report values for nutrient leaf concentrations in the range indicated by Quaggio in 1996 (see table 5). The few important exceptions are Taiwan that report higher N and K values, Thailand with higher values for Mn leaf content, Ivory Coast with lower values for Mg and Ca and Mexico that report lower calcium values (see Annex 5). A possible explanation for the cases of Taiwan, Thailand and Ivory Coast may perhaps be related to the use of cultivars different from those of Floridian origin cultivated in Latin-American countries. The discrepancy in the case of Mexico is because data reported in the survey are only experimental values far from those generally recommended in that country (Medina Méndez et al., 2014). Similar values to those given by Quaggio are mentioned by the fertilizer companies Yara (undated) as an adequate range for all the macro and micronutrients with the only notorious difference for Mn (60-500) and Zn (50-119) with higher values for the upper limit of the range in line with some recommendations by other authors (see table 2). Values for foliar content of N, P_2O_5 and K_2O reported by the fertilizer company Haifa (undated) to be found in high yielding trees can be also of great value for establishing a mango fertilizer program (see table 7).

Table 2. Leaf nutrient levels considered appropriate for mangos.

Element	Florida (1)	Florida (2)	India (3)	India (4)	India (5)	Brazil (6)	Aust. (7)	S.A (8)	S.A (9)
N (%)	1.54	1.0-1.5	1.00	1.23	1.18	1.2-1,4	1.0-1.5	1.25-1.40[c] 1,25-1,50[d]	1.0-1.2
P (%)	0.05	0.08 - 0.175	0.10	0.06	0.08	0.1 - 0.25	0.08-0.175	0.09-0.11	0.1-0.2
K (%)	0.97	0.3-0.8	0.50	0.54	0.52	1.0 - 1.2	0.3-1.2	0.8-1.0	0.8-1.2
Ca (%)	0.91	3.0-5.0	1.50	1.71			3.0-3.5[a] 3.5-5.0[b]	2.0-2.8	2.0-3.3
Mg (%)	0.26	0.15-0.40	0.15	0,91		0.3 - 0.6	0.2-0.4	0.2-0.35	0.2-0.3
S (%)			0.50	0.12			0.2-0.4		0.1-0.2
Fe(ppm)				171			50-100	70-100	120-900
Mn(ppm)				66			60-500	60-200	175-450
Zn (ppm)				25			20-150	20-100	30-75
Cu (ppm)				12			10-20	10-20	9-18
B (ppm)							70-200	30-100	40-80
Mo (ppm)									0,3-0,6

(1) Smith and Scudder (1991); (2) Young and Koo (1969); (3) Kumar and Nauriyal (1977);
(4) Bhargawa and Ghadha(1988); (5) Biswas et al., (1987); (6) Hiroce (1983;
(7/) Reuter and Robinson (1986); (8) Tomlimsom and Smith (1998); (9) 0sthiuyse (1998)
Aust. =Australia; SA. = Southafrica
(a) Acid soils; b = Alcaline soilsc =Young trees; d = Adult trees (>10 years)

Table 3. Leaf nutrient levels recommended in South Africa for two different cultivars (Mckenzie, 1995)

Cultivar	Nitrogen (%)	Potassium (%)	Calcium (%)
Kent	1.16 – 1.45	0.39 – 0.87	1.18 – 2.17
Sensation	0.78 – 1.00	0.27 – 0.85	1.55 – 2.07

Table 4 Suggested leaf levels for N in different cultivars in Australia (Anon., 2017).

Cultivar	Optimum leaf nitrogen level (%)
Kensington Pride	1.1 – 1.3
R2E2	1.3 – 1.4
Honey Gold	1.3 – 1.4
Calypso	1.0 – 1.5
Keitt	1.0 – 1.2
Others – Asian cultivars	1.2 – 1.4

Table 5. Nutrient range for healthy mango leaves found in different soils in Florida (Crane, 2019)

Element	Unit	Limestone soil	Acid soil	Muck soil
N	%	1.0-1.5	1.0-1.8	1.4
P	%	0.09-0.18	0.08-0.19	0.11
K	%	0.5-1.0	0.5-1.1	0.9
Ca	%	3.0-5.0	2.0-3.5	2.8
Mg	%	0.15-0.47	0.25-0.38	0.17
B	ppm	24-54	12	17
Fe	ppm	38-120	51	59
Mn	ppm	92-182	77	80
Zn	ppm	101-119	79	84
Cu	ppm	28-35	43	28

Table 6. Range of deficient, appropriate and excess values for leaf nutrient content in mangos (Quaggio, 1996)

Nutrient	Deficient (1)	Appropriate (2)	Excess (3)
N (%)	< 0.8	1.2-1.4	> 1.6
P (%)	< 0.05	0.08-0.16	> 0.25
K (%)	< 0.25	0.5-1.0	> 1.2
Ca (%)	< 1.5 (*)	2.0-3.5	> 5.0
Mg (%)	< 0.1	0.25-0.5	> 0.8
S (%)	<0.05	0.08-0.18	> 0.25
B (ppm)	< 10	50-100	> 150
Zn (ppm)	< 10	20-40	> 100
Mn (ppm)	< 10	50-100	Non determined
Fe (ppm)	< 15	50-200	Non determined
Cu (ppm)	< 5	10-50	Non determined
Cl (ppm)	Non determined	100-900	1,600

(1) Values below which deficiency symptoms or physiological disorders have been reported.
(2) Values reported from heathy and good yielding orchards with good fruit quality.
(3) Values indicated in cases of observed or potential toxicity.
(*) No deficiency symptoms observed but bad fruit quality.

Table 7. Nutrient levels found in leaves of high mango yielding tree (%)
(Haifa, undated)

Cultivar	N	P_2O_5	K_2O
Kent, Smith	1.28	0.119	0.5
Dashehari	1.33		
Haden	1.29	0.134	0.59
Desirable levels	1.32	0.12	0.5

Sampling techniques. -

The great majority of researchers indicates that 6 to 8-months-old healthy leaves, more precisely those fully mature from the last young flush sampled from all directions and heights are the most suitable for assessing the nutritional status of a mango tree. Those shoots are generally close to flowering, moment in which the leaf nutrient content seem to be more stable (Silva et al., 2002), but some differences regarding the precise phenological moment to take the sample are to be taken under consideration. The recommendation in Australia is to take leaf samples twice a year at postharvest and at preflowering 1-2 months before flowering (QDAF, 2015), However, in the subtropics and also in some Latin-American countries, leaves are taken only at the end of flowering (Galán Saúco, 2008; Anon., 2009). Notwithstanding, Oosthuyse (1997 a y b) in South Africa questions the suitability of this moment because of the rapid growth of fruits occurring, which gives rise to fluctuations in the leaf nutrient content. According to trials in Hainan, China, the foliar content of N, P and K and also that of Ca, Mg, S, Fe, Mn, Cu, Zn and B does not follow the same pattern for each nutrient along the different phases of the mango growth cycle and those content were also different depending on the location (Xiao-Tian et al, 2013; Ningning et al., 2010).

A clear example of the variation in leaf nutrient content depending on location and phenological phase can be seen in the information given in the nutrition survey received from India (see Annex 6). In addition, recent studies done in Nayarit, Mexico in mangos grown without irrigation indicate that the period in which the concentration of nutrients presented the least variation changes from cultivar to cultivar was defined as well as the one that define the appropriate leaf sampling period (ALSP) depending in whether spring (SpVF), summer (SuVF) or autumn vegetative flushes (AVF). In ‘Ataulfo’, the ALSP for the SpVF and SuVF was from 9 to 11 and 3.3 to 5.3 months of leaf age, respectively; in ‘Kent’, this period was from 8 to 10.5 for SpVF and 3.2 to 5.0 for SuVF months, and in ‘Tommy Atkins’ it corresponded to leaves from 8.7 to 12.2 months for SpVF and 8.6 to 9.4 months for AVF. The absorption of nutrient by plant tissues is also affected by environmental conditions (see table 8). The results of these studies obviously oblige to obtain specific information for each cultivar and location and complicates the interpretation of foliar analysis.

Care should be taken in plantings where nitrate applications are used for flower induction in which case sampling should be taken prior to their application to avoid logical alterations of nutrient leaf levels. This problem does not occur in the subtropics where, due to cold induction, nitrate application for flowering is not needed. Some differences regarding the position of the leaves to be sampled in the shoot exist. Chadha et al, (1980) recommend in India to take the leaves from the middle of the shoot, while Abercrombie (1998) in South Africa prefers the use of the lower leaf in the shoot and all reports from Australia recommends sampling the 3rd or 4th leaf below the shoot apex (Catchpole and Bally, 1995; Meurant et al., 1997; QDAF, 2015)

Table 8. Environmental factor affecting nutrient absorption in mango (Huete and Arias, 2007)

Environmental factor	Reduces concentration of nutrient in tissue of the elements indicated
Acid soils	N P Ca Mg Mn Mo
Alkaline soils	P K Mn Zn B
Low organic matter soils	Zn B Cu S
Dryness	N Mn B
Compacted soils	N P K Ca Mg Mn Mo Zn B Cu S Fe
Diseases	N Mg
High light intensity	B

Normally 4-5 leaves per tree are taken in 10-20 adult trees per hectare, well distributed within the orchard. However, 4-5 trees and 20-30 leaves should be enough (Koo and Young, 1972). Samples should not be taken from diseased shoots or those in a phenological stage different from the rest of the canopy. This is of particular relevance in tropical climates where erratic behaviour can occur. Since different results can also be obtained depending on the season (Rajput *et al.*, 1985) samples should be always taken in the same period of the year in each particular location.

Interpreting leaf nutrient levels

Despite the generalised use of leaf nutrient levels in establishing fertilizer programs in many mango farms, some authors indicate that there is not always a good correlation between these levels and yield, and that the balance and quantitative relations between nutrients are of greater value (Stassen *et al.*, 1997a and b). Many of the answers received from the nutrition survey indicate the importance of these relationships (see annex 7). One of the most mentioned is the N/Ca ratio. High N and low Ca favours the incidence of Internal fruit breakdown, reduces shelf life and may negatively affect fruit quality, reducing sugar and colour and even causing heterogeneous ripening. To be in the safe side, D. J. Silva from the San Francisco Valley Federal University, Brazil, recommends keeping the value of N/Ca below 0.5 for cultivars of Floridian origin which coincides with the indications of the Egypt's survey for different cultivars and agreed with the indications made by Cracknell Torres et al, (2003). A positive influence of the ratio Mg/B on fruit set is also indicated in the case of Taiwan. Guatemala also reports a positive influence of the ratios: Ca/N, Ca/K, N/Mg on flower induction. In the answers from Costa Rica the following optimum values for some nutrient ratios are indicated: Ca +Mg/K = 10-40; Ca/Mg = 2-5; Ca/K = 5-25; Mg/K = 2.5-15. In the Colombia survey results, the following adequate values for some nutrient ratios are indicated: Ca/Mg = 3-6; Ca/K = 15-30; Mg/K = 010-15, (Ca+ Mg)/K = 5-15, somehow different from those indicated in the case of Costa Rica.

An alternative method to interpret foliar analysis is the use of the Diagnosis and Recommendations Integrated System (DRIS) that evaluate the nutritional state based on the equilibrium between nutrients. The DRIS technique deals with nutrient concentration ratios, rather than individual nutrient levels. It also provides a mean of simultaneously identify imbalances, deficiencies, and excesses of nutrients, ranking them in the order of importance (Walworth and Summer 1986). Oosthuyse. (2000 b and c) also indicated that adequate nutrient levels for mangos should not only be established for each cultivar and location but also, that correlations between those levels and different desired characteristic such as to improve flowering, fruit set, resistance to diseases, soluble solid content and other ones, should be separately established to allow small adjustment in the fertilization program. However, Bally (2009) reports that this system has been used with varying success in mango. DRIS norms also varies from cultivar to cultivar and from location to location and are not totally independent from the age of the sample tissue (Raj and Rao, 2006). Raghupathy et al (2004) in India studied the use of them for the cultivars Alphonso and Totapuri and found that 'it was impossible to diagnose imbalance of any particular nutrient in isolation since large number of nutrients either increase or decrease together. Hundal et al (2005) studied the nutritional status of mango trees in different orchards of the submountainous area of Punjab, establishing DRIS derived sufficient nutrient ranges for leaf content (table 9), but not specifying the cultivars from which the samples were taken. Not much differences in this case can be observed between standard and DRIS derived sufficient range, particularly regarding some nutrients (see table 9).

Pinto (2002), cited by Silva et al, (2012) in Brazil, establishes DRIS norms about the sequence of limitations of elements for the cultivar Tommy Atkins in orchards of high and low productivity through calculations of the index of Nutritional Balance (IBN) and Interpreting the DRIS indexes established for each farm by the method of Potential of Response to Fertilization (Wadt,1996). The conclusion of these studies can be seen on table 10.

Table 9. Comparison between standard leaf norms and DRIS derived sufficient nutrient range

Element	DRIS derived sufficient range (Hundal et al., 2005)	Standard range (Reuter and Robinson (1986)
N (%)	0.92-1.37	1.0-1.8
P (%)	0.08-0.16	0.08-0.18
K (%)	0.21-0.44	0.30-1.20
Ca (%)	1.71-3.47	3.0-5.0
Mg (%)	0.15-0.37	0.20-0.40
S (%)	0.09-0.19	-
Zn (ppm)	11-19	20-150
Cu (ppm)	1-6	10-20
Fe (ppm)	63-227	70-220
Mn (ppm)	87-223	60-500
B (ppm)	16-44	50-100

Table 10: DRIS norms regarding sequence of limitations to nutrient deficiencies and excess

Orchard	Sequence of limitation to nutrient deficiencies	Sequence of limitation to nutrient excess
High productivity	Mg>Cu=K=Fe>Ca=B>Mn=Zn=P	Fe>K=Mg=Cu=Zn>Ca=B>Mn>N=P
Low productivity	B>Cu=Zn>Ca>N>Fe>Mn>P>K=Mg	Fe>P>Cu>Zn>Mn=K>B>Mg>N>Ca

The most relevant results, obtained by using DRIS, derive from the application of the most limiting nutrient. In an experiment by Bhupal and Rao (2006), the average productivity increase in young trees was 20% greater when the most limiting nutrient was applied in all the conditions tested, with a 45% average response for Zn and 32% for Ca. In adult mango trees, the average productivity increase was also greater than 20% for most of the nutrients tested, and reached 34% for Ca and 33% for N.

Recommendations for fertilization practices based on the nutritional state determined by DRIS indices has been growing as a way of deploying potential fertilizer response. Using this criterion, quantification of nutrients to be recommended varies in function of productivity and nutritional state determined by DRIS along with availability of nutrients in the soil. The current recommendations for fertilization with N, P_2O_5 and K_2O in Kg/ha in the case of a balanced nutrition situation in function of yield, N leaf content and P and K soil availability as indicated by Silva (2004) are shown on table 11. In a recent publication, Silva et al. (2012), adapting data from Silva et al. (2004) also summarise the recommendation of nitrogen, phosphorous and potassium in Kg/ha for Tommy Atkins in Brazil in function of availability of nutrient in soil, orchard yield and nutritional state determined by DRIS accordingly to 5 great classes of deficiency, moderate deficiency, balanced nutrition, moderate excess and excess of the element. More studies regarding the use of DRIS for mango fertilization are being carried out at EMBRAPA with other cultivars and nutrients (D, J. Silva. 2019. Personal Communication) but, at the moment of writing this report, those have not yet been published.

Table 11 Recommended quantities of N, P_2O_5 (*) and K_2O in Kg/ha in function of yield and nutrient leaf content (Silva et al (2004).

Expected Yield (t/ha)	leaf N (g/kg^{-1})				P in soil ($mg\ dm^{-3}$)				K in soil ($cmol\ dm^{-3}$)			
	<12	12-14	14-16	>16	<10	10-20	21-40	>40	>0.16	0.16-0.3	0.3-0.45	>0,45
<10	30	20	10	0	20	15	8	0	30	20	10	0
10-15	45	30	15	0	30	20	10	0	50	30	15	0
15-20	60	40	20	0	45	30	15	0	80	40	20	0
20-30	75	50	25	0	65	45	20	0	120	60	30	0
30-40	90	60	30	0	85	60	30	0	160	80	45	0
40-50	105	70	35	0	110	75	40	0	200	120	60	0
>50	120	60	40	0	150	100	50	0	250	150	75	0

(*) The authors recommend the use of calcium superphosphate to incorporate higher quantities of calcium to the plants but also mention that this also be obtained applying calcium nitrate to induce flowering.

Regarding the remaining nutrients the best recommendation will be to try to adjust the fertilizer program in such a way that their foliar levels remain close to the optimum standards levels and preventing any decrease.

As a summary, the use of the DRIS system allows to test the nutritional status of an orchard comparing the values of foliar analysis for an element with the values for the rest of them. With this system, it is possible to determine which nutrients are in excess as well as those in deficiency. Whether a nutrient is in excess/deficit its relationship with the rest of nutrients shows a positive/negative deviation. Nutrients having small deficiency presents minor negative values and the reverse, those nutrient in greater excess show much higher positive values. The sum of all the deviations of a particular nutrient with the rest of them constitute the DRIS index for this nutrient. The sum of all nutrient indexes, independent of their positive or negative sign, constitutes the Nutritional Balance Index (NBI). The lower the NBI, the more well-nourished is a plant and the higher is its potential productivity and the reverse.

The main problems for the use of the DRIS system consists in the need of realise a great number of foliar analysis representatives of orchards of good productivity and the great number of calculations needed for a correct interpretation of these analysis. This is not always possible for many farmers, particularly for small size farms. Probably because of this the only, country beside Brazil that mention the use of DRIS in its answer to the nutrient survey is Indonesia.

Nutrient extractions

Mango extracts important quantities of nitrogen, potassium, calcium and magnesium as well as smaller amounts of other elements. Because of this, it is also necessary to know the nutrient extractions per kg produced, in order to calculate an appropriate fertilization program during the production phase. This is not an easy task, since the existing reports to indicate nutrient extractions by mango reflect important differences depending on cultivars and locations (soil and climatic conditions, particularly temperature), cultural practices and age of the trees (Catchpoole and Bally 1995, Silva et al. 2002, Stassen et al. 1997; Fallas et al., 2010). An example of these variations can be seen on table 12. Big variations on crop nutrient removal can also be observed from the response of the different countries to the mango nutrition and fertilization survey which are summarised on Annex 8.

Table 12.- Nutrient extractions in mango per ton of fresh fruit

Nutrient Cv	Haden (1)	Haden (2)	T.A (1)	Extrema (2)	Carlota (2)	Jinhung(*) (3)	T.A. (4)	Keitt (4)
N (Kg)	0.86	1.22	2.01	1.18	1.45	5.46	1.07	1.06
P (Kg)	0.17	0.26	0.47	0.17	0.18	0.57	0.20	0.12
K (Kg)	1.84	1.81	1.43	1.84	2.30	4.62	1.54	1.59
Ca (Kg)	1.17	0.15	1.25	0.15	0.15	2,69	0.29	0,14
Mg (Kg)	0.52	0.17	1.09	0.19	0.17	0.40	0.19	0.15
S (Kg)		0.17		0.17	0.17	0,33	0.07	0.09
Mn (g)	23.6	2.30	14.3	3.8	4.3	400	3.5	2.1
B (g)	2.13	0.90	3.62	0.80	0.80	7.20	0.7	1.6
Zn (g)	5.63	1.30	5.30	1.50	1.50	9.43	1.20	0.97
Cu (g)	8.63	1.50	8.0	1.50	1.50	2.90	1.10	0.90
Fe (g)	3.26	3.40	10.12	3.90	3.40	51.62	8.50	2.50
Country	Venez.	Brazil	Venez.	Brazil	Brazil	China	México	México

(1) Laborem *et al.,* 1979; (2) Hiroce et al., (1977); (3) Ninging et al, 2011; (4) Fallas et al., 2010.
(*) Includes harvested fruits (50.70%), pruning leaves (22.31%), flowers and peduncles (17.17%), pruning branches (8.64%) and dropped fruits (1.26%).
T.A. = Tommy Atkins; Venez = Venezuela

It is interesting to note that the calcium content in the fruits planted in Venezuela in alkaline soils rich in calcium is much higher than those from Brazilian orchards which is of special interest since the incidence in soft nose reported for Venezuela is smaller than those indicated for Brazil (Quaggio, 1996, cited by Silva, et al., 2002). Differences regarding nutrient extractions between 'Sensation' in South Africa (Stassen et al, 1997a) and 'Kensington' in Australia (Catchpole and Bally (1995) also indicate different behaviour of different cultivars regarding nutrient crop removal. The main nutrients extracted by 'Sensation' were Ca and K, while in the case of 'Kensington' there is more extraction of N and K and then Ca. It is also interesting to note that according to studies done in South Africa with the cultivar Sensation (Stassen et al, 2000) nitrogen, magnesium and calcium content of fruits decrease with the age of the plant, but the decrease is much accentuated in the case of calcium which may have relevance regarding susceptibility to internal fruit breakdown. However, this has not been studied for other cultivars and locations. Big variations on crop nutrient removal can also be observed from the response of the different countries to the mango nutrition and fertilization survey which are summarised in Annex 8.

As can be observed from table 12, when comparing the extractions indicated by a mango plant, nutrient extraction is not only dependant on fruit production but also in dropped fruits and especially in leaves and branches removed by pruning. This explains that the recommendation given by Cruz-Barron et al., (2013) for macronutrient requirement in Kg per ton of fresh fruits harvested of mango 'Ataulfo', managed with annual or biannual pruning (N, 4.19; P, 0.79; K, 7.19; Ca, 3.67; Mg, 0.93) were much bigger than the macronutrient extracted by the fruits (N, 1.42; P, 0.27; K, 2.90; Ca, 0.60, Mg, 0.45).

It is also important to take in account other nutrient losses that varies from location to location according to environmental condition. As indicated in Australia (QDAF, 2015), 30-50 % of N can be lost by leaching and volatilisation, (QDAF, 2015), 30-50 % of N, 50-100% of P by soil fixation, 20-30% of K and Mg through leaching, 5-20% Ca and S by soil erosion or runoff and up to 60 % of B by leaching.

From all these considerations, it is obvious that no general rules can be applied, and nutrient extractions should be determined for each mango farm and cultivar. However, an example of using crop removal to establish a mango fertilization program is given at the end of Annex 4 following the survey report from the Philippines.

Role of specific nutrients for mangos and ways of application

Introduction

The effects of different nutrients in increasing yield of mango and in many other crops has been amply documented by different authors, but the excellent review by Bally (2009) complemented with more recent recommendations done by the Queensland Department of Agriculture and Fisheries (QDAF, 2015) will serve as main source for this section. The information received from the nutrition survey will also be discussed if pertinent. A quick understanding of the role of different nutrients in the different phases of the cycle of mango has been compiled by Yara fertilizer company and can be seen in table 13.

Although according to QDAF (2015) the 4 most critical nutrients for mangos are N, K, Ca and B, we will be following this section the classic division in macro and micronutrients.

Table 13.- Effect of nutrients alongside the phenological cycle (source: Yara, undated)

Element	Vegetative growth to preflowering	Flowering	Fruit development	Post harvest
N	reactivate and promote early growth of new plant tissues	maintain plant growth and maximize flowering strength	in small amounts together with higher rates of K to maintain growth	to build tree reserves available for new growth
K	reactivate and promote early growth of new plant tissues		to build fruit quality	to build tree reserves available for new growth
Ca	boost root and leaf growth to provide a platform for high yields	maximize fruit set and strong growth of healthy tissues	to help improve fruit integrity, quality and storability	to revitalize rooting and ensure strong availability for the next season
P	boost root and leaf growth to provide a platform for high yields	to encourage strong flowering		to revitalize rooting and ensure strong availability for the next season
Mg	Boost chlorophyll production and strong Leaf growth		for healthy leaf growth	
B	to maximize flowering	to maintain growth and development of flowers and good fruit set		
Zn	to maximize flowering	to maintain growth and development of flowers and good fruit set		
Fe	to ensure leaf flushes and growth	to maintain growth and development of flowers and good fruit set		
Other micronutrients	to ensure leaf flushes and growth			

Macronutrients

Nitrogen.-

As for many other fruit crops, this is the most important element for the mango crop, due to its strong influence on vegetative growth, flowering, yield and fruit quality Its concentration in plants tissues influences considerably the concentrations and effects of other nutrients (Sen et al, 1947). N is a building block for 22 of the 23 existent amino acids, and thus, becomes part of almost all proteins. N is also a building block for the chlorophyll molecule, having a direct influence on photosynthesis. N is taken-up by the roots preferably as NO_3^- but also as NH_4^+ forms but can also be absorbed by the leaves as ammonia (NH_3), urea and aminoacids. Nitrogen is easily leached by irrigation and rain, especially in sandy soils or soils low in organic matter.

The positive effect of N fertilization in mango yield was clearly indicated in Florida by Young et al., (1962) reporting that yields on Kent mangos growing on deep, acid, sandy soil were increased substantially by heavy N applications and later in another experiment, also in sandy soils of Florida with cultivars Parvin and Kent showing a significant yield increase for the four-year average after triplicating nitrogen and potassium fertilization (Young and Koo, 1974). They also found a good correlation between treatments and leaf concentration of N and K and observed that those leaf levels tended to decrease after a heavy crop.

Typical nitrogen deficiency symptoms, appearing as yellowing, and occasioning lack of vigour and slow growth, does not differs in mango from that observed in other crops. Yellowing of the old leaves precedes that of the younger leaves due to N mobility. As deficiency increases, the entire leaf, including the veins, becomes yellow. Direct N toxicity is rare in mango, but high N concentrations causes dark green colour of leaves and excessive vigour in detriment of flowering and yield (Tiwari and Rajput, 1976; Scholefield et al, 1986, Nguyen et al., 2004 et passim) and contribute to the apparition of internal fruit breakdown problems (Galán Saúco, 2009).

The main effect of nitrogen on mango is the stimulation of vegetative and floral growth, although excessive N leaf content favors vegetative growth instead of flowering It has also been reported to increase fruit set and retention and fruit weight, and yield (several authors mentioned by Bally, 2009). High nitrogen applications can reduce the intensity of sunburn damage but can affect negatively fruit quality occasioning not only reduction of the percentage of yellow skin in mature fruits, the lightness and vividness of the yellow colour, the percentage of blush in the skin and the intensity of the blush colour skin, and, particularly if applied excessively from flowering through harvest increase the severity of anthracnose during ripening (Bally et al, 2009). It is also pertinent to mention that the nutrition survey results from Sri Lanka indicate that application of N rich fertilizer makes the fruit more prone to insect and disease damage which is in line with what was indicated in Reunion Island about of a greater susceptible to scales (*Ceroplastes* sp) of mango trees with high nitrogen levels. In the Brazilian survey's response by D. J. Silva from the San Francisco Valley Federal University it was also indicated that an equilibrium of the relation between B and N is also recommended because an excess of N may prevent the absorption of boron (see Annex 5).

Although leaf N concentrations between 1.0 and 1.5 % are generally accepted as the optimal range for mango cultivation (Robinson et al., 1997), it is better, particularly for cultivars sensitive to Internal Fruit Breakdown (IFB) to maintain N leaf content below 1.25 (Galán Saúco, 2009). In addition, Crane et al., (2009) indicate that leaf levels of N

>1.5% may result in little or no flowering in Florida and that low N fertilizers are also recommended to avoid excessive growth and reduce IFB.

The role of N in stimulating flowering is especially important for mango cultivation. It is a well-known fact indicated by many authors (Mosqueda Vázquez and de los Santos, 1981; Núñez Elisea, 1986, 1988; Medina Urrutia,1994; Tongumpai et al., 1997, *et passim*) that 2-4 foliar sprays of NO_3K (1-10%), $(NO_3)_2Ca$ (2-4%), NO_3NH_4 (1-2%) or thiourea (0,5%), spaced each 10-14 days can stimulate flowering of mature buds in receptive trees, provided that flower induction had already occurred. Otherwise only vegetative shoots will be produced because the effect of the NO_3 is to stimulate shoot initiation (either floral or vegetative) but not to determine bud morphogenesis (Davenport, 2009). There are also indications that the application of potassium nitrate to the soil during the phase of flower induction increase both the percentage of flower shoots and the intensity of flowering (Bondad and Linsangan, 1979; Sergent et al., 1989; Goguey, 1993b). In this sense, it is interesting to note that a practice consisting in 2 applications to the soil, spaced 15-20 days, of 3-7 kg (depending on tree size) of Ammonium Phosphonitrate or Ammonium nitrate distributed in 5-6 holes inside of the 50-75% of the canopy, followed by a heavy irrigation, is being actually recommended in Michoacan, Mexico (Espinosa et al..2006) to induce flowering in mature mango buds, in absence of cold temperatures. They also recommend complementing this fertilization with an additional application of phosphorous, potassium and minor elements and advance the hypothesis that when the fertilizer is dissolved, it may cause a reduction of soil temperature which can generate a similar stimulus for flower induction than that induced by low environmental temperatures.

Another interesting application of fertilizer containing N and on fruit set and yield has been reported by (Oosthuyse 1996). Trials realized in South Africa indicate that Multi-K (13-0-46) at 2% or 4% applied either once at full-bloom, or twice during this period, first when the inflorescence was developing and later in full-bloom, increase fruit retention with no reduction in fruit size in 'Tommy Atkins'. In the case of 'Haden', one application with 4% Multi-K was the most effective treatment for increasing fruit retention, but, in this case, this increase was also accompanied with a reduction on fruit size and an increase on tree yield. As a consequence of these trials Multi-K application to 'Tommy Atkins', 'Haden' and 'Kent' trees during the flowering period is now a routine commercial practice in South Africa (Haifa, undated).

Applying N fertilizer increase the uptake of other nutrients but, if excessive or applied at the wrong time, it can have negative effects. Among these negative effects are: the translocation of Ca to the leaves in detriment of fruit absorption when applied at early fruit set, reducing K content and causing excessive leaf growth when applied at pre-harvest. When in excess, produces fruits softer and green or with less blush at maturity and more sensible to postharvest roots or IFB (QDAF, 2015).

Nitrogen is best applied as fertilizers dissolved in irrigation water through drip or micro-sprinkler systems. Common N fertilizers include, potassium nitrate, calcium nitrate, ammonium nitrate, urea and ammonium sulphate. In calcareous soils of Florida, soil application of urea is not effective and may damage roots and, in addition, significant amount of nitrogen may be lost to the atmosphere as ammonia (Crane, 2019). In soils with clay content >20%, over use of ammonium nitrate should be avoided, preferring instead NO_3^- fertilization because of that the adsorption and fixation of NH_4^+ by the exchange soil complex can make N available later during the fruit growth phase which is detrimental for fruit quality both in term of skin colour and incidence of internal fruit breakdown.

Phosphorous.-

Phosphorous is part of many important molecules such as those involved in the process of respiration, photosynthesis, DNA and RNA and many others, essential for plant growth. This element is generally associated with the production of roots and branch vigour and is important for seed and fruit development. Although there are not separate reports about the effect of P on mango, it has been indicated that the application of phosphorous in combination with N and K to mango, increases yield (Samra and Arora, 1997). The role of phosphorus in the reproductive processes has been emphasized from time to time in different fruit crops and particularly in mango (Singh, 1959; Singh, 1969). Narwadkar and Pandey (1988) indicate that the application of phosphorous during the early stages of fruit set is useful for reducing alternate bearing because it might promote the apparition of new spring growth that can be later forced to flower through chemical procedures. Phosphorous is more available for plants in soils with pH ranging from 6 to7 and is very mobile into the plant but not in the soil.

Both deficiency and toxicity are rarely observed in mango plantings but several authors cited by Bally, (2009), describe deficiency symptoms in mango, appearing initially in older leaves, as the development of a reddish purple colour initiated in the underside of the leaves, extending later to the whole leaf and even extending to the veins, causing also grossing and rigidity of leaves. P deficiency also restricts root development and the absorption of water and nutrients, reducing also yield, tree and fruit size (Stassen et al, 1999); Silva et al., 2002).

Except in very poor soils, phosphorous fertilizers are not generally applied to mango, although several fertilizers used in mango for applying other nutrients also contains phosphorous.

Potassium.-

Potassium plays an important role in expansion and development of thick epidermal cell walls which increase the resistance of trees to pests and diseases. One of its most important known function is that of maintaining ionic strength of the cytoplasm (Leigh and Wyn Jones, 1984). It also regulates water uptake and water losses through the stomata, contributing substantially to the regulation of tree water status (Salisbury and Ross. 1992). Potassium is taken from the soil solution as K^+ and its concentration is lower in sand, highly leached and acidic soils and other soils with low cation exchange capacity (several authors cited by Bally, 2009). The influence of K in mango yield is also cultivar dependant as indicated in the cited paper by Young and Koo (1974) reporting that highest yields in 'Parvin' were obtained with high rates of both N and K fertilization, but potassium rates had no significant effect on yield of 'Kent'.

Care should be taken if applying fertilizers high in Ca and Mg because they compete with K for exchange sites reducing the availability for the plant of this nutrient (Tong Kwee and Khay Chong 1985). Although potassium has been reported to influence fruit quality in many crops (Marschner, 1995) there are not many studies about its effect on mango except that of Shinde et al (2006) who found a positive relationship between increased potassium fertilization and fruit weight, ascorbic acid, organoleptic score, flavour, colour and shelf life, reducing also weight loss and internal fruit breakdown. Both a positive influence of K fertilization and increase in yield and fruit quality have been reported by many countries in the nutrition survey (see annex 5). It has also been indicated that when applied as monopotassium sulphate at 0.5-1.0 % during flowering, retards (Oosthuyse, 2000a) or even suppresses the (Reuveni et al., 1998. QDAF, 2015) development of powdery mildew in mango, reducing the cost of powdery mildew control. However, it is not clear if the effect is due to P or K.

K is very mobile both in soil and plant. Potassium toxicity is very rare in mangos. Potassium deficiency symptoms originates first in mature leaves shown as curling-up of the leaf edges and leaf margin chlorosis followed in severe cases by necrosis (death). Symptoms generally in affected trees manifest first in a reduction of new shoot extension, and smaller and less colored fruits at maturity and reduced shelf life. The typical symptoms of potassium deficiency in mangos appear usually after the dry season or in soils deficiently irrigated. (Tong Kwee and Khay Chong 1985; Silva et al., 2002).

Applications of potassium should be more frequent in light soils because this element is easily leached. The main potassium fertilizers used in mango orchards include potassium chloride (also named muriate of potash), potassium nitrate and potassium sulphate; this last one being preferred because of its pH neutrality and sensitivity of mangos to Cl^-. However, in order to reduce salinity in arid soils it is better to apply potassium nitrate instead of potassium chloride or potassium sulphate to meet the potassium demand of mango (Oosthuyse, 2006).

An adequate fertilizing management for K has not been defined yet by researchers as a standard and this will vary from location to location and also depending on cultivars and rootstocks. Recent work in Brazil by Cavalcante et al (2016) indicate that 225 $g \cdot plant^{-1}$ of KCl through fertigation could be recommended for the production of mango cv. Palmer in São Francisco River Valley (Brasil).

Many authors (Sergent and Leal, 1989; Oosthuyse, 1997, Shinde et al, 2006 et passim) agreed that potassium nitrate applied at 2-4% prior and at flowering, increased flower induction, fruit set and fruit retention (see above role of nitrogen).

Calcium.-

The major contribution of this nutrient is to give stability to cell membranes, protecting cells from toxins and pathogens. It also slows aging tissue and promotes longer shelf life of many fruits. (Kirkby and Pilbeam, 1984; Ferguson, 1984). Maintaining leaf calcium content ≥2.5% is essential for reducing IFB in mango (Galán Saúco, 2009), but the effect is clearly linked to nitrogen concentration (see above role of Nitrogen) with a positive correlation between the ratio Ca/N and the incidence of IFB (CracknelL Torres et al, 2003). Reports on the beneficial effect of Ca content in fruit on mango postharvest did not show clear result (several authors reported by Bally, 2009), although, it has been indicated that the presence of adequate amounts of Ca in the fruit is important to increase firmness, internal fruit quality and shelf life (QDAF, 2015). Many of the response form the nutrient survey also indicate a positive effect of Ca and the positive relation of the ratios Ca/N in enhancing fruit quality and shelf life. It is also interesting to note that there are countries which also report a positive influence of the relation Ca/N in increasing flower induction, fruit set and yield, as well as tolerance to cold conditions and tolerance to pests and diseases (see Annex 5).

While, as indicated above Ca deficiency is directly linked to IFB problems, probably through membrane degeneration (Burdon et al., 1991, 1992). Toxicity for Calcium excess have not been described as such in mangos, but it can create problems with the absorption of other nutrients like P, K, Mg, Zn, B and Cu. Because of this, care should be taken not to apply excessive quantities of fertilizers containing this nutrient (Silva et al, 2002).

Although Ca is needed all year round, the two more important moments for absorption of Ca by the root system are during the vegetative flush, immediately after harvest and in the early stages of fruit growth. Since Ca is not mobile through the phloem, it is not easily transported within the tree, making it difficult to get it into the fruit from soil or leaves, which also explains why foliar applications of Ca are not efficient. Absorption of Ca from the soil is best done in wet soils by young roots and uptake depends on particle size, the finer the better. For a better efficiency of Ca uptake, it is recommended to use liquid formulations during flowering and early fruit development (QDAF, 2015). Dolomite, gypsum, calcium carbonate and calcium nitrate are recommended as Ca sources in Florida (Crane et al., 2009). Surface application of gypsum at planting at a rate of 0.5 t/ha for sandy soils and 2.5 t/ha for clay soils is currently recommended in Brazil (Genú and Pinto, 2002), although to incorporate it at a rate of $280 g/m^2$ at a soil depth of 30 cm also before planting has also been reported to reduce IFB in soils of low pH (≈3.7) and very poor Ca content (Pinto et al., 1994).

Magnesium.-

A recent study done for the National Mango Board (Galán Saúco, 2018) allows us to discuss this nutrient more in depth that in the case of other major nutrients. The main role of Mg is enzyme regulation for more than 300 plant enzymes. Magnesium has also an essential function as a bridging element for the aggregation of ribosome subunits, a process that is necessary for protein synthesis. Adequate magnesium nutrition also increases the root growth and root surface area which helps to increase uptake of water and nutrients by roots, affecting the availability of other cations like calcium and potassium. In addition, Mg appears to provide a protective function similar to that of Ca in maintaining plant tissue integrity and providing protection against adverse environmental condition. Mg deficiency in plants is a common nutritional disorder that affects plant productivity and quality which particularly occurs in acid soils and in soils over-fertilized with either Ca and/or K. Magnesium deficiency can also occur under soil moisture stress even when the soil is adequate in available Mg. According to Marchal (1991) there is a clear antagonism between Ca and Mg. High Ca content in soil and plant would reduce Mg uptake but would not affect K uptake.

The earliest indications of Mg deficiency in many species consists of impairment in sugar partitioning leading to starch accumulation and the enhancement of antioxidative mechanisms, prior to noticeable effects on photosynthetic activity. The uptake of Mg^{+2} can be strongly depressed by other cations such as K^+, NH_4^+ as well as by H^+, that is by low pH, with availability of Mg declining significantly when the soil water pH is less than 5.4. Mg deficiency symptoms arise first in the oldest leaves, and systematically progress from them towards the youngest ones. Indeed, due to the mobility of the element, plants will remobilize Mg from older leaves to younger ones. Mg-deficiency can be confused with K deficiency. Typical symptoms are leaf chlorosis, beginning at the margins and progressing between the veins to the leaf interior, but with the area adjacent to the central and primarily veins remaining green. The affected inter-venial areas may become white, developing later, necrotic spots in the whitened areas. There is no evidence available on the direct effect of excessive Mg supply on plant metabolism.

The conclusion of the mentioned study for the NMB about the effect of magnesium in mango indicates that an appropriate Mg fertilization has the following effect in mango production:

1) Improvement of yield, vigor and general growth of the plant.
2) A positive or negative effect on skin color depending mainly on cultivars, causing greening of the skin in some of them. Within reasonable increases of Mg fertilization, no problems seem to occur for 'Tommy Atkins' or 'Kent' which color can be even improved.
3) Increase on fruit size, sugar content and vitamin C, not sufficiently proven for different cultivars and locations.
4) A variable effect on shelf life and internal fruit breakdown (IFB) and shelf life, positive or negative, depending probably on the interaction with other elements, mainly Ca.
5) Improvement of the tolerance of trees to high solar radiation.
6) A beneficial impact on cold resistance.
7) A positive effect of Mg fertilization in reducing skin burning of mangos during Hot Water Treatment.

Although not proven for mangos, magnesium nutrition in balance with other minerals has a clear impact on plant disease resistance**.**

Despite the beneficial impact of increasing Mg fertilization, it is difficult to make clear recommendations about appropriate levels for this element because of the following facts:

1) The existence of a clear interaction cultivar/environment, particularly regarding soil condition.
2) The strong interaction of Mg uptake mainly with K^+ and Ca^{+2}, but also with N and other elements which explains also that it is not possible to establish a precise adequate range for the ratios Ca/Mg y K/Mg, also dependent on the soil types.

In any case it is recommended to maintain foliar level between 0.25 and 1.0 %. No clear indications can be made regarding Mg soil content which varies much dependent on soil type.

Sulfur.-

As an important component of some amino acids that make up photosynthetic proteins and also as a component of some plant enzymes involved in the synthesis and breakdown of fatty acids, sulfur is required in large quantities by trees (Salysbury and Ross, 1992). Sulfur is very mobile in the soil but not in the plant. Most of the S present in soils is on the organic matter (Marschner, 1995) and is very easily leached from the soils (Bally, 2009). However, sulfur deficiency is not common in mangos as this element is a component of many fertilizers, fungicides and pesticides. Furthermore, in places like Florida (Crane,2019) sulfur may be applied 1 to 2 times per year to control powdery mildew.

Deficiency symptoms of this element are necrotic spots occurring in the vascular bundles and lamina showing on a very deep-green leaf occasioning premature defoliation (Smith and Scudder, 1951). Mangos have a high tolerance for S in the soil and atmosphere and no toxicity symptoms in leaves have been described specifically for mangos. Its role in tree growth and fruit quality is not fully understood, but low levels of S limit N uptake (QDAF,2015).

Micronutrients

The microelements are generally applied as foliar sprays, particularly in calcareous soil where soil applications are not effective due to high Ca content and pH. Despite that they can be applied individually there are many commercial formulations containing Mn, Zn, Cu, Mo, S and B that can be used in mango orchards. Although foliar sprays of micronutrients generally increase yield (Young and Sauls, 1979.; Ghosh *et al.*, 1995) nutrient uptake is, however negligible by mature shoots and developing fruits and aerial sprays should only be applied to soft new leaves or developing inflorescences.

Boron. -

Beside its important role in nucleic acid synthesis, protein synthesis and translocation of sugars (Salisbury and Ross, 1992; Gupta et al., 1985), boron is necessary for all new growth and is a crucial nutrient for flowering and fruit set in mango as a consequence of its essential role in pollen germination and pollen tube growth (Gupta et al, 1985; Stanley and Lichtemberg, 1963).

Boron is mainly taken by the roots as un-dissociated boric acid [$B(OH)_3$]. Light sandy soils derived from granites have the lowest concentration of this element and its content is low in heavy leached soils with high pH and high calcium (several authors cited by Bally, 2009). According to the information sent by the fertilizer company K+S (Kumar, undated) B is the only micronutrient lost due to leaching. As a consequence of the passive uptake of B by the xylem high humidity conditions reduces soil B uptake by mango trees. In addition, B is one of the most immobile micronutrients inside the plant and hence continuous supply is needed.

Boron deficiency causes poor flowering, and reduced fruit set, and their symptoms has also been clearly described by Bally (2009) in his review. Distorted leaves often having shot holes surrounded by a light-green halo and ragged margins are typical of B deficiency. Other symptoms include loss of apical dominance and swelling of the internodes, splitting of the bark and gummosis, lumpy and deformed fruits, splitting of fruits with brown discoloration of the mesocarp. High N concentration in trees can worsen B deficiency (Ram et al., 1989; Raja et al., 2005). The limit between deficiency and toxicity are rather narrow (QDAF, 2015) which explains that boron toxicity occurs in many mango orchards as a consequence of excessive application of this element. Typical symptoms of B toxicity show as coalescing dark spots on the margin of leaves that in severe cases originate marginal leaf necrosis.

The influence of boron in yield and fruit quality and shelf life has been clearly demonstrated by different trials. According to an experiment in Pakistan with cv. Sufaid Chaunsa (Ahmad et al., 2018a) the application of sucrose or potassium citrate are equally effective regarding the improvement in yield when applied with boric acid, indicating that foliar application of boric acid (0.2%) + Sucrose (10%) increased plant yield (19%), total soluble solids (29%) and reduced fruit acidity (37%). They recommend the foliar application of 0.4% potassium citrate + 0.2% boric acid to improve mango shelf life. The same authors also found that foliar sprays of 10% sucrose + 0.2% boric acid, applied at pre-flowering stage and at marble stage are of great efficacy for significant improvement in fruit setting and TSS, reduction in acidity and. Another experiment in Pakistan (Bibi et al., 2019) with cultivar Summer Bahisht Chaunsa indicates the effectiveness of pre flowering foliar application of KNO_3 (1.0%) + BA (0.2%) to increase quality and yield. It has been also indicated that a great imbalance of nutrients, especially B deficiency, might be the cause of internal flesh breakdown in mango (Ma et al, 2018). The influence of Boron in mango is also mentioned by Kumar (undated) who indicated that soil application of Borax at 150 g/tree each 2 years, resulted in reduction of spongy tissue from 40–60 % to 10 %. Improving also fruit size and skin colour.

An appropriate content of boron is reported in the mainland China survey as important to reduce IFB and Ecuador also indicates that an increase of B reduces the problem of 'Corte negro' (Cutting Black), a problem closely related with IFB. Other countries also report a positive influence of B in flower induction, pollination and fruit set, as well as in shelf life increasing yield (see annex 5). The influence of Boron in mango is also mentioned by Kumar (undated) who indicated that soil application of Borax at 150 g/tree each 2 years, resulted in reduction of spongy tissue from 40–60 % to 10 %. Improving also fruit size and skin color.

Boron fertilizers used in mango included sodium borate (borax or solubor), boric acid, calcium borate and calcium sodium borate. According to several authors mentioned by Bally, (2009) both soil and foliar application of B increase yield and fruit quality of mango, but the response varies between cultivars. Soil application of 20-25g/m^2 of borax (11%) during the summer wet season were effective in controlling boron gummosis deficiency symptoms, but the response time and effect differs between cultivars. (Nartvaranant et al., 2002). Although, as indicated before the response of mango to boron fertilization varies from cultivar to cultivar, leaf boron content of 27 ppm was found satisfactory for the cultivars Haden 2hH, Tommy Atkins, Winter and Van Dyke and 10 ppm critical for most of them (Rosseto et al., 2000). Foliar application of Boron at preflowering and flowering stages has also been reported to increase yield and fruit quality in mangos (Dutta, 2004; Coetzer et al., 1991) and are considered more effective than soil applications. Silva et al. (2002) and Oldoni et al., (2018) in Brazil considered that foliar sprays of boric acid at a concentration of 0.2-0.3 % as the most appropriate source of boron. However, it has been indicated that foliar application should only be made to soft tissues during flowering and that foliar uptake is very poor in old leaves (QDAF, 2015). However, there are authors that indicate that combined soil application of B and Zn mitigates leaf mineral deficiencies and improves the yield and quality of mango more efficiently than other individual or combined foliar or soil treatments (Ahmad, 2018b).

Zinc.-

Among other functions this element is essential for the synthesis of proteins and hormones, for the photosynthesis (Salysbury and Ross, 1992; Marschner, 1995; Weir and Cresswell, 1995) and for water regulation (QDAF, 2015). Due to its ready absorption through the leaves, Zn is usually applied through foliar sprays while soil applications are not recommended for being ineffective in most cases. Several authors cited by Bally, (2009) indicate that foliar applications of different Zn fertilizers, increase yield and fruit quality in mango, being Pakistan and South Africa the only countries that mention a positive effect of Zn in flower induction, pollination, fruit set and yield (see Annex 5).

Zn is important for leaf expansion and Zn deficiency is easily recognized by the apparition of a *rossete* of thick and not fully expanded leaves that do not reach full size and that are often stunted in one side of the lamina. It is frequently named as 'little leaf' and it is often associated to Fe deficiency in soils of high pH. Zn deficiency is aggravated by excessive applications of Calcium or phosphates (Rhuele and Ledin, 1955). Zn toxicity has not been described for mangos.

Zinc sulfate is currently used to correct Zn deficiencies (Galán Saúco, 2008; Silva et al., 2002). The recommended dosage for foliar applications of $ZnSO_4$ in Israel is 1%, preferably applied in spring (Gazit, 1970) while the current recommendation for mangos growing in high pH soils of Florida is 0.9-1.8 kg of zinc sulfate in 378-945 liters of water either alone or in a mix with other microelements (Crane,2019). The information supplied by K+S (Kumar, undated) also recommends two sprays of $ZnSO_4$ at 3 g/L of water, one before flowering stage and the second one coinciding with fruit set to correct Zn deficiency

Iron.-

Its role derives from being a component of chlorophyll and of several enzymes and, similarly to Zn, this nutrient is involved in water regulation. Although Fe is readily absorbed by the leaves, it is often applied as chelates, particularly in alkaline soils, either through the drip system (Galán Saúco, 2008) or as soil drench. The two forms of chelated iron shown to be effective are Fe-EDDHA and Fe-EDDTA, the first form for calcareous or high pH soils and the second for acid soils. When applied as soil drench a copious irrigation should be given before and after iron application to increase movement of iron chelate into the root zone (Crane, 2019).

Iron deficiency occurs first in young leaves which turn pasty yellowish developing typical chlorosis symptoms extending to the whole leaf as the deficiency increase causing eventually leaf necrosis and characteristic compact terminals which fails to develop.

Manganese.-

This element is a cofactor of many enzymes and essential for the biosynthesis of proteins, carbohydrates and lipids. As activator of oxidative processes also an important role in photosynthetic and respiration processes and protection against oxidative stress (Marschner,1995). The direct effect of Mn in mango has not been studied, but Schaffer (1994) indicated that the most deficient nutrients in orchards with mango declining trees were Mn, Fe or a combination of both elements. Furthermore, the only country that mention a positive influence of Mn in fruit quality is Brazil (see annex 5).

Mn deficiency affects leaves of any age. Mn deficiency symptoms in mango most frequently results from elevated soil pH and initiate as interveinal light necrosis of middle and younger leaves, later coalescing in necrotic spots following by leaf abscission. It may be confused with leaf symptoms of Fe deficiency, but in the case of Mn deficiency the leaf-blade areas further from the veins remains green. Mn deficiency is also aggravated by excessive applications of Calcium or phosphates. Deficiency symptoms have also been observed in young plants or new shoots of adult plants overfertilized with N as terminals of reduced size losing their leaves and typically showing an 'S' shape (Rhuele and Ledin, 1955). Necrosis can, in severe cases, initiate at the leaf tip, extending downwards (Smith and Scudder,1951; Agarwala, 1988).

According to Florida information (Crane,2019) soil applications of manganese to neutral and acid soils may be effective, but not in calcareous soils. The current recommendation for mangos growing in calcareous soils is a foliar application of 1.4-2.3 kg of manganese sulfate in 378-945 liters of water, either alone or in a mix with other microelements. Kumar (undated) also indicates that Mn deficiency is common in old trees in high pH soils and that the use of neem cake decoction or foliar spray of 0.5 % manganese sulphate to old trees can increase fruit size and reduce alternate bearing. However, many cupper fungicides sprays common in many mango orchards contain Mn and cover sufficiently the mango needs of this element.

Molybdenum. -

This element is needed for absorption and assimilation of N and also for a good uptake of, K and Ca and Fe and its deficiency affects growth and yield. Molybdenum is not mobile within the plant and new leaves require a constant supply during their development. It is needed in very low amounts and, if in excess, will reduce Fe availability. Molybdenum is usually a constituent of many micronutrient foliar mixes applied to mangos. Crane (2019) in Florida recommends a foliar application of 70 g of sodium molybdate mixed in 378 liters of water per ha, if molybdenum deficiency is suspected.

Copper. -

Copper is needed to activate several plant enzymes and regulate photosynthesis. It also aids lignin production and strengthening cell walls.
Trials with mango have shown small yield improvements and also increases in the sugar:acid ratio of the fruit. (Yara, undated). As indicated before, many fungicides contain Cu and because of this copper deficiency is not common in mango orchards.

Moment to apply fertilizers

The most rational way of applying nutrients, as indicated by Cull (1987) is having in account the phenological cycle. As a general rule, Huete and Arias (2007) recommend to apply around 50% of all required macroelements immediately after harvest and the rest after fruit set and the microelements in three moments: 40% after pruning, 30% 2 months later and the remaining 30%, 4 months after pruning They also recommends that, if possible, microelements should be applied in the wet season. Not many other fertilizer recommendations according to the phenological cycle, have been published, but of particular importance to this regard is the timing for the application of nitrogen because of its role regarding vegetative growth and flowering (see section **Role of specific nutrients in mango**). Theoretically the needs of N during the latent period preceding flowering could be considered minimum because it may stimulate vegetative growth instead of flowering but the situation is different in the subtropics, where normal winter temperatures are sufficiently low to induce flower, from the tropics where in absence of temperatures below 20ºC, although there may be necessary to apply nitrates after induction to obtain flowering in mature buds (Davenport, 2009). An adequate application of nitrogen both during the phase of quick fruit development (Samra *et al.*, 1977; Guzmán Estrada *et al.*, 1997) and immediately before harvest which allows quick replacement of the carbohydrates consumed during fruit development have been reported to increase yield (Robberts and Wolstenholme, 1993). Precisely, Wolstenholme and Robberts,

(1991) and also Oosthuyse, (1997) recommend to apply potassium nitrate at 2-4% during the phase of fruit growth. It has been also indicated that foliar sprays of urea at 2-4% during flowering increase yield (Whiley,1984). Care should however be taken not to over fertilize with N close to harvest not only because some cultivars like 'Kent' and 'Keitt' do not develop good color when N content is high (McKenzie, 1993), but specially to avoid internal fruit breakdown (IFB) problems due to calcium /nitrogen imbalance, In fact, as indicated before, there is general agreement that maintaining N leaf levels below 1.2% and Ca leaf levels higher than 2.5% minimizes the amount of fruit affected with IFB (Galán Saúco, 2009). It is also, of course, recommended to increase N application immediately after harvest to stimulate vegetative growth.

In Brazil, Silva et al., (2002) only indicate that phosphorous should be applied before flowering and that the best moment to apply Ca is during the vegetative flush immediately after harvest and in the early stages of fruit growth. They do not specify the best moment for application of other nutrients, except in the case of boron, for which they recommend that applications should be made during the period of emission of new vegetative flushes or during flowering, However, other authors (Singh, 1960; Robberts *et al.*, 1988; Goguey, 1993) indicate that this element should be applied during the stage of vegetative growth and before flowering starts because it is only demanded during flowering

More complete is the information given by Stassen *et al.*, (1997b) for South Africa indicating the following:

Nitrogen.- The best moments for applying this element are at beginning of spring (fruit set and quick fruit development phase), immediately after harvest and in autumn (vegetative growth phase)

Phosphorous.- If in case that the analysis showed deficiency of this element the recommended moment to incorporate P is in winter and spring, that is during the period of root growth (vegetative growth phase and at the beginning of flowering and quick fruit growing phase.

Potassium.- Better to apply this element before flowering to satisfy the high demand of this nutrient during the phase of quick fruit growth.

Boron, sulphur and magnesium are recommended to be applied before flowering and the rest of micronutrients during flowering,

The recommendations for Australia (QDAF, 2015) for the four more important nutrient for mangos are as follows:

Nitrogen: 60-70% at flushing time, 20-30% at the end of the dormant period before flowering and 10% (if needed) at fruit development.

Potassium: 20% at flushing time, 20% at flowering and 60% at fruit development stage.

Calcium: 50% at flushing time, 20% at the beginning of flowering and 30% at fruit set.

Boron: 20% at flushing time, 40% at flowering and 20% at fruit development.

Early recommendations for this same country (Anon.,1999) indicate that other micronutrients should be applied through foliar sprays at the moment of apparition of young vegetative foliage, with the exception of the Mg that is better applied after harvest, during vegetative stage and /or immediately before bud break. Recommendations for applying foliar sprays of micronutrients vary also among countries and locations. As an example, in Costa Rica, Ríos and Corella (1999) have developed a specific foliar fertilizer for mangos with the following composition: calcium chelate 1L/ha plus a multilateral chelate (Mg 5.8%, Fe 0.5%, Cu 0.12%, Zn 4.2%, B 2.5% and Mo 0.02%). Using this foliar fertilizer, they apply foliar sprays of microelements 4 times, the first, duringvegetative growth (May-June), the 2nd one at the preflower stage (October), the third at flowering (December-January) and the 4th during the fruit filling (February-March).

While the main fertilizers are applied to the soil as in the Philippines according to the season (see section **General recommendations for fertilising mangos),** foliar fertilizers are sprayed 4 times. The first two, needed to increase panicle length and in preparation for a good fruit setting are applied around 14 to 18 and 22 to 25 days after induction. The third application at 35 to 40 days after flower induction encourages fruit setting and retention while the fourth application at 50 to 55 days increases fruit size.

Finally, in the case of Pakistan they recommend (Bibi, 2018) nutrients according to the following schedule.

Immediately after harvest: 60-70% of N. 80-100% of P, 50% of K and 50% of micronutrients (B, Zn, Fe, Mn, Cu)

At flowering: 30-40% of N, 0-20% of P and 50% of K and 50% of micronutrients (B, Zn, Fe, Mn, Cu).

Despite all these considerations it is clear that in non-irrigated orchards the moment to apply fertilizers to the soil should coincide with the beginning of the rainy season in order to incorporate to the mango the maximum amount of nutrients for flowering, fruit set and vegetative growth.

Results from the nutrition survey (see Annex 9) indicate that practically all the countries apply fertilizers having in account the phenological calendar, but only few of them give precise information and, as in the case of the literature review, there are ample differences in the recommendations. Israel, indicate that most of the nutrients are applied after harvest, Oman only avoids fertilizing during flowering, Japan apply their fertilizers three times a year, at post-flowering/fruit setting stage, fruit developmental stage, and post-harvest (before pruning) stage. In the Mexico report they say that N, P; K and Ca are incorporated to the soil at the end of harvest to stimulate growth. More N and K formulations as well as microelements are applied at the beginning of flowering and during fruit set and additional K, Ca and also Mg are applied during fruit growth. In the case of Reunion Island nutrients are applied after harvest to favour vegetative growth, at flowering to favour fruit set, and after fruit set to favour fruit growth, but at this last stage no nitrogen is applied to avoid the negative effect of this nutrient in fruit quality and maturity. The report of Pakistan practically coincides with the one cited in the literature review (Bibi, 2018), except that indicating that boron should be applied before flowering and Zinc on young vegetative shoots.

As for the information collected from fertilizers companies the recommendation for India regarding time of application given by K+S (Kumar, undated) are as follows:

Irrigated orchards. Apply full dose of farm yard manure (FYM) and 50 % of N, P, K after harvest and the remaining N, P, K at pea stage.

Non- irrigated orchards. Apply full dose of FYM) and 50 % of N, P, K at the onset of the monsoon and the remaining N, P, K at the end of the monsoon.

Fertigation

With the more generalised use of localised irrigation (microsplinklers or drip irrigation) macronutrient in modern mango plantings are generally applied together with irrigation water (fertigation). This is of special value in soils with low cation exchange capability ≤ 2meq, such as sandy soils with low organic matter and pH ≤ 6 that has low water and nutrient retention capacity and low buffer potential. In addition, fertilizer application in combination with drip irrigation when applied with plastic mulch can keep moisture optimal in growing zone, increasing root biomass, regulate soil temperature, reducing its variation, improve soil fertility and can contribute to control soil erosion and weed population. Experiments done in Australia with the cultivar Kensington indicate that this practice can increase not only average fruit weight and yield but also contribute to the sequestration of soil organic carbon (Dickinson et al., 2019).

The fertilizers more used in fertigation are ammonium sulphate, urea, phosphoric acids, potassium nitrate or potassium sulphate (Crane et al., 2009). When preparing fertilizers mixtures for fertigation, care should be taken to avoid precipitations that can clog the irrigation system. To avoid this problem, Vásquez Hernández et al., (2011) recommend to use of two different tanks, the first one containing fertilizers without Ca like urea, ammonium nitrate, potassium sulphate, phosphoric acid, magnesium sulphate and chelated micronutrients, the other tank only fertilizers without phosphates or sulphates like urea, calcium, magnesium and ammonium nitrates and nitric acid. Generally, the only micronutrient provided through fertigation is iron, usually applied as chelates at reduced rate almost in any irrigation, with all the other micronutrients being applied as foliar sprays.

The dosage of fertilizers varies from location to location depending on type of soil, water quality and plant material (rootstock and cultivar), but it is generally agreed, and some experiments prove it that fertigation promotes more efficient use of nutrients than broadcasting of the same amount of fertilizers. This can be explained mainly because the liquid fertilizers used in fertigation are placed in close contact with the root system which results in quicker nutrient absorption and reduction of lixiviation losses. There are many examples of this greater benefit regarding increase in fruit weight, number of fruits per tree, improvement of fruit quality and bigger yield (Prasittikhet et al., 2000; Prakash et al, 2015; Kumar, undated). An example of macronutrient application through fertigation as recommended for South India conditions can be seen in table 14.

As can be seen from the answers to the nutrition survey (see Annex 10), many countries are applying soluble chemical fertilizers through fertigation: Despite the answers to the survey in some Asian countries, do not report the use of fertigation, this is common in many mango farms visited by the author in India, Malaysia, Indonesia, Thailand, the Philippines, Oman and Australia and probably in recent mango plantings almost in any country. Microelements are generally applied through foliar sprays and organic fertilizers directly to the soil or in some cases also through fertigation. (See table 14)

Table 14.- Recommended fertigation schedule for South Indian conditions according to K+S fertilizer company (Kumar, undated) (*)

Element	Right after pruning	Preflowering	Flowering - fruit set	Fruit development
N (%)	25	40	20	15
P (%)	40	30	20	10
K (%)	25	20	25	30

(*) fertigation and also water application are stopped in December, to favour flowering in January

Organic fertilization

Results from different experiments made in Mexico (Medina Urrutia, 2011; Peralta-Antonio et al. (2014, 2015) have not shown clear differences regarding yield between organic or chemical fertilization on mango. One of these experiments Peralta-Antonio et al. (2015) comparing vermicompost, bocashi and chicken manure at dosages of 5 and 10 t ha^{-1} (equivalent to 7.5 y 15 kg $tree^{-1}$) and two mineral dosages : 230-0-300 g of NPK $tree^{-1}$and 230-0-0 g de NPK $tree^{-1}$ plus one control treatment in cultivars Ataulfo, Tommy Atkins and 'Manila Cotaxtla 2' ('MC2') shows that no clear differences between mineral and organic sources regarding the absorption of most nutrient were found. However, as also shown in the experiment, the plants were also able to directly extract nutrients from the soil, because of which no clear conclusions can be derived from this experiment. This explains that organic nutrition in Mexico, as well as in other parts of the world is chosen according to a diversity of local formulations prepared by growers using local resources as a result of their own accumulated experience and no specific recommendations can be made. Compost, vermicompost, biofertilizers, chicken and other animal manures, plant residues and cover crop are usually the main sources to fertilize organic mango farms. Biofertilizers, are alternatives to incorporate a sizeable portion of nitrogen (N) from the atmosphere and also in making phosphorous available from the roots (Medina-Urrutia et al. 2011; Iyer, 2004; Guzmán-Estrada, 2004). It is interesting to note that in the answer to the nutrition survey from Dominus in Peru, it is indicated that an excess of organic matter in the soil may cause cupper deficiency (see Annex 7).

It is also worth to mention the potential use as soil amendment of Biochar, a solid C-rich matrix obtained by pyrolysis of biomasses, currently promoted as a soil amendment, particularly in acid soils, poor in nutrients (Sohi et al., 2009), with the aim to offset anthropogenic C emissions, while bettering soil properties and growth conditions. Field experiment about their use in mango fertilization has been very scarce so far, but the application of soil, sand and organic biochar in the ratio of 2:1:1 to a rooting media was found to enhance the germination percentage, rate of germination and seedling vigour (Jasmitha et al, 2018). However, the interaction of biochar with fertilizers and their effect on the soil biota are not well studied, and, in consequence before recommending its application, its use in mango cultivation must be investigated. In this sense, it is worth to mention that only Pakistan (see Annex 11) reports interest on the impact of phosphorus and biochar on small trees growth.

As a general recommendation to avoid possible contamination, it is convenient to place manure and compost piles far from the water sources and to reduce the organic fertilization close to harvest.

Possibilities for future research projects in mango nutrition and fertilization

At the present moment, no cooperative project on mango fertilization between countries is being carried out, but many countries, particularly Brazil, Peru, India, Pakistan and Vietnam are conducting trials in different aspects of mango fertilization. Many of the consulted countries also indicated important subjects for future lines of research in mango and the great majority indicated their willingness for cooperative trials in mango fertilization provided funding are available (see Annex 11). However, the diversity of the subjects mentioned by the different countries as interested topics for mango fertilization will probably make it difficult to execute future cooperative trials.

Summary of findings, general discussion and Conclusion

Because of the many factors influencing mango nutrition and fertilization in mango (mainly climatic considerations, soil type, quality of irrigation water, cultivar and rootstock, nutrient interactions, phenological stage and expected crop load), no general fertilizer formula can be given for designing a mango fertilizer program that have to be made for each particular plantation. This have to begin by conducting a soil analysis made before planting which will indicate the physicochemical characteristics of the soil where mango is going to be cultivated in order to setup the initial basal dressing and correction measures. Regular soil analysis, at least once per year will also be helpful to evaluate the trend of the evolution of nutrients in the soil. and, together with foliar analysis orientate about fertilizer rates to be applied. Appropriates values for a soil to be cultivated with mangos are discussed, and general recommendations are given in the paragraph **Soil analysis.**

Examples of general fertilizer programs that have been recommended in different countries for mango cultivation that can be useful for the first year, and also for adult trees in smaller farms with no access to laboratories are also given in the paragraph **General recommendations for fertilizing mangos.**

Despite that leaf nutrient content varies not only between cultivars but also depending on different factors related with the leaf itself (age, leaf position, orientation), soil type and phenological stage, foliar analysis is the most useful tool for a correct establishment of a mango fertilizer program. A complete review of the values recommended by different authors as well as a discussion about sampling techniques is reported in the paragraph **Foliar analysis.** But, most of the countries that are using foliar analysis as the main tool for establishing their fertilizer programs report values for nutrient leaf concentrations in the range recommended by Quaggio in 1996 (see table 5).

However, there is not always a good correlation between single nutrient content and yield being of greater value the balance and quantitative relations between nutrients. The importance of these relations and specially of the relation N/Ca which should be kept below 0.5 for obtaining good fruit quality and extending shelf life is discussed in the subparagraph <u>Interpreting foliar analysis</u>. An alternative method to evaluate the nutritional state based in the equilibrium between nutrients, the Diagnosis and Recommendations Integrated System (DRIS) to interpret foliar analysis is also commented in the mentioned subparagraph. According to the answer to the nutrition survey Brazil, India and Indonesia are the only countries where this system is being used more. Nevertheless, this system has also its drawbacks since DRIS norms also varies from cultivar to cultivar and from location to location and are not totally independent from the age of the sample tissue and also because of the great number of foliar analysis and calculations needed for a correct interpretation of them not always possible to be realised particularly for small size farms. This problem can be simplified, especially in Brazil by the existence in that country of a company named 'Nutrição de Plantas Ciência e Tecnologia (NPCT)' (<u>https://www.npct.com.br/</u>), recently created by ex. Directors and members of International Plant Nutrition Institute (IPNI) that offers to any mango farm from any country their services, under a reasonable fee, for the correct interpretation and use of the DRIS system.

As indicated in the section **Nutrient extractions,** reposition of macro and micronutrient losses due to crop load, dropped fruits and leaves and branches removed by pruning, as well as those removed by lixiviation, volatilization, soil fixation and runoff is essential for an appropriate mango fertilizer program. However, it is clear from our review the existence of important differences depending on cultivars and locations (soil and climatic conditions, particularly temperature), cultural practices and age of the tree) and, as a consequence, nutrient extraction should be determined for each mango farm and cultivar. However, as also indicated in this section an example of using crop removal to establish a mango fertilization program is given in Annex 4.

The role of macro and micronutrients, their effect in the plant at different moment of the growth cycle is reviewed in the paragraph **Role of Specific nutrients for mangos and ways of application.** It is recommended by practically all the reviewed papers dealing with mango fertilization that the most rational way of applying nutrients is by having in account the phenological cycle. Although, results from the nutrition survey indicate that practically all the countries apply fertilizers having in account the phenological calendar, only a few gives precise information and, as in the case of the literature review, there are ample differences in the recommendations (see paragraph **Moment to apply fertilizers**). In consequence, it is difficult to extract clear conclusion from this review, but having it seems evident that most macronutrients, and particularly nitrogen, should be applied immediately after harvest to stimulate new vegetative growth, stopping it at the end of winter to check growth for flower induction (applying nitrates if required for obtaining flowering). Nitrogen application should be specifically reduced or stopped, and application of Ca, Mg and K increased during fruit development to avoid IFB and improve fruit quality and shelf life. The majority of micronutrients should be applied preferably by foliar sprays during flowering.

In modern mango plantings macronutrients and also iron are generally applied together with irrigation water (fertigation) and their benefits for mango productivity are even increased when applied together with mulching, while the rest of micronutrients are applied through foliar sprays and organic fertilizers directly to the soil or in some cases also through fertigation. The benefits commented above as indicated in the paragraph **Fertigation** can be explained mainly because the liquid fertilizers used in fertigation are placed in close contact with the root system which results in quicker nutrient absorption and reduction of lixiviation losses and those derived from the use of mulching, besides those normally associated to this practice, such as better control of soil humidity and temperature, also due to the sequestration of soil organic carbon of importance this last one in the fight against global warming.

With the increasing demand of organic products, organic fertilization is becoming of great interest for mango cultivation. Experiments done in mango comparing organic and inorganic sources of fertilizers have not shown clear differences regarding nutrient absorption and yield. Although, as indicated in the paragraph **Organic fertilization,** compost, vermicompost, biofertilizers, chicken and other animal manures, plant residues and cover crop are usually the main fertilizers used in organic mango farms, organic fertilizers are generally chosen according to a diversity of local formulations and no specific recommendations can be made.

The great variability of interest in different topics of mango nutrition expressed by the different countries consulted makes very difficult the possibility of future cooperative trials on the subject, but ongoing trials will certainly bring new findings in the short or medium term for mango nutrition and fertilization (see paragraph **Possibilities for future research projects in mango nutrition and fertilization)**

As a **conclusion**, the many variables involved in mango nutrition and fertilization commented in this revision makes impossible to draw general recommendation for a mango fertilizing program that have to be established by each particular farm, and even for each cultivar inside the farm, based in the sound interpretation of soil and foliar analysis and forecasted nutrient extraction. Guidelines for a correct interpretation of these tools have been given along with this review that can serve mango growers for obtaining the maximum productivity of this crop derived from a sound fertilizer program.

Bibliography

Abercrombie, R.A. 1998. Leaf and soil analysis. In: de Villiers, E.A. (ed.). The cultivation of mangos. Institute for Tropical and Subtropical Crops. ARC. LNR. Nelspruit. Sudáfrica: 104-107.

Agarwal, S.C., Nautiyal, B.D., Chaterjee, C. and Sharma, C.P. !988. Manganese, Zinc and boron deficiency in mangos. Scientia Horticulturae, 35:99-107.

Ahmad, I., Bibi, F., Bakhsh, A.D., Ullah, H., Danish, S. and Asif-ur-Rehman. 2018. Assessment of various levels of potassium citrate and sucrose along with boric acid on quality and yield of Sufaid Chaunsa. International Journal of Biosciences. 13 (1): 188-195, http://www.innspub.net.

Ahmad, I., Bibi, F., Ullah, H. and Munir, T.M. 2018 b. Mango Fruit Yield and Critical Quality Parameters Respond to Foliar and Soil Applications of Zinc and Boron. Plants 2018, 7, 97; doi:10.3390/plants7040097

Anon 1999. Mango Information Kit. Queensland Department of Primary Industries

Anon. 1975. Seasonal guide for subtropical fruits. Citrus and Subtropical Fruits Research Institute. Inf. Bull., 36: 5.

Anon. 2009. Recomendaciones prácticas para la fertilización del cultivo de mango. FHIA - La Lima, Cortés, Honduras, C.A. • Hoja Técnica No. 3 •August, 2009.

Anon. 2017.Understanding crop nutrition. A guide for Australian mango growers. https://www.industry.mangos.net.au/resource-collection/2017/1/27/understanding-crop-nutrition-a-guide-for-australian-mango-growers. Downloaded 16/08/2019

Bally, I.S.E. 2009. Crop Production: Mineral Nutrition. In: Litz, R.E (ed.). The Mango, Botany, Production and Uses. 2nd edition- CAB International. Wallingford. U.K.: 404-431.

Bally, I.S.E., Hofman, P.J., Irving, D.E., Coates, L.M. and Dann, E.K..2009. The Effects of Nitrogen on Postharvest Disease in Mango (*Mangifera Indica* L. 'Keitt'). Acta Hort. 820. 365-370.

Bandopadhyay, B. 2009. Effect of organic and inorganic nutrients on improving flowering. Acta Horticulturae 820:371-380

Bibi, F. 2018. Mango Nutrition: A presentation made at "Mango Seminar", 20th February, 2018, Mango Research Institute, Multan, Pakistan.

Bibi, F., Ahmad, I., Bakhsh, A., Kiran, S., Danish,S., Ullah, H. and Asif-ur-Rehman. 2019. Effect of Foliar Application of Boron with Calcium and Potassium on Quality and Yield of Mango cv. Summer Bahisht (SB) Chaunsa. Open Agriculture, 4:98-106.

Bondad, N.D. and Linsangan, E. 1979. Flowering in mango induced with potassium nitrate. HorstScience, 14: 527-528.

Bhargava, B.S. and Chadha, K.L. 1988. Leaf nutrient guide for fruit and plantation crops. Fertilizer News, 33**:** 21-29.

Bhupal Raj, G. and Prasad Rao, A. 2006. Identification of Yield-Limiting Nutrients in Mango through DRIS Indices, Communications in Soil Science and Plant Analysis, 37:11-12, 1761-1774, DOI: 10.1080/00103620600710587

Biswas, P.P., Joshie, O.P. and Rajput, M.S. 1987. Establishment of critical leaf nutrient concentrations of mango cultivar Dashehari based on soil test. Journal of the Indian Society of Soil Sciences, 35**:** 331-334.

Burdon, J.N., Moore, K.G. and Wainwright, H. 1991. Mineral distribution in mango fruit susceptible to the physiological disorder soft -nose. Scientia Horticulturae, 48: 329-336.

Burdon, J.N., Moore, K.G. and Wainwright, H. 1992. A preliminary observation of the mango disorder soft-nose in mango fruit. Acta Horticulturae, 296: 15-22.

Campbell, T. and Mohr, M. 1991. Fertilizer for mangos. Mango Care Newsletter, **2:**6-7.

Catchpoole, D.W and Bally, I.S.E. 1995. Nutrition of mango trees: a study of the relationships between applied fertilizer, leaf elemental composition and tree performance (flowering and fruit yield). In: Mango 2000. Proceedings of Marketing Seminar and Production Workshop. Townsville. Queensland. Conference and Workshop Series QC 95006): 91 – 104.

Cavalcante, I.H.L, Lima, A.M.N., Carneiro, M.A., Rodriguez, M.S., and Silva, R. L. 2016. Potassium doses on fruit production and nutrition of mango (*Mangifera indica* L.) cv. Palmer. Rev. Fac. Agron. (LUZ). 2016, 33: 418-432. October-December.

Coelho, E.F. and. Borges, A.L. 2004. Irrigation and Fertirrigation of Mango. Acta Horticulturae, 645**:** 119-128.

Coetzer, L.A., Robbertse, P-J. and de Wet, E. 1991. The influence of boron application on fruit production and cold storage of mangos. South African Mango growers Association Yearbook,11: 29-31.

Cull, B.W. 1987. A whole plant approach to productivity research for mango. Mango – A review. Prensley, R.T. and Tucker, G. (ed.). Commonwealth Science Council. London.

Cull, B.W: 1991. Mango crop management. Acta Horticulturae, 291**:** 154-173.

Cracknell Torres, A., Cid Ballarín, M.C., Socorro Monzón, A.R., Fernández Galván, D., Rosell García, P. and Galán Saúco, V. 2003. Effects of nitrogen and calcium supply on the incidence of internal fruit breakdown in 'Tommy Atkins' mangos (*Mangifera indica* L.) grown in a soilless system. Acta Horticulturae, 645, 387-394.

Crane, J.H. 2019. Fertilizer Recommendations for Florida Mangos Mango Plant Nutrition and Leaf Analysis. (c://ext/factsheets/mango/mango fertilizer recs revised 2-15-19.doc).

Crane, J.H.; Bally, I.S.E.; Mosqueda Vázquez, R.V. and Tomer, E. 1997. Crop production. In: The Mango, Botany, Production and Uses. CAB International. Wallingford. U.K.: 203-256.

Crane, J. H., Salazar-García, S. Lin, T.S., de Queiroz Pinto, A.C. and Shu, Z.H. 2009. Chapter 13. Crop Production: management. In: Litz, R. E.(ed.). The Mango, Botany, Production and Uses. 2nd edition- CAB International. Wallingford. U.K.: 432-483.

Cruz-Barrón, V., Bugarín-Montoya, R., Alejo-Santiago, G., Luna-Esquivel, G. and Juárez-López, P. 2014. Revista Mexicana de Ciencias Agrícolas 5 (2): 229-239.

Chadha, K.L., Samra, J.S. and Thakur, R.S. 1980. Standardisation of leaf sampling. technique for mineral composition of leaves of mango cultivar 'Chausa'. Scientia Horticulturae, 13**:** 323-329.

Davenport, T.L. 2009. Reproductive Biology. In: Litz, R.E. (ed.) The Mango, Botany, Production and Uses. 2nd edition- CAB International. Wallingford. U.K.: 97-169.

De Carvalho, P.J. and de Queiros Pinto. A.C. (Eds.). 2002. A Cultura da Mangueira. Embrapa Informaçao Tecnológica. Brasilia. 452 pp.

Deewan, N., Lertpanit, K. and Popan, A. 2015. Comparison of soil properties and physical structure in Good Agricultural Practice (GAP) and conventional mango orchards at Pongtalong Sub-district, Pak Chong District, Nakhon Ratchasima Province. King Mongkut's Agricultural Journal: 33(2):1-8. (in Thai).

Dickinson, G.R., O'Farrell, P.J., Ridgway, K.J., Bally, I.S.E., Masters, B., Nelson, P. and Patisson, A. 2019. Nitrogen and carbon management in Australian mango orchards to improve productivity and reduce greenhouse gas emissions. Acta Horticulturae 1244: 49-60.

Dutta, P. 2004. Effect of foliar boron application on panicle growth, fruit retention and physio-chemical characters of mango cv. Himsagar. Indian Journal of Horticuture 61:265-266.

Espinosa A.J., Arías S.J.F., Rico P.H.R., Miranda S.M.A., Javier M.J., López A.A., Vargas G.E. and Teniente, O.R. 2006. Manejo y protección de la floración para cosecha temprana de mango cv Haden en Michoacán, México. Publicación Científica No. 1. INIFAP-CIRPAC-Campo Experimental Valle de Apatzingán, México. 46p.

Fallas, R., Bertsch, F., Miranda, E. and Henríquez, C. 2010. Análisis de Crecimiento y Absorción de Nutrimentos de Frutos de Mango, cultivares Tommy Atkins y Keith. Agronomía Costarricense 34(1): 1-15.

Ferguson, I.B.1984. Calcium in plant senescence and fruit ripening. Plant Cell and Environment 7: 477-489.

Galán Saúco, V. 2008. El Cultivo del Mango (2nd ed.). MundiPrensa. Madrid. 340 pp.

Galán Saúco, V. 2009. Physiological disorders. In: Litz, R.E. (ed.). The Mango, Botany, Production and Uses. 2nd edition- CAB International. Wallingford. U.K.: 303-316.

Galán Saúco, V. 2016. Mango Rootstocks. Literature Review and Interviews. https://www.mango.org/research-resources.

Galán Saúco, V. 2018a. Magnesium fertilization in mango. https://www.mango.org/research-resources.

Galán Saúco, V. and Lu, P. (eds). 2017. Achieving sustainable cultivation of mangos Burleigh Dodds Science Publishing, Cambridge, UK. 549 pp.

Gazit, S. 1970. C. Mango, 3. Nutritional Problems. In: The Division of Subtropical Horticulture. The Volcani Institute of Agricultural Research, 1960-1969: 101-104.

Genú, P.J.C. and Pinto, A. C. Q. A cultura da mangueira. Brasília: Embrapa Informação Tecnológica, 2002. 454p.

Goguey, T. 1993a. Principales causes de la faible productivité du manguier (*Mangifera indica* L.). In: Journées FLHOR vergers tropicaux, CIRAD-FLHOR Montpellier: 111.

Goguey, T. 1993b. Study of the effect of three flower-inducting substances on 'Kent' and 'Zill' mangos- Acta Horticulturae, 341, 216-224.

Gupta, U.C., Jame, Y.W., Campbell, C.A., Leyshon,A:J. and Nicholaichuk, W. 1985. Boron toxicity and deficiency: a review: Canadian Journal of Soil Science 65: 318-409.

Guzman-Estrada, C. 2004. Evaluation of a biofertilizer, clearing and fruit bagging in mango Kent. Acta Horiculturae. 645:217-221.

Guzmán Estrada, C.; Mosqueda Vázquez, R. and Alcalde-Blanco, S. 1997. Content and extraction of several nutrients by mango fruits of Manila cultivar. Acta Horticulturae, 455**:** 465-471.

Haifa, Undated. Mango fertilizer: a fertilization program for mango trees. https://www.haifa-group.com/mango-fertilizer-fertilization-program-mango-trees. Downloaded 15/07/2019

Hiroce, R., Piza Júnior, C.T., Kakuta, I. and Scalopi, E.J. 1986. Teor des nutrientes das folhas de mangueira do Estado de Sao Paulo, Brazil. In Anais Congresso Brasileiro. De Fruticultura, 8 Brasilia, DF. Brasilia, SBF: 371-379.

Huete, M. and Salvador, S. 2007. Manual para la Producción de Mango. Proyecto de Diversificación Económica Rural. USAID-RED.

Hundal, H.S., Singh, D. and Brar, J.S. 2005. Diagnosis and Recommendation Integrated System for Monitoring Nutrient Status of Mango Trees in Submountainous Area of Punjab, India. Communications in Soil Science and Plant Analysis, 36: 2085–2099.

Isarangkool na Ayutthaya, S., R. Taepongsorat, A. Dongsansuk and S. Techawongsatian. 2006. Growth and development and nitrogen, phosphorus, and potassium quantity in leaves of ‘Mahachanok’ mango after planting in 1 to 2 years. Agricultural Science Journal 37(6 special): 513-516. (in Thai)

Iyer, C.P.A. 2004.Growing Mango Under Organic System. Acta Horticulturae, 645: 71-84.

Jasmitha, B.G., Honnabyraiah M.K. Anil Kumar S., Swamy G.S.K., Patil SV and Jayappa J. 2018. Effect of enriched biochar on growth of mango seedlings in nursery. International Journal of Chemical Studies; 6(6): 415-417.

Kadman, A. and Gazit, S. 1984. The problem of iron deficiency in mango trees and experiments to cure it in Israel. Journal of Plant Nutrition, **7:** 283-290.

Kirkby, E.A. and Pilbeam, D.J. 1984. Calcium as a plant nutrient. Plant Cell and Environment, 7:397-405.

Koo, R.C.J. and Young, T.W. 1972. Effects of age and position on mineral composition of mango leaves. J. Amer. Soc. Hort. Sci., 97(6): 792-794.

Kostermans, A.J.G.H. and Bompard, J.M. 1993. The mangos, their Botany, Nomenclature, Horticulture and Utilization. Academic Press. London. 233 pp.

Kumar, N. Mango in India. Maximising yield and quality through adequate cultivation and nutrient management. Sulphate of Potash Information Board. www.sopib.com.

Kumar, S. and Nauriyal, J.P. 1977. Nutritional studies on mango – tentative leaf analysis standards. Indian Journal of Horticulture, 34**:** 100-106.

Laborem, G.E., Avilán, L.R. and Figueroa, M. 1979. Extracción de nutrientes por una cosecha de mango (*Mangifera indica* L.). Agron. Trop., 29 (1): 3-15.

Leigh, R.A. and Wyn Jones, R.G. 1984. A hypothesis relating critical potassium concentrations for growth to the distribution and functions of this ion in the plant cell. New Phytologist 97:1-13.

Levin, A. 2017. Ch. 10 Improving fertilizer and water-use efficiency in mango cultivation. In Achieving sustainable cultivation of mangos (Galán Saúco, V. and Lu, P. (eds.) Burleigh Dodds Science Publishing, Cambridge, UK: 269-312.

Littlemore, J.; Winston, E.C.; Howitt, C.J.; O’Farell, P. and Wiffen, D.C. 1991. Improved methods for zinc and boron applications to mango (*Mangifera indica* L.) cv.

Kensington Pride in the Mareeba-Dimbulah district of North Queensland. Australian Journal of Experimental Agriculture, 31**:** 117-121.
Litz, R.E. 2009.The Mango, Botany, Production and Uses. 2nd edition- CAB International. Wallingford. U.K.
Mango Production Guide. Undated. Department of Agriculture. Bureau of Plant industry, Manila. Th ePhilippines. https://www.bdi.da.gov.ph. Downloaded 15/11/2019
Ma, X., Yao, Q., Ma, H., Wu, H., Zhou, Y. and Wanga, S: 2018. Relationship between Internal Breakdown and Mineral Nutrition in the flesh of 'Keitt' mango. Acta Horticulturae 1217: 351-355.
Marchal. J. 1991. Détermination des besoins en engrais du manguier dans le Nord de la Côte d'Ivoire. Bilan mineral du manguier cultivar Amélie. Rapport d'étude IRFA/CIRAD, 19 avril 1991. CIRAD Montpellier. 20 p.
McKenzie, C.B. 1995. Field survey method for determining mango leaf norms. South African Mango Growers' Association Yearbook, **15:** 48-53.
Majunder, P.K.and Sharma, D.K. 1985. Mango. In**:** Bose, T.K. and Mitra, S.K. (eds.). Fruits: Tropical and Subtropical. Naya Prokash. Calcuta: 1-62.
Marschner, H. 1995. Mineral Nutrition of Higher plants. 2nd edn. Academic Press. London.
McKenzie, C.B. 1993. The background skin colours of exported mango fruit in relation to tree nitrogen status. South African Mango Growers' Association Yearbook, 14**:** 20-28.
McKenzie, C.B. 1995. Field survey method for determining mango leaf norms. South African Mango Growers' Association Yearbook, 15: 48-53.
Medina-Méndez, J., Volke-Halle, V., Cortés-Flores, J. I., Galvis-Spínola, A., González-Ríos. J. and Santiago-Cruz, J. 2014. Estado Nutrimental y Producción de Fruto de Mango (*Mangifera indica* L.), cv. Tommy Atkins en Suelos Luvisoles del Estado de Campeche, México. Chapingo Serie Horticultura 20(3): 253-268.
Medina Urrutia, V.M. 1994. Poda y aspersión de nitrato de amonio para adelantar la cosecha de mango en Colima. 11° Congreso Latinoamericano de Genética y XV Congreso de Fitogenética Memorias. Sociedad Mejicana de Fitogenética A.C.: 209.
Medina-Urrutia, V. M., Vázquez-García, M. and Virgen-Calleros, G. 2011. Organic Mango Production in Mexico: Status of Orchard Management. Acta Horticulturae 894: 255-263.
Meurant, N.; Holmes, R.; MacLeod, N.; Fullelove, G., Bally., I.S.E: and Kernot, I. 1998. Mango Information Kit. Agrilink Series Queensland Department of Primary Industries. Nambour. Australia.
Mosqueda-Vázquez, R. and. de los Santos de la Rosa, F. 1981. Aspersiones de nitrato de potasio para adelantar e inducir la floración del mango cv. Manila en México. Proceedings of the Tropical Region of the American Society for Horticultural Science, 25**:** 311-316.
Mostert, P.G. and, Abercrombie, R.A. 1998. Soil requirements and soil preparation. In**:** E.A. de Villiers (ed.). The Cultivation of Mangos. Institute for Tropical and Subtropical Crops ACR. LNR.: 19-26.
Narwadkar, P.R. and Pandey, R.M. 1989. Studies on the Phosphorous translocation in Mango with special reference to alternate bearing. Acta Horticulturae. 231: 440-447.
Nartvaranant, P., Subharabandhu, S. and Whiley, AW. 2002. Effect of soil boron appication on gummosis and leaf boron content of mango (*Mangifera indica* L) cvs. Khieo Sawoei and Nan Dok Mai. Acta Horticulturae. 575: 875-879.

Nguyen, H., Hofman,P., Holmes, R., Bally, I.S.E., Stubbins,B. and McConchie, R. 2004. Effect of nitrogen on the skin colour and other quality attributes of ripe 'Kensington Pride' mango (*Mangifera indica* L.) fruit. Journal of Horticultural Science and Biotechnology 79(2). DOI: 10.1080/14620316.2004.11511749.

Ningning, C., Dian, L., Zhiq,i L., Heli, H. and Xi, Y. 2010. Research on the Rules of Nutrition Content in Jinhuang Mango Leaves in Hainan. Chinese Agricultural Science Bulletin 26(8): 305-309. In Chinese with English abstract.

Ningning, C.Dian, L., Heli, H., Xi, Y., Jie,X and Jianming, L. 2011. Research on the Annual Accumulation of Dry Matter and Nutrient in 'Jinhuang' Mango in Hainan. ChineseAgricultural Science Bulletin 27(22):243-246. In Chinese with English abstract.

Núñez-Elisea, R. 1986. Producción temprana de mango 'Haden' y 'Manila' con aspersiones de nitrato de potasio. Secretaría de Agricultura y Recursos Hidráulicos (SARH). Instituto Nacional de Investigaciones Forestales y Agropecuarias. Centro Estatal de Investigaciones Forestales y Agropecuarias. Campo Agrícola Experimental de Tecomán. Tecomán. Colima. México. Folleto para productores, 8: 9 pp.

Núñez-Elisea, R. 1988. Nitrato de amonio: nueva alternativa para adelantar la floración y cosecha del mango. Secretaría de Agricultura y Recursos Hidráulicos (SARH). Instituto Nacional de Investigaciones Forestales y Agropecuarias. Centro Estatal de Investigaciones Forestales y Agropecuarias. Campo Agrícola Experimental de Tecomán. Colima. México. Desplegable para productores, 8: 1 p.

Oldoni, F.C.A, Lima, A.M.N., Cavalcante, I.H.L., de Sousa, K. dos S.M., Carneiro, M.A. and de Carvalho, I.R.B. 2018, Rev. Bras. Frutic. Jaboticabal, 2018, 40 (3): (e-622). DOI: http://dx.doi.org /10.1590/0100-29452018622.

Oosthuyse, S.A. 1997a. Effect of KNO_3 sprays to flowering mango trees on fruit retention, fruit size and fruit quality. Acta Horticulturae 455: 359-366.

Oosthuyse, S.A. 1997b. relationship between leaf nutrient concentration and cropping on fruit quality in mango. South African Mango Growers'Association Yearbook 17: 1-15.

Oosthuyse, S.A. 1998. Effect of fertilizefertilizer applications to the soil after harvest on leaf nutrient concentrations in mango. S.A. Mango Growers Assoc. Yearbook 18:10-14.

Oosthuyse, S.A, 2000 a. Cost reduction of powdery mildew control in mango with mono potassium phosphate. Acta Horticulturae 509:719-723.

Oosthuyse, S.A, 2000 a. Determinations of Optimum Leaf Nutrient Concentrations Norms for a number of mango cultivars. South African Mango Growers' Association Yearbook 19 20**:** 8-13

Oosthuyse, S.A. 2000 b. Use of the Remedial Measures Techniques to enhance Fruit Quality in Mango. South African Mango Growers' Association Yearbook 19-20**:** 27-29.

Oosthuyse, S.A, 2006. CropKit. Special Plant Nutrition Guide. Mango. SQM Europe N. V. Belgium. www.sqm.com

Panwar, R. Singh, S.K., Singh, C.P. and Singh, P.K. 2007. Mango fruit yield and quality improvement through fertigation along with mulch. Indian Journal of Agricultural Sciences 77 (10): 680-684.

Peralta-Antonio, Rebolledo-Martínez, N.A., Becerril-Román, A.E., Jaén-Contreras, D. and del Ángel-Pérez, A.L. 2014. Response to organic fertilization in mango cultivars: Manila, Tommy Atkins and Ataulfo. J. Soil Sci. Plant Nutr 14 (3) Epub 02-Ago-2014. http://dx.doi.org/10.4067/S0718-95162014005000055.

Peralta-Antonio, N., Becerril-Román, A., Rebolledo-Martínez, A. and Jaén-Contreras. D. 2015. Estado nutricional foliar de tres cultivares de mango fertilizados con abonos orgánicos. Idesia (online) 33 (3): 65-72. http://dx.doi.org/10.4067/S0718-34292015000300010.

Pinto, P.A. da C. Avaliação do estado nutricional da mangueira Tommy Atkins pelo DRIS e da qualidade pós-colheita de frutos no Submédio São Francisco. 2002. 124p. Dissertação (Doutorado) - Universidade Federal de Visçosa, Visçosa.Brazil.

Pinto, A. C, de Q., Ramos, V.H.V., Junqueira, N.V., Lobato, E. and de Souza, D. M. 1994. Relaçao Ca/N nas folhas e seu efeito na produçao e qualidade da manga 'Tommy Atkins' sob condiçoes de Cerrados . Abstract Congresso Brasileiro de Fruticultura 13, Salvador, Bahía. Brazil: 763.

Prakash, K., Vijayakumar, R.M., Balamohan, T.N. and Sundhar Singh, S.D. 2015. Effect of Drip Irrigation Regimes and Fertigation Levels on Yield and Quality of Mango Cultivar 'Alphonso' under Ultra High-Density Planting. Acta Horticulturae 1066: 147-150.

Prasittikhet, D., Ruencharoen, S., Hinthao, U. and Luksanawimol, P. 2000. Preliminary study of Fertigation of Khiew Sawoey Mango. Acta Horticulturae 509:315-320.

QDAF. 2015.Food for Fruit – Nutrition management in mangos. AMIA. Part 1 – General Mango Nutrition and Part 2 – Designing a mango fertilizer program. www.industry.mangos.net.au/resource-collection/food-for-fruit-nutrition.

Quaggio, J.A. Adubação e calagem para a mangueira e qualidade dos frutos. In: São José, A.R.; Souza, I.V.B.; Martins Filho, J.; Morais, O.M. (ed.) Manga, tecnologia de produção e mercado. Vitória da Conquista: DBZ/UESB, 1996. p.106-135.

Radanachaless, T. and Tiyayon, C. 2017. Good Agricultural Practices for Mango, Community Version 2, Chiang Mai Mango Growers Group Community Enterprise. 2nd edition. Center for Agricultural Resource System Research, Faculty of Agriculture, Chiang Mai University. 93 p. (in Thai).

Raghupathi, H.B., Reddy,Y.T.N, Kurian Reju, M. and Bhargava, B.S. 2004. Diagnosis of Nutrient Imbalance in Mango by DRIS and PCA Approaches. Journal of Plant Nutrition, 27:7, 1131-1148.

Rajput, M.S., Chadha, K.L. and Thakur, R.S. 1985. Standardization of leaf sample size for nutrient analysis in mango. Indian Journal of Horticulture, 42**:** 210-212.

Raj, G.P. and Rao, A.P.2006. Identification of Yield-Limiting Nutrients in Mango through DRIS Indices. Communications in Soil Science and Plant Analysis, 37: 1761–1774.

Raja, M.E., Kumar, S: C: A. and Raju, S.Y. 2005. Boron deficiency in mango (*Mangifera indica* L.) a cause delineation study in acidic soils of Maharashtra. India. Soil Science and Plant Nutrition 51:751-754.

Ram, S., Bist, I.D. and Sirohi, S.C. 1989. Internal fruit necrosis of mango and its control. Acta Horticulturae 231: 805-813.

Reuter, D.J. and Robinson,J. B. 1986. Plant Analysis – an Interpretation Manual. Iakarta Press. Melbourne.

Reuveni, M. Harpaz, M. and Reuveni, R. 1998. Integrated control of powdery mildew on field grown mango tress by foliar sprays of mono-potassium phosphate fertilizer, sterol inhibiter fungicides and the strobilurin kresosym-methyl. European Journal of Plant Pathology 104: 853-860.

Rhuele, G.D. and Ledin, R.B. 1955. Manga growing in Florida. Florida Agriculture Experiment Station. Bull 574.

Ríos, R. and Corella, F. 1999. Manejo de la nutrición y fertilización del mango en Costa Rica. Conferencia 83. XI Congreso Nacional Agronómico / III Congreso Nacional de Suelos: 277-290. .www.mag.go.cr/congreso_agronomico_xi/a50-6907-III_277.pdf Downloaded at 05/08/2019

Robbert, J.P. and Wolstenholme, B.N. 1993. Phenological cycles and seasonal carbohydrate fluctuations of three mango cultivars: An update on current research in the Nkwalini Valley, Natal. South African Mango Growers' Association Yearbook, 13**:** 2-10.

Robbert, J.P., De Wet, E. and Coetzer, L.A. 1988. The influence of temperature and boron on pollen tube growth in mango. South African Mango Growers' Association Yearbook, **8:** 4-6.

Rosssetto, C.I., Furlani, P.R., Bortoleto, N., Quaggio, J.A. and Igue, T. 2000. Differential response of mango varieties to boron. Acta Horticulturae 509. 259-264.

Salazar-García, S., Medina-Torres, R., Ibarra Estrada, M. E., & González-Valdivia, J. (2018). Appropriate leaf sampling period for nutrient diagnosis in three mango cultivars. Revista Chapingo Serie Horticultura, 24(3), 167-179. doi: 10.5154/r.rchsh.2017.09.035

Salisbury, F B. and Ross, C.W. 1992. Plant Physiology. Watdsworth. Belmont. California.

Samra, J.S. and Arora, Y.K.1997. Mineral nutrition. In Litz, R.E. (ed.). The Mango, Botany, Production and Uses. CAB International. Wallingford. U.K: 175-201.

Samra, J.S.; Thakur, R.S. and Chadha, K.L. 1977. Effect of foliar application of urea on yield and yield parameters of mango. Indian Journal of Horticulture, 234 (1): 26-29.

Santasup, C. 2013. Nutrient Management. p. 227-238. In Radanachaless, T., Kampuan, W. and Jaroenkit, T. Mango: Production and Postharvest Technology. Postharvest Technology Innovation Center, Office of the Higher Education Commission, Chiang Mai. (in Thai).

Schaffer, B.; Larson, K.D.; Snyder, G.H. and Sánchez, C.A. 1988. Identification of mineral deficiencies associated with mango decline by DRIS. HortScience, 23**:** 617-619.

Schaffer, B.; Whiley, A. W. and. Crane, J.H. 1994. Mango. In: Schaffer, B. and Andersen. P. (eds.). Handbook of Environmental Physiology of Fruit Crops. Library of Congress. United States of America: 165-198.

Scholefield, P.B., Oag, D.R. and Sedgley, M, 1986. The relationship between vegetative and reproductive development in the mango in Northern Australia. Australian Journal of Agricultural Research 37:425-433.

Sen, P.K., Roy, P.K. and De, B.N. 1947. Hunger signs on mango: Indian Journal of Horticulture 5: 35-44.

Sergent, E. and Leal, F. 1989. Flowering induction in mango (*Mangifera indica,* L.) with KNO_3. Revista de la Facultad de Agronomía. Universidad central de Venezuela 16:17-32.

Sergent, E.,Ferrari, D. and Leal, F.1996. Effects potassium nitrate and paclobutrazol on flowering induction and yield of mango (*Mangifera indica* L.) cv. Haden. Acta Horticulturae 455:180-187.

Shinde, A. K., Dabke, D: J., Jadhav, B.B., Landalkar, M.P. and Burondkar, M.M. 2006. Effect of dose and source of potassium on yield and quality of Alphonso mango (*Mangifera indica* L.). Indian Journal of Agricultural Science 76: 213-217.

Silva, D. J.; Pereira, J. R.; Mouco, M.A. do C., Albuquerque, J.A. de; Raij, B, Silva, C. A. 2004. Nutrição mineral e adubação da mangueira em condições irrigadas. Petrolina: Embrapa Semi-Árido. 13 p. (Embrapa Semi-Árido, Circular Técnica, 77).
Silva, D. J., Quaggio. J. A. ,Pinto, P. A. da C. ; Pinto, A.C. de Q. and Magalhaes, A. F. de J.. 2002. Capítulo 10. Nutriçao e Adubaçao. In**:** Genú, P. J. C. y Pinto. A. C. Q: (eds.) . A Cultura da Mangueira. Embrapa Informaçao Tecnológica. Brasilia: 191-222.
Silva, D. J., Wadt, P.G.S. and Mouco, M.A. do C. 2012. Diagnose foliar da cultura da manga In**:** Prado, R., de M, (ed.). Nutriçao de plantas: diagnose foliar em frutiferas. Jaboticabal. UNESp. Facultade de CiEncias Agrárias e Veterinárias. Zh.12:311-342.
Singh, L. B. 1959. Biennial bearing in mango related to the ehemieal cornposition of shoots. Hort. Adv., 3 : 50-75.
Singh, L.B. 1960. The mango, botany, cultivation and utilisation. World Crops Books. Interscience Publishers. Nueva York: 438 p.
Singh, R. 1969. Biennial bearing in mango (*Mangifera indica* L.). Studies on apical dominance, flowering and fruit growth. Ph.D. thesis, IARI, New Delhi.
Smith, P.F. and. Scudder, J.R. 1951. Some studies of mineral deficiency symptoms in mango. Proceedings of the Florida State Horticultural Society, 64**:** 243-248.
Sohi, S. Loez-Capel, E., Krull, E. and Bol, R. 2009. Biochar’s roles in soil and climate change: A review of research needs”. CSIRO Land and Water Science Report 05/09, 64pp.
Stanley, R. G. and Lichtenberg, E.A. 1963. The effect of various boron compounds on *in vitro* germination of pollen. Physiologia Plantarum 16:337-346.
Stassen, P.J.C.; Janse Van Vuaren and Davie, J.S. 1997a. Macroelements in mango trees. Requirements Guidelines. South African Mango Growers’ Association Yearbook, **17:** 20-24.
Stassen, P.J.C., Janse Van Vuaren and Davie, J.S. 1997c. Uptake, distribution and requirements of macro elements in Sensation mango. South African Mango Growers’ Association Yearbook 17**:** 16-19.
Stassen, P.J.C., Mostert, P.G. and Smith, B.L. 1999. Mango tree nutrition. A crop perspective. Neltropika Bulletin 303:41-51.
Stassen, P.J.C.; Grove, H.G.,and Davie. S.J. 2000. Macroelements in mango trees. Acta Horticulturae,509(1): 365-374.
Suktamrong, A., O. Surayapan, P. Laksanawimol, J. Prasitket, R. Khamlert and Fuangchan, S. 2002. Plant nutrition management for mango yield increase and quality control. Final report. The Thailand Research Fund (TRF), Bangkok. 282 p. (in Thai).
Tiwari, J.P. and Rajpit, C.B.S. 1975. Significance of nitrogen on the gr0wth, flowering and Fruiting of mango cultivars. Acta Horticulturae, 57:29-36.
Tomlinsom, I.R. and Smith, B.L. 1998. Principles of liming and fertilization. In: E.A. de Villiers (Ed.). The cultivation of Mangos. Institute for Tropical and Subtropical Crops. Nelspruit. South Africa: 91-103.
Tong Kwee. L. and Khay Chong, K. 1985. Diseases and Disorders of Mango in Malaysia. Tropical Press SDN. BHD. Kuala Lumpur. Malaysia
Tongumpai, P., Charnwichit, S., Srisuchon, S., Subhadrabandhu, S. and Ogata, R. 1997. Effect of thiourea on terminal bud break of mango. Acta Horticulturae, 455:71-75.

Vásquez Hernández, A., Meneses Márquez, I. and Cabrera Mireles. H. 2011. Nutrición en Mango. In Memoria IV Jornada de transferencia de tecnología en el cultivo del mango. Fundación Produce Sinaloa, A.C: 43-56.
Vincenot D., 2003. Elaboration et développement d'un programme de lutte intégrée en vergers d'agrumes et de manguiers à l'île de La Réunion. Mémoire de fin d'étude d'ingénieur, Ecole Nationale Supérieure Agronomique de Montpellier, France, 67 p. + annexes.
Vincenot D. (ed) and Normand F. (ed) 2009. Guide de production intégrée de mangues à La Réunion. CIRAD et Chambre d'Agriculture de la Réunion, Saint-Pierre, Ile de la Réunion, 122 p.
Wolstenholme, B.N. and Robbert, J.P. 1991. Some horticultural aspects of the mango yield. Problems and opportunities for research. South African Mango Growers' Association Yearbook, **11:** 11-16.
Wadt, P.G.S. 1996. Os métodos da chance matemática e do sistema integrado de diagnose e recomendação (DRIS) na avaliação nutricional de plantios de eucalipto. 1996. 99p. Dissertação (Doutorado) - Universidade Federal de Viçosa, Viçosa.
Walworth, J.L and Sumner, M.E. The diagnosis and recommendation integrated system (DRIS). Adv. Soil Sci., 6, 149–188.
Whiley, A.W. 1984. Crop Management – A review. Proceedings First Australian Mango Research Workshop. Cairns. Queensland. 26-30 November 1984: 186-195.
Whiley, A.W. and Schaffers, B. 1997. Stress Physiology. In**:** Litz, R.E. (ed.). The Mango, Botany, Production and Uses. CAB International. Wallingford. UK.: 147-176.
Xiao- Tian, L., Dian, L., Hua-dong, L. and Zheng, Y. 2013, The rules of nutrition contend of N P K in Tainong mango. China Academic Journal Electronic publishing office (http://www.cnki.net) doi: 10. 11838/sfsc. 20130613. In Chinese with English abstract.
Yara. Undated. Tropical Fruit Tree Plant Master. www.yara.com. Downloaded 25/05/2018.
Young, T.W. and Koo, R.C.J. 1969. Mineral composition of Florida mango leaves. Proceedings of the Florida State Horticultural Society, 82**:** 324-328.
Young, T.W. Koo, R.C.J. and Miner, J.T. 1962). Effects of Nitrogen, Potassium and Calcium Fertilization on Kent Mangos on Deep, Acid, Sandy Soil. Florida State Horticultural Society: 364-371.
Young, T.W. and Koo, R.C.J. 1974. Increasing mango yield of 'Parvin' and 'Kent' mangos on Lakewoods sands by increased nitrogen and potassium fertilization. Proceedings of the Florida State Horticultural Society. 87: 380-384.
Young, T.W. and Sauls, J.W. 1979. The mango industry in Florida. Florida Cooperative Extension Service Bull, 189: 70 pp.

ANNEX 1. LIST OF INTERVIEWED PEOPLE
(includes not only those answering the survey but also people which not answering the survey has given valuable information for this report)

Australia
Joanne Tilbrook
Plant Industries Development
Department of Primary Industry and Resources
joanne.tilbrook@nt.gov.au
Telephone: +61 8 89992306
www.dpif.nt.gov.a

Brazil
Francisco Pinheiro Lima Neto
EMBRAPA Semiárido
pinheiro.neto@embrapa.br
Telephones (office and mobile): +55 (87) 3866-3600 | + 55 (74) 3617-7117
+ 55 (74) 9-9121-9227

Davi José Silva
EMBRAPA Semiárido
davi.jose@embrapa.br
Telephones (office and mobile): +55.87.3866.3644

Altamir Guilherme Martins
Finobrasa Agroindustrial S/A
altamir@finoagro.com.br
Telephones (office and mobile): +55 84 3335 22 16 y +55 84 99138 42 93

Italo Herbert Lucena Cavalcante
Federal University of São Francisco Valley
italo.cavalcante@univasf.edu.br
Telephones (office and mobile): +55 87 21014865 (office) / +55 87 996798734 (mobile)

Colombia
Diego Miranda Lasprilla
Universidad Nacional de Colombia
(dmirandal@unal.edu.co)
Telephones (office) 57-1-3165000 (ext. 19051) and mobile 57-1-3166259668.

Costa Rica
Jimmy Roberto Gamboa Porras
Private consultant and retired from Instituto Nacional de Innovación y Transferencia de Tecnología Agropecuaria (INTA)
jimgamp@gmail.com
Telephones (mobile): 506-83769773; (home): 506-22754816.

Chile
Jorge Alache González.
Private Consultant
(j-alache@hotmail.com)
Telephones (office) 56-58-2214500 (Mobile): 56-999056617

China
Hongxia Wu

South Subtropical Crops Research Institute Guangdong Province
(whx1106@163.com)
Telephone+86 0759-2859312

Dominican Republic
Mr. Carlos José Jiménez
Ministerio de Agricultura
carlosjimenez21033@hotmail.com
Telephone (office and mobile) (1) 809-547-3888 ext 080/809-714-3832

Egypt
Adel Ahmed Aboul-Saud
Horticulture Research Institute. Cairo
adelaboelsoaud@gmail.com

Ecuador
Diego F. Salvador. G.
Manager of plantings from Durexporta Mango Group
(dsalvador@guitran.com)
Telephones (office and mobile) 593-999401420/593-993735685

France
Dr. Frédéric Normand
CIRAD. Reunion Island
normand@cirad.fr
Telephones (office and mobile) (+262) 262969364/(+262) 692201882

Guatemala
Carmelino García / Alan Pérez
Departamento de Fruticultura y Agroindustria –DEFRUTA-Ministerio de Agricultura, Ganadería y Alimentación –MAGA. Suchitepéquez
alanmangos@yahoo.com
Telephones (mobile) 32140541

Santos Marroquin
Comunidad Agraria La Verde. Chmpanico. Retalhuleu
Telephone 41841951

Mr. Salvin Yac
Finca El Mango.
Comunidad Agraria El Mango. Chmpanico. Retalhuleu
Telephone:49432427

India
P. M. Haldankar
Secretary General & Director of Research
Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli
dorbskkv@rediffmail.com
Telephones (office and mobile) 02358-282417/ 9421809721

Indonesia
Sri Yuliati

Indonesian Tropical Fruit Research Institute
sriyuliati_balitbu@yahoo.com
Telephones (office and mobile) : +62 755-20137/+62 82169924559

Israel

Micky Noy.
Ministry of agriculture. Extension Service. Israel.
mazorknoy@gmail.com
Telephones (office and mobile) 972-506241605

Nurit ben Hagai
Director of the Soil Laboratory for the North East of Israel
nuritgamla@gmail.com

Ivory Coast
Achille Aimé N'da Adopo.
National Agronomic Research Center (CNRA)
(Achille_adopo@yahoo.fr)
Telephones office = 00 (225) 36 86 09 71 and Mobile = 00 (225) 07 09 02 60/02 00 86 46

Japan
Chitose Honsho
University of Miyazaki
chitose@cc.miyazaki-u.ac.jp

Mexico
Víctor Manuel Medina Urrutia. CUCBA-Universidad de Guadalajara
(muv20099@cucba.udg.mx) (vmmedinau@gmail.com)
Telephones (office and mobile): +52-3337771150 ext.33128/3316054252

Samuel Salazar
INIFAP. Nayarit
samuelsalazar@prodigy.net.mx
salazar.avocado@gmail.com

Oman
Rashid Al Yahyai
Sultan Qaboos University
alyahyai@gmail.com
Telephones (office and mobile) +968-24141201

Pakistan
Aman Ullah Malik
Director, Institute of Horticultural Sciences
University of Agriculture, Faisalabad
malikaman1@gmail.com
Telephones (office and mobile) +92-41-9200161-69/2941/2944

Hameed Ullah
Director Mango Research Institute, Multan
mrimultan@yahoo.com
Telephone 92-614423535

Peru

Angel Gamarra Condori
PROMANGO
angeldiga@promango.org
Telephones (office and mobile) +51 073 311054 +51 969686129

Fernando Ché Hidalgo
Dominus SAC
fche@dominus.com.pe
Telephone +51 945131092

Philippines

Pablito M. Magdalita
Institute of Crop Science, UPLB
pabsmagdalita@gmail.com
Telephone 639217648938

Portugal

Luís Dantas
Centro de Experimentação de Fruticultura das Quebradas. Madaira
luis.dantas@madeira.gov.pt
Telephones (office and mobile) +351 291 761211

Puerto Rico

Yair Aron
Martex Farms
yairaron@martexfarms.com
Telephones (office and mobile) 1-787-845-4909/1-787-385-8901

Spain

Pedro Modesto Hernández Delgado. Departamento de Fruticultura Tropical. Instituto Canario de Investigaciones . Islas Canarias
(pmherdel@gmail.com) (pmdelgado@icia.es)
Telephones 34 922923307

José Jorge González Fernández/Ignacio Hormaza Urroz
IHSM La Mayora, CSic. Málaga
ihormaza@eelm.csic.es

South Africa

Pieter Buys
Nyalani Estates (Pty) Ltd. / South African Mango Growers Association.
buyspb@gmail.com
Telephone: +27 82 577 6431

Steve Oosthuyse
Hort Reeaarch SA
hortres@pixie.co.za

Sri Lanka

H.M.S. Heenkenda
Retired Additional Secretary (Agriculture Technology) to the Ministry of Agriculture
subhahkn@yahoo.com
Telephones (office and mobile): 0094812420890; Mobile: 0094714455690

Taiwan

Chang, Chin-Hsing
Institution: Tainan District Agricultural Improvement Station
cschang@mail.tndais.gov.tw
Telephones: office +886-6-5912901; mobile +886-933299047

Thailand

Daruni Naphrom/Chantalak Tiyayon
Department of Plant and Soil Sciences. Faculty of Agriculture, Chiang Mai University
dnaphrom@gmail.com/ chantalak@gmail.com
Telephones (office and mobile) Office 66-53-944-040-1 Mobile 66-85-036-5649

USA

Jonathan H. Crane
University of Florida, IFAS, Tropical Research and Education Center
jhcr@ufl.edu
Telephones (office and mobile) office 786-217-9271, mobile 786-255-5878

Vietnam

Tran Van Hau.
College of Agriculture and Applied Biology, Can Tho University
tvhau@ctu.edu.vn
Telephone: Mobile: 84918 240259

ANNEX 2. MANGO NUTRITION AND FERTILIZATION SURVEY

Name
Institution
Email.
Telephones (office and mobile)

1) How do you establish a FERTILIZATION PROGRAM for a mango plantation?
    A) Based in leaf analysis
    B) Based in soil analysis
    C) Based on both
    D) Based in crop nutrient removal
    E) Having in account A), B) and C)
    F) Following the traditional recommendations in your country
    G) Following literature recommendations
    H) By any other way
2) CROP NUTRIENT REMOVAL

If you have unpublished data for your area /country please fill the table below, indicating if possible, cultivar, rootstock and soil type to which the values refer If you have published data, please give the reference and/or send the published paper.

Element	Nutrient removal per ton produced (kg/ha) (*)
N	
P	
K	
Ca	
Mg	
Fe	
Cu	
Mn	
Zn	
B	

(*) you can give a different unit (i.e. ton/acre)

3) SOIL ANALISYS

If you have unpublished data for your area /country please fill the table below, indicating if possible, cultivar, rootstock and soil type to which the values refer. If you have published data, please give the reference and/or send the published paper.

Element	Level in soil (mg/kg) (*) Low Adequate High
N	
P	
K	
Ca	
Mg	
Fe	
Cu	
Mn	
Zn	
B	

(*) you can give a different unit (i.e. % or cmol/kg)
Please indicate extraction technique

4) FOLIAR ANALISYS

If you have unpublished data for your area /country please fill the table below, indicating if possible, cultivar, rootstock and soil type to which the values refer If you have published data, please give the reference and/or send the published paper.

Element	Leaf concentration (%) (*) Minimum Adequate High
N	
P	
K	
Ca	
Mg	
Fe	
Cu	
Mn	
Zn	
B	

(*) you can give a different unit (i.e. ppm). Please indicate if the values are for young trees or for trees at full production stage and also indicate your sampling norm and season of sampling.

5) In case that you have a standard recommended mango fertilization program for your area/country please describe it or, if you have published data, please give the reference and/or send the published paper.
6) How do you apply nutrients to the mango?
A) By foliar spray
B) To the soil
C) Through fertigation
D) Combining A and B
E) Combining A and C
7) Do you apply nutrients according to the phenology calendar?
8) Did you find any direct relation between a mineral nutrient, fertilizer or mineral relation (i.e. Ca N) and?
   A) Increasing yield.
   B) Flower induction
   C) Fruit set
   D) Fruit quality (size, shape, sugar or acid content…)
   E) Tolerance to cold condition.
   F) Tolerance to Internal Fruit Breakdown
   G) Tolerance to pests or diseases (Please specify)
   H) Shelf life
   I) Any other
9) If you have any specific non-published information about the relations Ca/N, Ca/K, Mg/K, or any other nutrient ratio considered ideal for mangos Please share it with me. If you have published data, about this, please give the reference and/or send the published paper.
10) Do you use chemical fertilizers, organic fertilizers or both? Please indicate which ones and if you apply them through foliar spray, through the soil or through fertigation.
    A) By foliar spray
    B) To the soil
    C) Through fertigation

11) Please indicate if you have any publication (scientific, extension or other) and/or lecture or power point specific for mango fertilization in your country and, if available, please, email it to me or give the reference.

12) If you are working for a Research Centre (private or public) or University please answer the next questions:

A) Are you conducting any research on mango fertilization? Please indicate which type of research.

B) Are you (or somebody at your institution) interested in any line of research on in mango fertilization? Please specify.

C) Are you interested in future cooperative trials mango fertilization.?.

13) Add any comments you wish.

ANNEX 3. SOIL ANALYSIS REPORTED FROM THE SURVEY

Question:

If you have unpublished data for soil analysis in your area /country please fill the table below, indicating extraction technique and, if possible, cultivar, rootstock and soil type to which the values refer If you have published data, please give the reference and/or send the published paper

Element	**Level in soil (mg/kg) (*)** **Low Adecuate High**
N	
P	
K	
Ca	
Mg	
Fe	
Cu	
Mn	
Zn	
B	

(*) you can give a different unit (i.e. % or cmol/kg)

Answer:

No data reported: Reunion Island), Spain Malaga and Canary Islands. Israel, Sri Lanka, Oman, Chile, Puerto Rico, Florida, Ivory Coast, Guatemala, Japan, Colombia, India (*)

Reports from different countries

Mexico.- Cultivars Ataulfo, Manila and Tommy Atkins, polyembryonic criollo rootstock in a soil of pH 6.5

Element	Soil level Experimental (mg/kg) Low Adequate High
N	17.1
P	18,4
K	303,1
Ca	2568,2
Mg	461,8
Fe	23,1
Cu	1,6
Mn	15,3
Zn	1.5
B	

Brazil.-

San Francisco Valley Federal University

Element	Soil level range Adequate
N	<10 mg/kg
P	60-80 mg/kg
K	0.25-0.4 meg/100 g
Ca	3 - 5 meq/100 g
Mg	0.75 – 1.25 meq/100 g
Fe	4 - 100 mg/kg
Cu	0.3 – 10 mg/kg
Mn	4 – 50 mg/kg
Zn	2 – 15 mg/kg
B	1 - 2 mg/kg

EMBRAPA

Element	Soil level (mg/kg) Low	 Adequate	 High
N			
P	< 10	10-40	> 40
K	< 62	62-175	> 175
Ca	<400.........................> 1000		
Mg	< 96.........................> 180		
Fe	< 8	19-30	> 45
Cu	0,3	0.8-1.2	1,8
Mn	2,0	6.0-8.0........12,0	
Zn	0,4	1.0-1.5	2,2
B	0,15	0.36-0.60	0,90

Finobrasa Agroindustrial S.A

Element	Nivel en suelo (mg/kg) (*) Low	 Adequate	 High
N	-	-	-
P – ppm	<10	10 – 20	>20
K – mmolc/dc³	<30	30 – 60	>60
Ca – mmolc/dc³	<10	10 – 20	>20
Mg – mmolc/dc³	< 3	3 – 5	> 5
Fe – ppm	<20	20 – 80	>80
Cu			
Mn – ppm	< 1	1 – 2	> 2
Zn – ppm	< 5	5 – 8	> 8
B	-	-	-

Ecuador.-

Element	Soil level low	 Adequate	 High
N (ppm)	< 20	20-40	>40
P (ppm)	<10	10-20	>20
K) (meq/100ml)	<0.2	0.2-0.4	>0.4
Ca(meq/100ml)	<4	4-8	>8
Mg(meq/100ml)	<1	1-2	>3
Fe (ppm)	< 20	20-40	>40
Cu (ppm)	<1.1	1-4	>4
Mn (ppm)	<5	5-15	>15
Zn (ppm)	>3	2-7	>7
B (ppm)	0.2	0.5-1	>0.49
Cl (ppm)	>17	17-34	>33
Al (meq/100ml)	<0.51	0.51-1.5	>1.5
Na (meq/100ml)	>0.31	0.31-1.0	>1.0
OM (Organic matter) (meq/100ml)	<3.1	3.1- 5.0	>5.0

Peru.-

(Dominus)

Element	Soil level Low	 Adequate	 High
N	1.15%		
P			26.1 mg/Kg
K		172.56 ppm	
Ca			78%
Mg			20%
Fe			62.1 ppm
Cu			13.2 ppm
Mn			6.1 ppm
Zn			16.4 ppm
B		0.3 ppm	

(Promango)

Element	Nivel en suelo (mg/kg) (*) Bajo	 Medio	 Alto
N %	0.01		
P ppm		9	
K ppm		173	
Ca meq	6.23		
Mg meq	1.3		
Fe			
Cu			
Mn			
Zn			
B			

Dominican Republic.-

Element	Soil level(mg/kg) Low Adequate High
N (M.O.)	1.24
P	0.3
K	0.05
Ca	70.3
Mg	28
Fe	0.9
Cu	0.7
Mn	0.7
Zn	0.3
B	

Costa Rica.-

K, P, Mn, Cu, Zn and Fe determination were made with the Olsen modified method (Olsen EDTA) 1:10.

Al, Ca y Mg determination were made with the extract solution se KCl 1N, 1:10.

pH value was measured in water 1:2.5

Ca, Mg as well as the extractable acidity were determined in an extract of solution of ClK 1N, 1:10.

S and B were determined in an extract of $Ca(H_2PO_4)_2$ in H_2O in a proportion of 1:2,5.

N determination was made with the burning method of Dumas

Element	Soil level Low Adequate High
N	0.2-0.3%
P	11-20 mg/l
K	0.21-0.40 Cm(+)/l
Ca	4-20 Cm(+)/l
Mg	1-10 Cm(+)/l
Fe	10-50 Mg/l
Cu	1-20 Mg/l
Mn	5-20 Mg/l
Zn	3-15 Mg/l
B	0.8 ppm

Vietnam.-

Element	Level in soil (mg/kg) (*) Low Adequate High
N_{total}	Low yield: 0.11% Medium: 0.13% High: 0.22% Very high: 0.29%
P_2O_{5total}	Low yield: 0.20% Medium: 0.17% High: 0.14% Very high: 0.18%
P_2O_5 exchange	Low yield: 6.85 mg/100 g soil Medium: 7.11 High: 7.73 Very high: 13.63
Ktotal	Low yield: 1.54% Medium: 1.46% High: 1.59% Very high: 163%
$Ca_{exchange}$	10.32 meq/100 g 9.52 11.44 15.24
$Mg_{exchange}$	3.45 meq/100 g 4.41 4.71 5.85

Thailand.-

Data from Deewan and Popan. (2015). Soil samples collected from GAP orchards at 0-30 cm depth. Extraction technique followed methods in: Soil Sciences Staff. 1998. Elementary Soil Sciences, 9th edition. Faculty of Agriculture, Kasetsart University, Bangkok. (in Thai)

Element	Level in soil (mg/kg) (*) Low Adequate High		
	Mango plant ages		
	4-6 years	7-12 years	13-16 years
N	-	-	-
P	3.15	3.04	1.45
K	28.7	23.0	38.0
Ca	988.0	2189.0	1729.0
Mg	278.0	221.0	443.0
Fe	6.68	16.3	19.5
Cu	-	-	-
Mn	5.83	47.7	58.3
Zn	0.14	0.07	0.13
B	-	-	-

China (Mainland).-

Element	Level in soil (mg/kg) (*) Low	Adequate	High
N	14.85	57.81	102.39
P	3.71	11.98	32.03
K	20.50	72.42	141.50
Ca	30.69	143.60	253.30
Mg	4.55	9.85	20.20
Fe	6.32	26.39	59.95
Cu	0.31	1.25	3.64
Mn	12.44	46.89	99.89
Zn	0.21	2.27	5.35
B	131.0	350.35	596.00

China (Taiwán).-

Element	Level in soil (mg/kg) (*) Low Adequate High
N	Not determined
P	20~100
K	80~180
Ca	570~1145
Mg	48~97
Fe	-
Cu	< 20
Mn	-
Zn	<50
B	Not determined

Indonesia
Ultisol of Situbondo, East Java

Element	Method	Level in soil
N (%)	Kjeldhal	0.15 (low)
P (%)	Olsen	1.6 (low)
K (%)	Morgan	1.67 (low)
Ca (cmol/kg)	NH4-acetate 1 N pH 7	20.99 (adequate)
Mg (cmol/kg)	NH4-acetate 1 N pH 7	6.31 (adequate)
Fe (mg/kg)	DTPA	14.31 (high)
Cu (mg/kg)	DTPA	1.8 (high)
Mn(mg/kg)	DTPA	33 (high)
Zn (mg/kg)	DTPA	1.0 (adequate)
B (mg/kg)	DTPA	0.5 (adequate)

Pakistan.-

Element	Level in soil (mg/kg) (*) Low	Adequate	High
N (Organic Matter %) Walkey-Black	< 0.86	1.29	>1.29
P ($NaHCO_3$ Method)	<8	8-15	> 15
K(NH_4OAc)	<100	100-150	>150
Ca	-		
Mg	-		
Fe (DTPA)	<4.5	>4.5	
Cu (DTPA)	<0.2	0.2-0.5	>0.2
Mn (DTPA)	<1.0	1.0-2.0	>2.0
Zn (DTPA)	<0.5	0.5-1.0	>1.0
B (HCl)	<0.45	0.45-1.0	>1.0

South Africa.-

(ideal soil conditions):

Element	Soil level Low	Adequate	High
N (M.O.)			
P (ppm)		30-60	
K (%)		7.5-9	
Ca (%)		65-70	
Mg (%)		15-20	
Fe (ppm)		10-20	
Cu (ppm)		1-2	
Mn (ppm)		6-10	
Zn (ppm)		4-10	
B (ppm)		0.5-2	
Na		<1	
S (ppm)		<20	

Cation exchange (CEC) per soil type in c mol (+)/kg:

Soil type	CEC
Sand	1.5-7
Loam	8-25
Turf (high clay%)	20-60
Kaolinitic clay	5-15
Iolite clay	15-40
Montmoillonite clay	40-120
Humic	100-400

Madeira (Portugal).-

Element	Soil level Low Adequate High
N	
P	183 ppm
K	936 ppm
Ca	18.4 meq/100g
Mg	8.1 meq/100g
Fe	150 ppm
Cu	8 ppm
Mn	260 ppm
Zn	10 ppm
B	0,7 ppm

Egypt.-

Element	Level in soil (mg/kg) (*)		
	Low	Adequate	High
N (%)	<1	1-.1.5	2.3-5
P (ppm)	<20	20-30	>40
K (ppm)	50-100	100-150	>300
Ca (ppm)	<1000	1000-1500	>2000
Fe (ppm)	<3.5	3.5-5.5	>7.5
Cu (ppm)	<0.5	0.5-1.0	>1.5
Mn (ppm)	<1	1.1.5	>3.0
Zn (ppm)	<0.5	0.5-1.0	>1.5
B (ppm)	0.25	0.25-0.50	>1.25

ANNEX 4. ESTABLISHMENT OF FERTILIZATION PROGRAMS IN DIFFERENT COUNTRIES

Question; How do you establish a fertilization program for a mango planting?

A) Based in leaf analysis
B) Based in soil analysis
C) Based on both
D) Based in crop nutrient removal
E) Having in account A), B) and C)
F) Following the traditional recommendations in your country
G) Following literature recommendations
H) By any other way

Answer:

Based in leaf analysis
Malaga
Based in soil analysis
Sri Lanka, Madeira, Thailand, Guatemala, Japan, Israel
Based on both
Indonesia, Mexico, Florida, Pakistan, Dominican Republic, Ivory Coast, South Africa, Taiwan, Puerto Rico, Costa Rica, Vietnam, Egypt, Australia, Peru, Colombia. Brazil, Ecuador, Guatemala, Canary Islands
Based in crop nutrient removal
Costa Rica, Thailand, Philippines (1)
Having in account A), B) and D)
Costa Rica, Vietnam, Egypt. Australia, Peru. Colombia, Brazil. Ecuador, Philippines
Following the traditional recommendations in your country, Puerto Rico
France (Reunion Island), Israel, Thailand, India, Guatemala, Florida, Ivory Coast, Japan, Taiwan, Philippines
Following literature recommendations
Costa Rica, Oman, Florida, Chile, China, Philippines
Other way
Israel and Brazil (expected yield), Ivory Coast (colour and quality of the pulp of mango)

(1) **Fertilization based on nutrient crop removal** for 'Carabao' mangos (Lifted from lecture of Dr. Calixto Protacio on Crop Physiology as Applied to Off-season Production of Mango)

'Carabao' fruits contain 0.3 - 0.15 - 3.0 kg of NPK / ton

A) Nutrient extraction /ha

• If yield is 6 tons/ ha, multiply the above by 6=1.8- 0.9- 18 kg of NPK removed per ha
• If yield is 10 tons/ha, multiply the above by 10 = 3.0 - 1.5 – 30 kg of NPK removed per ha

B) Amount of fertilizer needed per tree:

Divide the above by no. of trees/hectare

• If 100 trees per hectare, then = .03 N - .015 P – 0.3 K equivalent to
65 g urea – 70 g superphosphate- 500 g muriate of potash/tree
• If your yield triples to 30 tons/ha, then the amount of fertilizer will have to be multiplied by
For big trees:
• If your planting density is 25 trees/ha (at 20x20 m), then the amount of fertilizer needed
= 260 g urea + 280 g superphosphate + 2,000 g muriate of potash
(this is also the amount to apply if your tree yields 400 kg fruits)

ANNEX 5. FOLIAR ANALYSIS. SURVEY RESULTS.

Question

If you have unpublished data for your area /country please fill the table below, indicating if possible, cultivar, rootstock and soil type to which the values refer. If you have published data, please give the reference and/or send the published paper.

Element	**Leaf concentration (%) (*)** **Minimum Adequate** **High**
N	
P	
K	
Ca	
Mg	
Fe	
Cu	
Mn	
Zn	
B	

(*) you can give a different unit (i.e. % o cmol/kg)
Please indicate extraction technique

Answer

No data reported: Madeira, Israel, Costa Rica, Sri Lanka, Oman, Japan. Indonesia, Guatemala, Chile, China. Some countries like South Africa report punctual analysis of specific farms but those are particular cases and are not included here.

Information from different countries:

<u>Ivory Coast</u>.-

Element	Leaf concentration (% of element in dry matter) (*)		
	Minimum	Adequate	High
N		0.75 - 1.40	
P		**0.1 - 0.17**	
K		0.61 - 1.19	
Ca		1.03 - 1.77	
Mg		0.09 - 0.22	
Fe		0.24 - 0.26	
Cu		0.0056 - 0.009	
Mn		0.017 - 0.037	
Zn		0.002 - 0.006	
B		0.00056 - 0.00085	

Data from MARCHAL. (1991). Cv. Amelie, trees aged 5 years harvest in April 1990, production = 22.2 kg of fruit / tree at 5 years (year of first significant production), meaning 2,222 kg / ha regarding common planting at a density of **100 trees / ha** in Côte d'Ivoire. Analysis of elements was set up in November 1990 (before blooming).

Leaf nutrient content reported from Spain and different Latin-American countries (Values in % for N; P, K, Ca and Mg and in ppm for Fe, Cu, Mn, Zn and B unless specified)

	Mála Adeq .	Brazil (1) Adeq.	Brazil. (2) Mín. Adeq. High	Brazi l (3) Min Max Adeq	Mex (4) Adeq	Peru (5) Min.	Perú (6)	Ec..	PR (7)	DR Adeq
N	1.20- 1.40	1.2– 1.4	<0.8 1.2-1.6 >1.8	<1 1,4 >1.6	1.25- 1.39	1.1	1-1.2 Min.	1.2- 1.6	1.4	1.28
P	0.08- 0.17	0.08- 0.16	<0.05 0.08-0.15 >0.25	- 0.12 -		0.08	0.12 Adeq.	0.1- 0.25	1.25	0.10
K	0.30- 0.80	0.5 -1.0	<0.25 0.6-1.00 >1.20	- 1.2 -	0.84- 1.45	0.8	1.17 Max.	0.4- 1.2	0.6	0.88
Ca	3-5	2 – 3.5	<1.5 2.2-3.5 >5.0	- 3.5 -	0.62- 0.72	0.91	4.1 Max.	2-5	2.5	2.54
Mg		0.25– 0.5	<1 2-4 >8	- 0.3 -	0.07- 0.10	0.51	0.2 Adeq.	0.2- 0.5	0.25	0.30
Fe		5 – 20	<15 10-200	<85 85- 120 >150	68.6- 117	142	74 Min.	50- 200		68
Cu	>5		<5 20-45 >100	- 30 -	15.0- 19.4	7	7 Adeq	10- 50		10
Mn		5 – 10	<10 50-100	<150 600 >800	71.7- 88.0	92	16.5 Max.	50- 250	100	96
Zn	>30 ppm	2 – 4	<10 30-60 >100	<60 80 >100	24.1- 33.5	34	22 Min.	20- 50	75	22
B		> 250	10 40-70 >150	<60 80 >100		143	134 Adeq	25- 100	50	44.3

Abreviations. Mala= Malaga (Spain); Ec. = Ecuador; PR = Puerto rico; DR = Dominican Republic
Adeq = Adequate; Min = Minimum; Max= Maximum.
(1) San Francisco Valley Federal University. These are general values but they also make differences depending in cultivars and phenological phases.
(2) EMBRAPA.Values for trees in full production and for all cultivars;
(3) Finobrasa Agroindustrial S.A
(4) Universidad de Guadalajara. A detailed information on foliar analysis for the main areas of production of Mexico can also be found in http://cesix.inifap.gob.mx/tienda.html
(5) Promango;
(6) Dominus. Sampling of 5´6 months old leaves taken homogeneously from the 4th cardinal sides from the middle third of the tree canopy.
(7) 1.4% of N in Puerto Rico conditions is bringing good results and 2.5% Ca is good for shelf life and internal quality. The range of our soils is mostly 7-8 pH, in this range usually Ca is no problem. They would like to have in their trees 200 ppm of Fe and 75 ppm of Zn. Deficiency of Fe and Zn influences mostly the vegetative stage. The best way to correct this type of deficiencies is applying chelate through the irrigation system.

India.- Data given for leaf nutrient concentrations at different growth stages in different locations (see Annex 6)

Thailand.-

Element	Leaf concentration	
	'Namdokmai'	'Mahachanok'
N	1.22-1.46 %	1.04-1.46 %
P	0.23-0.38 %	0.11-0.22 %
K	0.62-0.91 %	0.88-1.256 %
Ca	1.47-2.19 %	N/A
Mg	0.30-0.37 %	N/A
Fe	48.3-124.9 mg/kg	N/A
Cu	4.14-8.96 mg/kg	N/A
Mn	211-379 mg/kg	N/A
Zn	14.7-34.4 mg/kg	N/A
B	18.8-42.9 mg/kg	N/A
Part of plant	3 to 4 months old mango leaves, the 4th leaf from shoot tip, 8 leaves per plant from around canopy for 15 plants (1-2 years old plant)	Mature leaves from shoot, 3 leaves per plant
Reference	Suktamrong et al. (2002)	Israngkoon na Ayuthaya et al. (2006)

Vietnam.-

Element	Leaf concentration (%) (*) Minimum Adequate High
N	Low yield: 0.66%[b] Medium yield: 0.64%[b] High yield: 1.49%[a] Very high yield: 2.0%[a]
P	0.2 0.3 0.21 0.19
K	0.68 0.78 0.62 0.74
Ca	1.45 1.27 3.21 4.68
Mg	0.14[c] 0.13[d] 0.24[b] 0.35[a]

Taiwan.-

Element	Leaf concentration (%) (*) Adequate	High
N	2.2~2.58	>3.5
P	0.12~0.18	>0.3
K	1.4~1.7	>2.3
Ca	2.5~4.5	>6.0
Mg	0.26~0.5	>1.0
Fe	60~120	>250
Cu	5~16	>50
Mn	25~200	>300
Zn	25~100	>200
B	25~150	>200

Reunion Island.-

Element	Leaf concentration Minimum	High
N (% MS)	1.06	2.32
P (% MS)	0.10	0.31
K (% MS)	0.42	1.29
Ca (% MS)	1.15	3.38
Mg (% MS)	0.18	0.46
Fe (ppm)	58	224
Cu (ppm)	4	33
Mn (ppm)	65	95
Zn (ppm)	13	42

Data from Vincenot (2003). Survey of the nutritional status of 26 unfertilized, more than 10-year old mango orchards carried out in Reunion island in 2000. Soils were ferralitic soils, generally acid with pH ranging between 3.5 and 7.5. Cultivares 'Cogshall' and 'José'. 6-month-old leaves of the terminal growth units sampled (4 leaves per tree, 10 trees per orchard). The sampling period is not known. It was concluded that the general nutritional status of the trees was satisfactory, and that fertilizing is not necessary.

Egypt.-

Element	Leaf concentration (%) (*) Minimum	Adequate	High
N	0.7-0,99	1-1.5	>1.5
P	0.05-0.07	0.08-0.25	>0.25
K	0.25-0.39	0.41-0.9	>0.9
Ca	1.0-1.99	2.0-5.0	>5.0
Mg	0.15-0.19	0.2-0.5	>0.5
Fe	25-49	50-250	>250
Cu	5-6	7-50	>50
Mn	25-49	50-250	>250
Zn	15-18	20-200	>200
B	20-24	25- 150	> 150

ANNEX 6. DIFFERENCES IN LEAF NUTRIENT CONTENT DEPENDING IN LOCATIONS AND PHENOLOGICAL PHASES

India.- Leaf nutrient content at different growth stages in different locations.

1. L-1 Ratnagiri District of Maharastra. Soil type. Lateritic soil

Element	Preflowering	Full Flowering	Egg stage	Harvest
N (total) (%)	1.37 (1.00-1.62)	0.82 (0.67-1.06)	1.43 (0.95-1.93	1.06 (0.75-1.51)
P (total) (%)	0.15 (0.12-0.25)	0.10 (0.06-0.15)	0.10 (0.06-0.13)	0.14 (0.11-0.24)
K (total) (%)	0.33 (0.18-0.55)	0.37 (0.28-0.49)	0.43 (0.27- 0.85)	0.41 (0.12-0.61)
Ca (%)	1.37 (0.84-2.00)	1.43 (1.04-1.88)	1.53 (1.20-2.24)	1.22 (0.68-1.60)
Mg (%)	1.62 (O.62-2.56)	0.94 (0.21-0.95)	0.75 (0.31-1.14)	0.74 (0.21-1.33)
S (total) (%)	0.52 (0.31-0.74)	0.61 (0.33-0.88)	0.66 (0.39-0.75)	0.65 (0.44-1.00)
Fe(total) (ppm)	246.47 (140.1-333.2)	297.35 (105.0-408.1)	392.64 (124.8- 645.3)	235.83 (165.5-362.1)
Mn (total) (ppm)	452.58 (215.9-579.8)	480.98 (292.4-628.7)	464.37 (118.0-643.8)	437.37 (297.8-582.0)
Zn (total) (ppm)	23.93 (13.1-52.5)	17.99 (9.0-22.2)	24.38 (18.7-25.5)	15.83 (12.5-18.2)
Cu(total) (ppm)	16.65 (8.3-31.1)	19.07 (13.1-23.6)	28.72 (19.9-69.1)	37.50 (21.8-59.8)

2. L-2 Ratnagiri District of Maharastra. Soil type. Lateritic soil

Element	Preflowering	Full Flowering	Egg stage	Harvest
N (total) (%)	1.14 (1.00- 1.26)	0.83 (0.67-1.12)	1.18 (0.92-1.37)	0.88 (0.53-1.23)
P (total) (%)	0.16 (0.13-0.19)	0.14 (0.09-0.20)	0.12 (0.09-0.17)	0.15 (0.12-0.18)
K (total) (%)	0.43 (0.32-0.62)	0.49 (0.22-0.65)	0.52 (0.31-0.79)	0.43 (0.34-0.85)
Ca (%)	1.66 (1.00-2.16)	1.87 (1.56-2.20)	1.91 (1.44-2.60)	2.04 (1.12-2.64)
Mg (%)	1.47 (O.20-2.15)	0.83 (0.29-1.41)	0.53 (0.12-0.85)	0.47 (0.07-1.21)
S (total) (%)	0.65 (0.56-0.84)	0.70 (0.51. 1.36)	0.75 (0.49-0.91)	0.71 (0.54-0.88)
Fe(total) (ppm)	202.57 (172.1-263.1)	306.34 (235.2-372.2)	294.69 (200.4- 443.1)	312.40 (108.9-622.3)
Mn (total) (ppm)	392.51 (245.7-478.7)	433.46 (367.8-508.3)	450.69 (322.1-643.8)	429.43 (267.1-560.1
Zn (total) (ppm)	24.04 (19.2-26.4)	30.41 (20.7-95.3	21.43 (16.4-25.1)	15.19 (10.5-20.2)
Cu(total) (ppm)	20.31 (15.1-28.5)	24.01 (18.2-42.1)	9.64 (6.8-14.5)	15.19 (17.8-34.5)

3. L-3 Ratnagiri District of Maharastra. Soil type. Lateritic soil

Element	Preflowering	Full Flowering	Egg stage	Harvest
N (total) (%)	1.10 (0.78- 1.28)	0.89 (0.67-1.12)	1.53 (1.34-1.87)	1.12 0.78-1.68)
P (total) (%)	0.17 (0.13-0,20)	0.15 (0.05-0.20)	0.14 (0.10-0.15)	0.15 (0.12-0.19)
K (total) (%)	0.43 (0.31-0.77)	0.50 (02.4-0.67)	0.49 (0.29-0.69)	0.32 (0.19-0.58)
Ca (%)	1.87 (1.12-3.16)	1.76 (0.64-2.48	2.02 (1.56-2.36)	1.89 (1.28-2.64)
Mg (%)	0.94 (0.28-1.52)	0.67 (0.31-0.99)	0.72 (0.19- 1.14)	0.39 (0.09-0.85)
S (total) (%)	0.43 (0.28-0.61)	0.49 (0.31-0.66)	0.67 (0.49-0.87)	0.55 (0.47-0.65)
Fe(total) (ppm)	210.13 (127.2-244.9)	268.35 (183.3-497.2)	311.97 (212.5- 563.5)	237.63 (202.3-314.3)
Mn (total) (ppm)	471.82 (361.3-478.7)	536.15 (367.8-508.3)	560.86 (462.3-643.8)	484.05 (292.4-638.4)
Zn (total) (ppm)	23.1 (17.6-30.0)	24.04 (16.5-37.9)	22.19 (16.6-34.1)	14.6 (8.2-28.2)
Cu(total) (ppm)	20.98 (15.4-30.8)	19.8 (16.6-23.3)	11.0 (8.4-11.9)	95.0 (63.1-119.1)

4.. L-4 Ratnagiri District of Maharastra. Soil type. Lateritic soil

Element	Preflowering	Full Flowering	Egg stage	Harvest
N (total) (%)	1.15 (0.78-1.37)	0.88 (0.67- 1.09)	1.65 (1.44-1.87)	1.34 (0.86-1.93)
P (total) (%)	0.18 (0.13-0.24)	0.17 (0.10-0.22)	0.15 (0.11-0.19)	0.16 (0.12-0.18)
K (total) (%)	0.33 (0.27-0.47)	0.47 (0.32-0.62)	0.49 (0.34-0.71)	0.29 (0.14-0.44)
Ca (%)	1.55 (1.24-1.96)	1.55 (1.32-2.12)	1.84 (1.24-2.20)	1.49 (0.80-2.32)
Mg (%)	1.41 (0.62-2.22)	0.70 (0.51. 1.36)	0.71 (0.12-1.33)	0.52 (0.2-1.14)
S (total) (%)	0.43 (0.27-0.55)	0.57 (0.37-0.87)	0.70 (0.61-0.97)	0.47 (0.34-0.64)
Fe(total) (ppm)	286.84 (50.4-412.9)	284.33 (204.5-338.3)	485.22 (328.4- 890.8)	295.85 (220.6-464.9)
Mn (total) (ppm)	315.34 (208.8-378.4)	391.17 (315.8-530.9)	379.23 (297.6-473.7)	328.04 (179.2-428.0)
Zn (total) (ppm)	39.1 (15.7-62.5)	30.71 (25.7-36.9)	26.33 (17.7-38.8)	19.05 (13.7-24.6)
Cu(total) (ppm)	27.95 (19.5-37.5)	23.67 (20.6-25.5)	16.07 (10.0-20.0)	91.65 (75.8-108.7)

ANNEX 7. INFLUENCE OF NUTRIENT RELATIONS IN MANGO

Question1:

Did you find any direct relation between a mineral nutrient, fertilizer or mineral relation (i.e. Ca N) and:

A) Increasing yield.
B) Flower induction
C) Fruit set
D) Fruit quality (size, shape, sugar or acid content…)
E) Tolerance to cold condition.
F) Tolerance to Internal Fruit Breakdown
G) Tolerance to pests or diseases (Please specify)
H) Shelf life
I)Any other

Answer:

A) Increasing yield. Madeira, Costa Rica, Sri Lanka, Vietnam, Thailand, Brazil (4), Ivory Coast, Taiwan, Egypt (6). India, Indonesia, Mexico (8), Colombia, Chile, Puerto Rico (12), Pakistan (13), Philippines

B) Flower induction (**): Sri Lanka (2), Vietnam, Oman (3), Thailand, Brazil (4), Egypt (6), India, Guatemala, Mexico (8), Colombia, Dominican Republic, Pakistan (13), Philippines

C) Fruit set: Sri Lanka (2), Thailand, Brazil, Taiwan (5), Mexico (8), Colombia, South Africa (10), Pakistan (13), Philippines

D) Fruit quality (size, shape, sugar or acid content…): Reunion Islands (1), Thailand, Brazil (4), Ivory Coast, Taiwan, China (mainland), Egypt (6), Mexico (8), Colombia, Puerto Rico, Pakistan (13), Philippines

E) Tolerance to cold condition, Brazil (4), Ivory Coast, Chile, South Africa (10)

F) Tolerance to Internal Fruit Breakdown (Ca/N) (*), Spain (Malaga and Canary Islands), Israel, Sri Lanka; Thailand, Brazil, Ivory Coast, Peru, Colombia, Ecuador (9), Chile, Puerto Rico,

G) Tolerance to pests or diseases: Reunion Islands (1), Sri Lanka (2), Brazil (4)

H) Shelf life: Israel, Sri Lanka (2), Brazil (4), Ivory Coast, Taiwan (5), Egypt (6), Guatemala (7), Puerto Rico, China (11), Pakistan (13)

I) Any other

J) No information: Japan

(*) The higher the ratio the lower the incidence of IFB

(**) This is normally related with N leaf content which if excessive favour growth instead of flowering or to the applications of nitrates to favour flowering

(1) High nitrogen and low calcium contents generally affect fruit quality (lower sugar and color) and maturity. Maturity is heterogeneous: one face matures before the other for José, and fruit apex matures before the rest of the fruit for cv. Cogshall. Mango trees with high nitrogen levels are generally more susceptible to scales (*Ceroplastes* sp).

(2) Application of K rich fertilizer prior to flowering to favour flower induction and of Boron to favour fruit set. Application of N rich fertilizer makes the flush more prone to insect and disease damage. Spraying Calcimore-Plus extends shelf life. Application of Ca fertilizer into soil gives this effect in long run.

(3) Application of potassium in the fall to enhance flowering of mango is recommended

(4) The application of potassium fertilizer increase yield. Low N foliar content favours flower induction. The relations N/Ca and N/B have influence on fruit quality and the applications of K, Mg and Mn are positively related to fruit quality. A high Mg content improve cold tolerance. Low Mn leaf content favour the incidence of mango malformation. Better shelf

life with high content of Ca. Based on Quaggio (1996), N/Ca should not exceed 0.5for cultivars of Floridian origin (Tommy Atkins, Kent, Palmer...) ,because if higher favours the incidence of internal fruit breakdown, An equilibrium of the relation between B and N is also recommended because an excess of N difficult the absorption of Boron but there is not an specific limit

(5) Positive influence of Mg/B ratio for fruit set. Positive influence of Ca/N ratio for shelf life.

(6) NO_3K at full bloom increase yield and quality. $(NO_3)_2Ca$ (2%) favours flower induction. Adequate B leaf level favour shelf life.

(7) The ratios Ca/N, Ca/K, N/Mg influences positively flower induction and the ratio Ca/K on increasing shelf life

(8) Several nitrogen and potassium combinations stimulate early flowering, Applying N, K and microelements favours fruit set. Applying K, Ca y Mg during fruiting can increase yield and fruit quality.

(9) Besides the influence of the Ca/N ratio, an increase of B reduces the problem of 'Corte negro' (black cut).

(10) Zn and B plays a big role in pollination and fruit set. K and Ca levels are important for good internal quality.

(11) A great imbalance of nutrient internal breakdown fruits, especially B deficiency, might be the cause of internal flesh breakdown in mango,

(12) N increase growth, flowering and yields, but too much reduces internal quality, shelf life and color. 1.4% of N in their conditions is bringing good results and 2.5% Ca is good for shelf life and internal quality

(13) N, P, K, Zn and B have positive impact in increasing yield, Zn and B have positive impact in increasing flower induction and fruit set, K and Ca have positive impact in increasing fruit quality and shelf life.

Question 2. Please indicate f you have any specific non-published information about the relations Ca/N, Ca/K, Mg/K, or any other nutrient ratio considered ideal for mangos Answer

Non data reported. Madeira, Reunion Islands, Spain (Malaga and Canary Islands, Japan, Taiwan, Thailand, Vietnam, Guatemala, Mexico, Pakistan, India, Puerto Rico, Ecuador, Chile, Dominican Republic, Florida, South Africa

Costa Rica.

They consider optimum the following values of the ratios below

Ca +Mg /K: 10-40
Ca/Mg: 2-5.
Ca/K: 5-25.
Mg/K: 2,5-15

Ivory Coast

Clear antagonism between Ca and Mg. High Ca content in soil and plant would reduce Mg uptake, but would not affect K uptake (Marchal,1991)

Peru (Dominus S.A.C).

An excess of organic matter in the soil may causes cupper deficiency

Egypt

N/Ca ratio should be <0.5

China (mainland)

Relationship between internal breakdown and mineral nutrition in the flesh of 'Keitt'

Colombia

Cation Relations	Ca/Mg	Ca/K	Mg/K	(Ca+Mg)/K
Adequate level	3.00-6.00	15.00-30.00	10.00-15.00	30.00-40.00

ANNEX 8. CROP NUTRIENT REMOVAL (KG/HA) PER TON OF PRODUCTION

Question: If you have unpublished data for your area /country please fill the table below, indicating, if possible, cultivar, rootstock and soil type to which the values refer

Element	**Nutrient removal per ton produced (kg/ha) (*)**
N	
P	
K	
Ca	
Mg	
Fe	
Cu	
Mn	
Zn	
B	

(*) you can give a different unit (i.e. Ton/acre)

Answer

Table 1. Crop nutrient removal reported by countries

	Israel	Costa Rica (1)	Pak.	Brazil (2)	Mexico (3)	Eg.	Thai (**)	Ecua	Perú (4)	Colombia (5)	Ivory Coast (6)	Philip
N	25	24.62	64	1.02/1.0	4.19/1,28	44	5.78	4.25	6.75	100-105	50.12-66.28	0.3
P	5	1.99	16	0.14/0.13	0.79/0.18	8	0.86	0.89	81.5	12-15	42.72-54.91	0,15
K	40	16.99	70	1.7/2.0	7.19/1.97	60	5.56	5.75	70	100-110	42.72-54.51	3
Ca		3.56		0.5/0.25	3.67/0.18	12		7.65	46.8	50-55	90.06-103.95	
Mg		1.62		0.17/0.12	0.03/0.18	4		1.37	21.8	80-90	7.27-12.93	
Fe	50	0.45		/0.001	/0.004			0.42	0.4	10-13	16.15-27.28	
Cu		0.02		0.5/0,001	/0.001			0.46	1.75	12-15	0.38-0.80	
Mn		0.05		0.87/1.8	/0.003			0.42	0.9	25-30	1.03-3.02	
Zn		0.03		/2.7	/0.001			0.47	0.9	10-12	0.27-0.52	
B		0.03		0.66/1.2	/0.008			0.48	1.5	2-3	0.056-0.068	

(1) Tommy Atkins.; (2): First value Cv Palmer, 2nd value unknown cultivar, (3) Cv. Ataulfo. First value in Veracruz; 2nd value in Sinaloa. A detailed information on mango nutrient removal for the main areas of production in Mexico can also be found in http://cesix.inifap.gob.mx/tienda.html; (4) Cv. Kent, on rootstock `Criollo de Cholucanas'. Soil sandy clay loam; (5) Cultivars Tommy Atkins and Keitt in warm areas, with average temperature of 27ºC;

Blank spaces = Data not available.

Country abbreviations. Pakistan (Pak); Egypt (Eg); Thailand (Thai); Philippines (Philip)

(**) Data from Suktamrong et al., (2002) cited by Santasup (2013)

No data reported:
Reunion Island, Spain (Málaga and Canary Islands), Sri Lanka, Vietnam, Oman, Madeira, Japan, India, Guatemala, Indonesia, Florida, South Africa, China (mainland and Taiwan), Puerto Rico, Dominican Republic, Ivory Coast (*)
(*) Data reported in MARCHAL (1991).

ANNEX 9. APPLICATION OF NUTRIENTS AND TREE PHENOLOGY

Question
Do you apply nutrients according to the phenology calendar?

Answer

Yes: Spain (Malaga and Canary Islands), Reunion Island (1), Israel (2), Costa Rica, Sri Lanka, Vietnam, Oman (3), Japan (4), Florida, Pakistan, Peru, Guatemala, Indonesia, Ecuador, South Africa, Chile, Puerto Rico, Dominican Republic, Taiwan, Mexico (5), Thailand, Ivory Coast, (6), Madeira island, Brazil, India, Egypt, Philippines

(1) Nutrients are applied after harvest (January-February) to favor vegetative growth, during flowering (July to September) to favor fruit set, and after fruit set to favor fruit growth (no nitrogen applied at this date to avoid negative effects on fruit quality and maturity, potassium only is applied).
(2) Most of the nutrients are applied after harvest
(3) Only avoid fertilizing during flowering season
(4) Fertilizers are applied three times a year, at post-flowering/fruit setting stage, fruit developmental stage, and post-harvest (before pruning) stage.
(5) At the end of harvest N, P; K and Ca are incorporated to the soil to stimulate growth. At the beginning of flowering and during fruit set N and K formulations and microelements are applied and during fruit growth K, Ca and Mg are applied.
(6) The time of application and the fractionation of the manure are important, they are flexible according to the rainy season in the non-irrigated system (see the table below).

Fractionation of the annual fertilization of the mineral concerned in %

Element	**Percentage of annual fertilization (%)**	**Form of application**	**Time of intake**
Nitrogen	50	On the ground	After harvest
Nitrogen	30	On the ground	Blooming
Nitrogen	20	On the ground	Fruit set
Potassium	50	On the ground	After harvest
Potassium	50	On the ground	Blooming
Phosphore	100	On the ground	Before rainy season
Boron	100	Foliar spray	Before flowering
Zinc	100	Foliar spray	On young vegetative shoots

No: China (mainland)

ANNEX 10. WAY OF APPLYING FERTILIZERS

Question

Do you use chemical fertilizers, organic fertilizers or both? Please indicate which ones and if you apply them through foliar spray, through the soil or through fertigation

Answer

A) By foliar spray (unless specified this refers to microelements)
Reunion Island (2), Costa Rica (5). Sri Lanka (6), Brazil (8), China, Thailand (9). Puerto Rico (10), Costa Rica, Dominican Republic, Pakistan , Chile (14), South Africa, Peru (16), Florida (17), Mexico., India, Philippines (23)

B) To the soil
Madeira (1) Reunion Islands (2), Spain (Malaga (3), Canary Islands (4)), Sri Lanka (6), Vietnam, Oman (7), Brazil (8), Taiwan; China (mainland), Thailand (9), Costa Rica, Pakistan (11), Guatemala (12), Ecuador (13). Chile (14), Colombia (15), South Africa, Indonesia, Florida (17), Japan (18), Mexico (19). India (20), Egypt (21), Philippines (23)

C) Through fertigation
Reunion Island, Spain (Malaga (3), Canary Islands (4)), Sri Lanka (6), Brazil (8), Puerto Rico (10), Dominican Republic. Ecuador (13), South Africa, Peru (16), Florida (17), Mexico, India (22), Philippines (23)

(1) Madeira use Dix 10, Fenix and organic fertilizer with a 9-2.5-3 equivalency and with microelements, humic and fulvic acids

(2) Rarely applied by foliar spray. Only for micronutrients. Soli applications is the most common way to apply fertilization. Chemical fertilizers are generally applied, except in organic orchards where organic fertilizers are used.

Chemical fertilizers are generally NPK fertilizers with an equivalency of (15-12-24), but they recommend better to use single nutrient fertilizers, such as urea, superphosphate and potassium sulfate in order to adjust the quantity brought for each nutrient. Different types of organic fertilizers prepared from plant or animal materials are used. Only few growers use fertigation. Soluble fertilizers are then used, such as urea and potassium sulfate.

(3) Potassium and ammonium nitrates, monoamonium phosphate, potassium sulphate, iron chelate, calcium complex, fulvic and humic acids via fertigation, only Zinc sulphate is applied directly to the soil close to the drippers

(4) Chemicals and organics through fertigation, but organics also directly to the soil.

(5) Foliar sprays only of microelements if necessary. They use chemical fertilizers containing NPK and also in some cases B and other microelements. They also use K-Mag (potassium and magnesium sulphate) and potassium nitrate, calcium carbonate and dolomites as amendments when necessary. If available organic fertilizers are also used but there are difficulties for getting them and in consequence are not much used

(6) By foliar spray: Inorganic/ Chemical fertilizers; To the soil Chemical and organic fertilizers. Through fertigation: Chemical fertilizers.

(7) Both organic and chemicals.

(8) Organics to the soil, chemicals by foliar sprays (microelements, S and K) soil and fertigation

(9) chemicals to the soil or through foliar sprays. Organics to the soil

(10) By foliar sprays microelements. Via fertigation ammonium Sulfate, potassium nitrate and phosphoric acid.

(11) They apply to the soil chemical fertilizers, green manure and organic manure (Farm yard manure, chicken and poultry manure).

(12) only chemical fertilizers usually complex such as 15-15-15, 20-20-20, 12-18-12, 0-46-0, or18-46-0.

(13) To the soil organic fertilizers (vegetal or animal composts). Chemical fertilizers like nitrates, sulphates, mono ammonium phosphate, also to the soil or though fertigation.

(14) To the soil: Urea, monoammonium phosphate, potassium nitrate calcium nitrate, magnesium nitrate. humic and fulvic acids, aminoacids and iron chelates.

Foliar: besides microelements, potassium nitrate for flower induction after removal of the first flowering, algae extract and occasionally calcium nitrate or other source of calcium.

(15) chemicals: Urea, potassium sulphate, potassium nitrate, calcium nitrate, microelements, diammonium, phosphate, (10-30-10).

Organics: only decomposed chicken manure.

(16) Through fertigation: Ammonium nitrate, calcium nitrate, phosphoric acid, boric acid, potassium sulphate, magnesium sulphate, copper sulphate, Zn, Fe and Mn chelates.

Foliar. The same that through fertigation plus crystallised potassium nitrate to induce flowering.

(17) By foliar spray – pre-mixed multi-nutrient liquid materials mixed with water then sprayed.

To the soil – chemical fertilizers, combination chemical – organic (e.g., composted sludge) fertilizers, organic chicken composted manure fertilizers -chelated iron (EDDHA) materials as soil drench

Through fertigation - chelated iron (EDDHA) materials

(18) Mainly chemicals but some growers also put organics.

(19) they use both chemicals and organics like vermicompost 5-10 t ha^{-1}; Bokashi 5-10 t ha^{-1}, and chicken manure at 10 t ha^{-1}

(20) Both organic and chemical fertilizers.

(21) only organics

(22) Not reported in the survey but indicated in the information by K+S fertilizer company

(23) KNO_3 by foliar spray, Urea, superphosphate and muriate of potassium to the soil. Several fertilizers through fertigation mixed with paclobutrazol

.

ANNEX 11. RESEARCH AND/OR INTEREST IN MANGO NUTRITION

Question. If you are working for a Research Centre (private or public) or University, please answer the next questions.

A) Are you conducting any research on mango fertilization? Please indicate which type of research
B) Are you (or somebody at your institution) interested in any line of research on in mango fertilization? Please specify
C) Are you interested in future cooperative trials mango fertilization?

Answer:

A) Perú (Dominus): Trials to evaluate the effect of different foliar sprays on: Increasing external colour of fruits, consistency and firmness of the pulp, uniformity of maturation and size of fruits, protection against sunburn, maturation of shoots and flower induction.
Indonesia: Management of organic-inorganic fertilizer based on soil and leaf nutrient analysis on mango.
Brazil
(San Francisco Valley Federal University). Influence of Ca, B and N in mango.
(EMBRAPA). Use of the DRIS System for better mango fertilization
Pakistan: Impact of Boron on fruit setting and retention. Impact of Phosphorus and Biochar on small trees growth and impact of modified organic fertilizers on mango.
Israel: Fertilization in mango.
Vietnam: Field experiments on mango fertilization.
India: Ongoing experiments:
1. Effect of integrated nutrient management with respect to biofertilizer on yield and quality of mango.
2. Nutritional Survey of mango.
3. Evaluation of substrate dynamics for Integrated Plant Nutrient Management (IPNM) in mango.
4. Fertigation scheduling for quality fruit production of mango.
5. Development of organic package of practice for mango.
6. Fertilizer scheduling for high density planting in mango.
7. Effect of micronutrient on yield and quality of mango.

B) Peru (Dominus): Changes and demand on nutrient concentration during all the phenological phases´.
Indonesia: Management of properly fertigation on ultra-high-density planting on mango.
Guatemala: Relation of fertilization with ‘mango niño’ (embryo abortion)
Ivory Coast: Effect of fertilization in fruit quality and yield,
Florida: Use of more “organic” type materials and improved products and foliar application methodology for Fe applications
Thailand: Effect of fertilization in fruit quality
Mexico (University of Guadalajara): Effect of fertigation in high density plantings.
Brazil:
(San Francisco Valley Federal University). Biostimulation, Pruning and nutrition in relation with the fasis.
(EMBRAPA). Relation between nutrients and nutritional state of mango.

Pakistan: Biofortification of mangos with Fe and Zn and Vitamin A. Nutrient relations to quality issues.
Portugal (Madeira Island). Ratio N/Ca.
Costa Rica. Relation between nutrient extractions and total need of the mango plant in a productive cycle.
Vietnam: Correlation between the concentration of nutrients in the soil, leaves and fruits and yield. Effect of amount of N, P, K to yield, quality and evaluate DRIS system at different ages.
Colombia: Nutrition and flower induction.

C) Yes: Perú (Dominus), Indonesia, Guatemala, Ivory Coast, Florida, Thailand, Mexico, South Africa, Brazil, Pakistan. Portugal, Spain, Oman. Indi, Colombia, Philippines.

D) No: France (CIRAD).