MAGNESIUM FERTILIZATION IN MANGO. GENERAL ASPECTS AND INFLUENCE ON YIELD AND FRUIT QUALITY (LITERATURE REVIEW AND INTERVIEWS).

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TABLE OF CONTENTS

ANNEX 3. 'YARA TROPICAL FRUIT TREE PLANT MASTER'
ANNEX 4. 'KUMAR, N. MANGO IN INDIA MAXIMISING YIELD AND QUALITY THROUGH ADEQUATE CULTIVATION AND NUTRIENT MANAGEMENT'
ANNEX 5. 'INFORMACION MG-FRUTALES-MANGO'
ANNEX 6. 'BALANCED NUTRIENT MANAGEMENT INCLUDING MAGNESIUM AND MICRONUTRIENTS'
ANNEX 7. 'ESTA® KIESERITE A PRODUCT OF NATURE'

BACKGROUND AND INTRODUCTION

Despite Magnesium (Mg) being one of the nine essential macronutrients for growth and reproductive success of plants (Williams and Salt, 2009) and that magnesium ions (Mg^{+2}) are the second most abundant cations in living plant cells (Tanoi and Kobayashi, 2015), little research on the role of Mg in nutrition in crop quality and production, compared with other nutrients, has been done so far (Cakmak and Yazici, 2010). As an example, only 13 papers on magnesium fertilization has been presented in the twelve ISHS symposium dealing with mineral nutrition of plants, only 7 of it dealing with fruit crops, mostly in apples. However, a growing interest on this nutrient is being considered by researchers which recently organized the First International Magnesium Symposium held at Georg.August University. Gottingen. Germany in 2012 (Cakmak, 2013), but again none of the paper presented dealt with mango, nor with other tropical fruit trees, except one in citrus.

The information about magnesium fertilization on mango is also rather scarce as can be deducted from what is written in the main reference books for mango [(de Carvalho Genú and de Queiroz Pinto (2002), Galán Saúco (2008), Litz, 2009)]. Although all of them report appropriate levels of magnesium content in leaves or in soils, none gives specific references to correct the excess or deficiency of magnesium. In fact, the only reference appearing in Galán Saúco (2008) about magnesium fertilization indicates that either 0.8 g of Mg /kg of yield of this element are added to mango trees as part of the fertilizer program in South Africa. Crane et al., (2009), in Litz's book, only cites that dolomite is commonly used in Taiwan to adjust soil acidity and as a Mg supplement, with variable application rates according to soil types from 1 t/ha/year for sandy soils, to 1.5 t/ha/year for loamy or salty soils and 2 t/ha/year for clay soil There is no even any recommendation about magnesium fertilization in de Carvalho Genú and de Queiroz Pinto's book.

There is also a few more specific papers dealing with mango fertilization but, even in them, the information about magnesium is also scarce. Oosthuyse, (2006) in his 'Special Plant Nutrition Guide for Mango' only gives as specific information that Magnesium sulphate is appropriate for both low and high pH soils and that magnesium should be incorporated to the soil during the month preceding flowering. Xiuchong et al. (2012) in China indicate an application rate of 40 g Mg/plant/year for acidic sandy loam soils, with low available N and deficient levels of available P, K, Mg, S, and Zn. Prado et al. (2012) only indicate that chlorosis and premature leaf dropping are the characteristic symptoms of Mg deficiency in mango and that Mg deficiency usually appears in acid or highly lixiviated soils due to its low exchange capacity or because of high levels of Ca and K.

The main global objective of this project is to review and update the existing information about magnesium fertilization in mango and its role not only in yield but in fruit quality (total soluble solids, acidity, size and weight of the fruits) and shelflife, as well as in tolerance to adverse conditions, particularly to cold conditions. Since the written information existing about magnesium fertilization in mango is relatively scarce the literature review for this project covers also the information existing about the effects of magnesium fertilization on other fruit crops. To complement the existing available printed and electronic sources about the subject, interviews (by email, telephone, and/or in person) with people, either researchers or producers, involved in the mango industry of different mango producing countries of the whole world, will be done. An important source of information has also been obtained trhough a magnesium fertilization survey sent to the main producing mango countries around the world. The information obtained from the most important fertilization companies producing magnesium fertilizers has served us as an important additional source for updating the existing knowledge about magnesium fertilization in mango.

GENERAL INFORMATION ABOUT THE ROLE OF MAGNESIUM IN PLANTS

The numerous physiological and biochemical roles that Mg plays in plant metabolism are discussed in several reviews (Barker and Pilbean, 1937, Wilkinson et al., 1990, Cakmak and Marschner, 1992, Mengel and Kirby, 2001, Hermans et al., 2004; Hermans and Verbruggen 2005; Ding et al., 2006, Cakmak and Kirby, 2008, Grzebisz, 2009, Cakmak, 2010, Römheld, 2012, Hawkesford et al., 2012, Benton Jones, 2012, Cakmak, 2013a,b, Verbruggen and Hermans, 2013, Gerendás and Führs, 2013, Merhaut, 2015, et passim).

The main role of Mg is enzyme regulation for more than 300 enzymes (including carboxylases, phosphatases, kinases, RNA polymerases, and ATPases) and also the regulation of cellular pH and the cation-anion balance, but the major function of Mg in green leaves derives of its position as the central atom of both chlorophyll a and chlorophyll b molecule. As a consequence of being an integral part of the chlorophyll molecule and the enzymatic processes associated with photosynthesis and respiration, the processes of carbon assimilation and energy transformations are directly impaired by magnesium deficiency. Magnesium also has an essential function as a bridging element for the aggregation of ribosome subunits, a process that is necessary for protein synthesis. Mg plays a critical role in stabilizing the specific conformation of nucleic acids required for their synthesis and functions and act as a cofactor and allosteric modulator. 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.

In summary, magnesium is an indispensable nutrient for plant growth playing part in many plant processes like:

- Chlorophyll formation:
- Photo-absorption of the green pigment
- Capturing the energy of sunlight and turns it into chemical energy
- Synthesis of organic compounds useful for plant growth and functioning (carbohydrates, lipids, proteins, aminoacids)
- Uptake and migration of phosphorus in plants
- Phloem loading and transport of photoassimilates into sink organs such as roots, shoot tips and seeds
- Resistance to unfavourable factors

Mg concentrations required for optimal growth vary and are usually between 0.15 and 1.00 % of the dry weight in leaf tissue, with the sufficiency value being 0,25% for most crop plants. There had been much more research interest in Mg deficiency than in toxicity, probably because toxicity symptoms are hardly visible in plants, even upon culture with concentrations as high as 60 mM Mg^{+2} (Shaul et al., 1999). Despite the abundance of magnesium in the environment - with more than 20,000 ppm in the earth's crust, making it the eighth most abundant element – 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.

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. According to experiments realized in apples on sand culture, nitrogen fertilization has a positive effect on magnesium absorption (Forshey, 1963). Another impressive impact of adequate Mg supply is related to its mitigating effect on aluminium toxicity in plants which is a common growth-limiting constraint in acidic soils globally. Generally the concentration of Mg^{+2} in the soil solution is higher than the K^{+} concentration but the uptake rate of Mg^{+2} by the roots is much lower than that of K^{+}. The uptake of Mg^{+2} can be also greatly depressed by an excess of K^{+} and NH_4^{+} and this can lead toMg deficiency in plants. Not only the uptake but also the translocation of Mg^{+2} from roots to upper parts of the plant can be restricted by K^{+} and Ca^{+2}.

Magnesium deficiency may suppress the overall increase in plant mass or specifically suppress root or shoot growth. However, the extent of growth inhibition of roots and shoots will be influenced by the severity of the magnesium deficiency, plant type and stage of plant development, environmental conditions, and the general nutritional status of the crop. As a consequence, low availability of Mg in an agricultural field leads to a decrease in yield. The first reaction of Mg deficient plants prior to noticeable effects on photosynthetic activity is the accumulation of up to 4 times more sucrose in leaves compared with those well nutried with Mg which indicates a severe inhibition in sucrose transport through the phloem out of the deficient leaves limiting plant growth, most probably by down regulation of photosynthesis activity. Mg deficiency symptoms arise first in the oldest leaves, and systematically progress from them towards the youngest ones. Indeed, due to the fairly mobility of the element, plants will remobilize Mg from older leaves to younger ones. Despite Mg deficiency symptoms are well depicted in aerial parts of the plant, studies by Cakmak (1994 a and b) indicate an inhibition of root growth before any other thing occurs in Mg deficient plants. A characteristic deficiency symptom is leaf interveinal chlorosis which is enhanced by high light conditions promoting the spreading of chlorosis and necrosis. Plants grown under high light intensity, in fact, appear to have a higher requirement for Mg than those grown under low light intensity.

Conditions of the soil and rhizosphere such as drought or irregular water availability, poor drainage or excessive leaching, low soil pH, or cold temperatures will exaggerate magnesium deficiency symptoms. Two reasons may explain this fact. Either magnesium is not physically available under these environmental conditions or physiologically, the plant roots are not capable of absorbing adequate magnesium to sustain normal plant growth.

There is no evidence available on the direct effect of excessive Mg supply on plant metabolism. Generally speaking, high Mg concentrations improve the nutritional quality of plants. However, since direct Mg toxicity has not been observed (and which might not be expected due to its roles in plant physiology) impairments in the plant's physiology are rarely produced - exceptions are under unusually high Mg leaf content (>1.0%), which particularly appear mostly in extreme serpentine (high magnesium: calcium soils and in semi-arid regions, under severe water stress conditions - and might be merely related to nutrient (K, Ca Mn and even Fe) imbalances in plants.

FERTILIZATION WITH MAGNESIUM ON MANGO AROUND THE WORLD

To obtain updated information about the actual practice in different countries of magnesium fertilization and the observed effects of it in mango, 41 people, including researchers, and producers or producer associations from 32 countries, of the most important mango producing countries and especially those exporting mangoes to USA (Annex 1), where interviewed. The procedures 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 (Galán Saúco, 2016). The main findings of the different sections of these interviews are commented below.

Summary of interviews on the use and effects of magnesium fertilization in mango

A) Mango Producers and Researchers

1.- Ways of determining the quantity of magnesium to be included in the fertilization program.

The great majority of the countries determine the quantity of magnesium to apply based on both leaf and soil analysis, complemented sometimes with traditional recommendations in the own country or literature recommendations from other countries. Only in the case of Ecuador and Costa Rica, studies done in the country about nutrient extraction are reported to be used to determine fertilizing practices (see table 1).

Table 1. Way by which countries determine the quantity of magnesium to be included in their mango fertilizing program (Source: Magnesium Fertilization Survey) (1)

Only leaf analysis	Philippines, Reunion (France), Florida (USA), Oman
Only Soil analysis	Indonesia, Thailand
Leaf and soil analysis	China, Martinica (France), Guatemala, Ecuador, South Africa, Puerto Rico, Málaga (Spain), Taiwan, India, Peru, Sudan, Venezuela, Brazil, Australia (2), Mexico, Chile, Dominican Republic, Vietnam, Costa Rica, Madeira (Portugal), Ivory Coast
Traditional recommendations in the country	Philippines, Martinica, Japan, China
Literature recomendations	Reunion, Venezuela, Florida, Thailand, Vietnam, Brazil, Oman, Vetnam
Studies done in the country	Ecuador, Costa Rica
Nutrient extractions	Ecuador, Costa Rica
Not applying or rarely applying Mg	Sri Lanka, Canary Islands (Spain) (2), New Caledonia (3), (Pakistan (4), Israel, Málaga

(1) Many countries use leaf analysis only for experimental purposes;
(2) Irrigation water rich in Mg, in some places of Australia also rich in calcium; 3) Soils are too rich in magnesium; (4) Ocasionally added as one of the micronutrients applied as foliar spray.

.- Range and Optimum Levels of Magnesium

A). - In leaf Analysis.

Almost all surveys reported a range of 0.15- 0.60 % as an appropriate level for Mg with 0.20-0.40 % as optimum. Only India differs from the others. In one of the two surveys from this country levels for deficient, low, optimum, high and excesive levels for Magnesium content in the leaf are given (see table 2), which mainly differs from the other countries in indicating as low the range considered optimum by other countries. The other report from this country is less precise indicating an optimum leaf content between 0.19 and 0.90 % which almost coincide with the range normally found (0.12-0.89%)

Table 2. Values for Mg leaf content in India

Leaf nutrient standard	Deficient	Low	Optimum	High	Excessive
Mg (g/100g)	**< 0.21**	**0.21- 0.39**	**0.40 -0.65**	**0.65-0.87**	**> 0.90**

By contrast, one of the surveys from Peru indicates that a value of 0.5% should be considered high. Florida reports also small differences depending on the soil type (limestone soil, 0.15%-0.47% versus acid sandy soil, 0.25%-0.38% and 0.17% for muck soil), while the report from Perú indicates an optimum of 0.20-0.30%, variable according to phenological phases. Note that these values coincides *grosso modo* with those reported in literature as Mg concentrations required for optimal plant growth in many crops (see section before **GENERAL INFORMATION ABOUT THE ROLE OF MAGNESIUM IN PLANTS)**

B) In Soil Analysis.

Although there are small differences between countries the most common figures are on an optimum range of 1.5-3 meq/100g (1-10 as extreme), around 60-90 ppm (48-200 as extremes) or in the proximity of 20% of the cation exchange capacity.

3.- Relation of Magnesium with Other Nutrients

The interaction of Mg with other elements is reported in many of the surveys. Coinciding with what was indicated in the previous paragraph of this report '**GENERAL INFORMATION ABOUT THE ROLE OF MAGNESIUM IN PLANTS',** the uptake of Mg can be strongly depressed by other mineral elements, mainly Ca, K, but also N, P, Mn, Fe, B and Zn and even Na. However, there is one report, from Ivory Coast, which indicates that high levels of Ca in soil seem to lead to an increase of Mg absorption. Values for the ratio of Mg to other nutrients is also reported in somecases like for example Japan, which indicates as optimum a Ca/Mg ratio between 4-8 (in the report from Costa Rica it is said that it must be >1) or an Mg /K ratio between 2 and 5. Venezuela also gives more precise ratios (see table 3) but. as one of the reports from Peru indicates, each soil is different and not a precise range can be established as a valid general rule which seems logical to accept and explains the differences in the values given in different reponses to the survey.

Table 3. Adequate nutrient ratios for Mg, Ca and K in Venezuela.

Mg/K	< 1 ⇒ Mg defficient	3 normal	> 18 ⇒ K defficient
Ca+Mg/K	10 normal	> 40 ⇒ K defficient	

4.- Fertilizers Used to Apply Magnesium to Mangoes

a) Under Conventional Cultivation.

Most countries use either Magnesium sulphate or dolomite. As an example, we can see on table 4 which fertilisers apply some of the important mango producing countries.

Table 4. Fertilizers used to apply Magnesium under conventional cultivation in some important mango producing countries

Country	**Fertilizer used**
Mexico	Magnesium sulphate, magnesium nitrate, Epsom salts
Ecuador	Magnesium sulphate, Magnesium nitrate, dolomite
Brazil	Magnesium oxide and dolomite (to the soil), Magnesium sulphate (foliar and through fertigation), Magnesium nitrate (foliar). $MgCl_2$ and leaf bioestimulants like Kamab or Versatil also used
Peru	Magnesium sulphate, dolomite, Magnesium nitrate, Magnesium oxide
Puerto Rico	Key-Plex 20:20:20
Australia	Magnesium nitrate, Magnesium thiosulphate, Magnesium chelate
India	Magnesium sulphate, dolomite, micronutrient foliar sprays

Note: dolomite is used normally as corrector of pH

b) Under Organic Cultivation. Composts, Bokashi, Guanumus (organic fertiliser from fish debris), humus and biofertilisers are commonly used. The magnesium content of most of these products is not usually known, and particularly the best biofertilisers used in Mexico contains only 200 ppm of magnesium. Some countries also use dolomite, Magnesium sulfite or K-Mag (Potassium-magnesium sulphate), when authorized.

5.- Way by which Magnesium is Applied to the Mango Plantings.

In the majority of the surveys form the different countries consulted magnesium is applied directly to the soil but some of them also applied magnesium through foliar spray or incorporate it through fertigation (see table 5).

Table 5. Way by which magnesium is applied to the mango plantings in different countries.

Way of aplication	**Country**
Foliar spray	India, Pakistan, Thailand, Japan, Oman, Australia, Mexico, Florida, Puerto Rico, Dominican Republic, Brazil, Sudan, Ecuador, Costa Rica
To the soil	India, China, Thailand, Indonesia, Japan, Oman, Australia, Philippines, Mexico, Florida, Dominican Republic, Guatemala, France (Martinica and Reunion), Venezuela, Ecuador, Brazil, Sudan, Taiwan, Costa Rica
Trough fertigation	India, Oman, Australia, Mexico, Dominican Republic, Ecuador, Perú, Brazil, Chile, Spain (Málaga), France (Reunion), South Africa, Costa Rica,

6.- Influence of Mg Fertilization in Different Cuantitative and Qualitative Characteristics of Mango Cultivation.

As referred in table 6, twelve (12) countries have reported that Mg fertilization improves yield although none of them give any quantitative data to support this statement.

Table 6. Influence of Mg fertilization in different cuantitative and qualitative characteristics of mango cultivation

Characteristic	**Country**
Increase yield	Brazil, Thailand, Dominican Republic, Oman, India, Chile, Florida, Indonesia, Vietnam, Ecuador, Guatemala,Sudan, Costa Rica, Ivory Coast
Increase fruit quality	Oman, Martinica, Ecuador, India, Dominican Republic, Sudan, Brazil, Peru, Sudan, Thailand, Costa Rica
Increase tolerance to low temperatures	Florida, Ecuador, Brazil
Increase tolerance To hidrotermic treatment	Ecuador, Brazil
Reduce IFB	Venezuela
Increase shelf life	Ecuador, Peru, Thailand. Ivory Coast
Increase tree health or vigor	Thailand, Australia, Ecuador
Increase flower intensity	Philippines

Ten countries reported also an influence of Mg on fruit quality. Reports from India, Indonesia, Ecuador and Dominican Republic indicate a positive effect of magnesium fertilization on improving skin colour, particularly for the cultivar Kent in Ecuador in the case of foliar sprays containing Mg one month before harvest that makes fruits more attractive. An increase of size was reports from Brazil, Thailand, Peru and Vietnam in the case of Oman improvement of taste and increase of sugar content, this last also for Sudan, Perú and Costa Rica was reported.

Three countries (Ecuador, Perú and Thailand) indicate that improving Mg fertilization can increase shelf life, although in the report from Ecuador it is stated that both the approprriate levels of Magnesium and Ca, and not separatedly, gives the fruit more consistency and consequently improves shelf life, but again not any quantitative data about these levels was given

Another 3 countries (Thailand Australia and Ecuador) indicate that Mg fertilization improve tree health or tree vigour while only Philippines reported that it increases flower intensity**,** but, as in the case of improvement of yield, not any quantitative data was indicated in the reports.

The survey from Venezuela indicates that an adequate Mg content reduces Internal Fruit Breakdown (IFB). This information was based on an experiment (Assis et al. 2004) in which it was observed that fruits of 'Tommy Atkins' with higher magnesium and calcium content were less affected by IFB (see table 7). Observations from Brazil also indicate a relationship between magnesium and mango soft nose, but not yet clarified. In one of the two surveys from Ecuador it is said that both Mg and Ca should be at an adequate concentration in order to give the fruit an appropriate consistency.

Table 7. Mineral content of Tommy Atkins mango fruits with or withouts symptoms of IFB (Source Assis et al., 2004)

Nutrient	Fruits with symptoms		Fruits without symptoms	
	Skin	Flesh	Skin	Flesh
Magnesium ($g.kg^{-1}$)	2.49	0.90	2.75	1.23
Calcium ($g.kg^{-1}$)	1.90	0.33	2.30	0.51

Three countries (Florida, Ecuador and Brazil) also report that Mg fertilization increase cold tolerance**.** It is interested to notice that in the case of Florida (information given by Dr. Jonathan Crane, University of Florida. IFAS) it was reported that 'in just a general way, nutrient deficient trees do not tolerate exposure to cold and freezing temperatures as well as trees with sufficient nutrient content; nor do they recover as quickly' and particularly that magnesium deficiency is most prevalent in our area on mango and other crops (e.g., avocado and lime and carambola) during the winter months when soil temperature and rainfall are reduced'. He explains that historically this problem was termed "winter chlorosis". This chlorosis was attributed to lack of soluble Mg in the soil solution, with Mg bound to the calcareous limestone-based soil, and to the reduced root capability to absorb Mg when soil temperatures are cool. For trees growing in the calcareous soils of South Florida the Mg deficiency was corrected with foliar magnesium sulfate or magnesium nitrate applications. For trees growing in sand or muck soils magnesium sulfate or magnesium nitrate was added to the NPK and applied in granular form to the soil or applied foliarly'.

In relation to the tolerance to hidrotermic treatment (HWT) the information obtained from Brazil indicates that in the case of Mg deficiency the fruits of 'Tommy Atkins' presented problems of skin burning during the HWT. Specifically, burning of fruits by cold occurs during the cooling process in the tunnels (temperatures of 9ºC during around 6 hours) or in the loaded containers (temperatures ≈ 8-9 ºC), particularly in the external layer of fruits more exposed to the air steams. According to their observations increasing Mg, Cu, Fe and Mn fertilization and correcting nutrient disequilibrium with Ca and K excess in the soil solution the problem disappears. They also indicate that the content of Mg in the peel of mango fruits at maturity to avoid skin burning should be between 2 and 2.5 g/kg, which coincides*, grosso modo* was indicated by Assis et al (2004) to also avoid IFB (see table 7). Some recent data indicate that the magnesium concentrations of pulp and skin below 1.2 and 2.8 g/kg respectively, make the pulp softer and more susceptible to hidrotermical treatment. On the other hand, magnesium deficiency is associated with the carmelite color of the mango peel and its yellow bark (I. H. L. Cavalcante. 2017. Federal University of São Francisco Valley. Petrolina, Brazil). Similarly, in the case of Ecuador, it is reported that Mg deficient fruits of 'Tommy Atkins' present a red yellowish colour and are more sensitive to burning by excessive heat or cold during the HWT. Both reports, from Ecuador and Brazil indicate that an adequate Mg fertilization improves the tolerance of mango fruits to the hot water treatment (HWT). The key role of magnesium in chlorophyll formation (see section **GENERAL INFORMATION ABOUT THE ROLE OF MAGNESIUM IN PLANTS**) supports these comments. However, the observations made in both countries refer mainly to 'Tommy Atkins', a cultivar which despite its still great market importance is in clear regression on the world trade. One of the reports from Ecuador also indicates, without quantitative data, that the colour of 'Kent', the cultivar 'favourite' of the World trade, is enhanced by increasing magnesium fertilization.

7.- Possibilities for Future Research Projects.

At the present moment, not any cooperative project on Mg fertilization between countries is being carried out, but many countries are interested in studies regarding the effect of magnesium fertilization in mango and the possibility of doing cooperative research (see table 8), in most cases without indicating any specific subject. Furthermore, with the only exception of Brazil, none of them are doing research or expressed specific interest in the effect of Mg in tolerance to cold, one of the main subjects of this report, and even in that country does not constitute the main subject of research.

Table 8. Countries with interest in studies regarding the effect of Mg fertilization in mango

Country	Research on course	Main subject of interest
Mexico	None	Non- specified
Brazil	Effect of bioestimulants containing Mg in improving growth and branch maturation to reduce the time for PBZ application	Same that research on course
Guatemala	None	Mg dosage to increase yield
Ecuador	None	Non- specified
Peru	None	Non- specified
Dominican Republic	None	Non- specified
Venezuela	None	Effect of Mg in IFB
Florida	None	Non- specified
South Africa	None	Ways of dealing with excess of Mg in the soil
Sudan	General fertlizer project	Effect of fertilizers on mango yield
India	None	Use of Mg as foliar or soil application
China	None	Non- specified
Philippines	None	Non- specified
Thailand	General fertlizer project	Non- specified
Indonesia	None	Mg nutrient management for increasing yield
Vietnam	None	Non- specified

B) <u>Fertiliser Companies</u>

An email was sent to the 11 biggests fertilizers companies in the world (Roy, 2015) demanding any information they may have:

1) About magnesium fertilization in mango or in another fruit crops and its influence in yield, fruit quality and tolerance to adverse conditions, particularly cold tolerance.

2) Of any experiment or experiments, either finalized or in course about magnesium fertilization

3) Any paper on the subject.

None of them reported any experiment on Mg fertilization either on mango or in another tropical fruit crop, and only two companies, Yara and K+S apported valuble information for this report which will be commented below, with the other ones indicating they were not producing magnesium products or not using in fruit crops.

B.1.- Information of Interest Obtained from Yara

B.1.1. - General information.

According to the 'Yara Tropical Fruit Tree Plant Master' (Annex 3) on page 43 of the document, high levels of potassium and/or calcium can restrict and compete with uptake of magnesium, recommending that these nutrients should always be well balanced in any fertilizer program. However, they also explain that poor magnesium supply is most common on acid soils and often occurs where there is low calcium uptake and that acidic Oxisol and Ultisol soils, especially in areas of high temperature and heavy rainfall, are particularly prone to magnesium deficiency.

B.1.2.-Influence of magnesium in quantitative and qualitative effects of mango production. -

In the same page of the document submitted as Annex 3, it is reported that yield responses to Mg fertilization have been recorded in both, mango and longan, in China. In the case of mango, the experiment was done in a planting of mangos at a density of 856 plant/ha. Comparing the application of 40 g Mg/tree to the treatment without Mg it was observed that mangoes with Mg applied had 11.1 more fruits per plant, weighing 6 g more per fruit, with a significant yield increase of 2,570 kg/ha (21.1 percent). Each kg of Mg produced 64.3 kg fruit. Net profit increased 7,790 Yuan/ha when Mg was applied. Higher Mg rates gave a slightly higher yield, but no economic benefit. Thus, the proper application rate of Mg should be 40 g Mg/plant/year (Xiuchong et al., 2001).

In the case of longan it was also reported an improvement on the fruit quality providing larger, sweeter fruits with higher vitamin C content

B.2. - Information of Interest Obtained from K+S

B.2.1. - General information.

In one of the three documents received from this company 'Kumar, N. Mango in India Maximising yield and quality through adequate cultivation and nutrient management' (Annex 4), it is indicated that there is an approximate Mg removal of 1.11 kg by each 100 kg of fruit produced, this quantity being variable depending on cultivar and location. The fertilizers used include Potassium magnesium sulphate and Potassium schoenade (23% K_2O; 11% MgO), this last one not reported in the Indian survey (see table 4). It is worth to note that based on Bhargava and Chadha, (1988) it is reported a critical leaf nutrient standard of 0.91 % Mg which is slightly higher than the value reported as excessive in the Indian survey (table 2).

In the report named 'Informacion Mg-Frutales-Mango', included as Annex 5, it is indicated that there is a risk for Mg uptake at pH lower than 5.5 or bigger than 7.5, - the lower value coinciding almost exactly with that reported in the bibliography (see section before **General information about the rol of magnesium in plants)-** and that it is necessary to equilibrate the K/Mg because the antagonism K/Mg induces nutritional deficiencies in the case of desequilibrium between these 2 elements, with this values as follows:

K/Mg = 8:1 → High probability of Mg defficiency
K/Mg = 2:1 → Optimum value

K/Mg = 0.75:1 → High probability of K deficiency

These values are notoriously different and even contradictory for the optimum value from those reported in the surveys received from different countries (see section **FERTILIZATION WITH MAGNESIUM ON MANGO AROUND THE WORLD.** paragraph **3.** Relation of magnesium with other nutrients) which mentioned optimum values for the Mg/K ratio between 2 and 5 with those <1 being indicated as soils defficient in Mg.

In the K+S Kali documents by Gransee, A, named 'Balanced Nutrient Management including Magnesium and Micronutrients (Annex 6) and ESTA® Kieserite A product of nature (Annex 7), the general role of Mg in plant metabolism, based in literature review done by K+S Kali, is described. As the result of this review does not differ much from that indicated in the previous section (**GENERAL INFORMATION ABOUT THE ROLE OF MAGNESIUM IN PLANTS)** of this document they will not be written here, except for important complementary information relevant for this report like:

- A description of the abiotic stresses alleviated by Mg nutrition which include drought, heat, high light, frost, wind, rain and low pH)
- That K and Mg fertilization improves N uptake. This explains the need of a previously commented well balanced K/Mg ratio for an adequate yield
- That Mg supply increase tolerance toward Aluminium
- That, by improving root growth, Mg increases water and nutrient uptake from the soil

B.2.2. - Influence of magnesium in quantitative and qualitative efects of mango production

The importance of Magnesium for mangoes is indicated in the mentioned Annex 5 where it is said that Mg increase fruit size, sugar content and vitamin C as well as root growth. In the same document, and based in a work by Tan et al. (1997) named 'Effect of the SOP (K_2SO_4 and ESTA® Kieserite ($MgSO_4 \times H_2O$) on the yield of mangos 4 years old in Tiandong, Guangxi (China)', it is reported an increase of mango shelf life when incorporating the magnesium fertilizer Kieserite to an NPK fertilization program.

BIBLIOGRAPHIC REVIEW ABOUT THE INFLUENCE OF MG FERTILIZATION IN MANGO AND OTHER FRUIT CROPS

For a better understanding of this literature review, it will be grouped in different sections related with possible effects of magnesium on the different quantitative and qualitative characteristics of mango production, reported in the interviews realized for this project and described in the first part of this report**.**

Influence of Magnesium in Fruit Size, Fruit Weight and Yield

Many general statements in most of the books and papers dealing with magnesium (see Section **GENERAL INFORMATION ABOUT THE ROLE OF MAGNESIUM IN PLANTS)** indicate that adequate levels of Mg increase plant yield or, the reverse, that low availability of Mg in an agricultural field leads to a decrease in yield. Several papers indicate a clear relation between Mg and yield in cereals, vegetables or grapes, but there are not much specific experiments for mango or other fruit crops that quantify the relation between different levels of magnesium either in soil or in leaves and yield (Gerendás and Führs, 2013, Brunetto et al., 2015). The information by (Xiuchong et al., 2001) already commented about a significant yield increase of 2,570 kg/ha (21.1 percent) in mango due to adequate magnesium fertilization (see previous section B) Fertiliser companies**.** Information of interest obtained from Yara) is also in line with experimental work done in South Africa (Oosthuyse, 1997) with 5 mango cultivars: ZiII, Tommy Atkins, Sensation, Heidi, and Kent in which it was found that tree yield was positively related to leaf Mg concentration, indicating that the application of Mg will generally enhance tree yield. However, observations from this last experiment also indicate that Mg and Zn leaf concentration were negatively correlated with fruit size which may look contradictory with the positive effect of Mg in fruit yield. The explanation may however be due to the negative influence of Zn in fruit retention also found in this trial. Another trial with 'Dashehari mango (Pathak and Pandey (1977) indicates that suitable Ca and Mg concentrations after flowering improve fruit set and fruit size.

Apart from these two specific papers dealing with mango, other reports worth to be mentioned here regarding the influence of Mg fertilization on yield of fruit trees deal with apples and citrus. In the case of apples, results from an experiment indicate that applying corrective $MgS0_4$ sprays to trees showing Mg-deficiency symptoms did not affect yield, in other experiments, however, postblossom $MgSO_4$ sprays applied to apple trees showing severe Mg deficiency increased the yield by increasing fruit set and fruit size and reducing fruit drop (several authors cited by Swietlik and Faust, 1984). Experimental work in Argentina (see below **Tolerance to high light intensity**) also indicates a beneficial role of Mg in fruit size. Regarding *Citrus*, results from an experiment done with mandarins (*Citrus reticulata*) in India by Ram and Bose (2000) indicate that the treatments with Mg and micro-nutrients, except Cu, gave higher fruit yields than the control (without foliar applied fertilizer) and that the application of Mg + Cu + Zn gave the highest fruit yield but did not affect fruit quality. More specific indications are given in a paper by Quaggio et al., (1992) with 'Valencia' sweet orange on Rangpur Lime done in Brazil where it was found that maximum yield was obtained in plots in which exchangeable Mg in the soil and Mg leaf content was respectively higher than 0.9 meq/100 cm^3 and 0.35%, values which, especially for leaf content, are similar to those indicated in the surveys as optimum for mangoes (see section **FERTILIZATION WITH MAGNESIUM ON MANGO AROUND THE WORLD).** It is worth to mention here that according to Zekri and Obreza (2016) alternate bearing is common in seedy citrus cultivars growing in a Mg-deficient condition.

Influence of Magnesium in Fruit Quality

The number of studies addressing the significance of Mg for the quality of agricultural and horticultural produce appears very limited as compared to other major elements. According to Wesler (2012) plant quality is predominantly controlled by genetic and physiological factors. Quality varies with species, cultivars and plant parts. But, apart of genetic limits, natural (climate and soil fertility) or anthropogenic (harvest method, processing, soil cultivation, fertilization, watering, etc.) exogenous factors, may considerably modify quality. Bramlage et al., (1980) indicate that there is only very little evidence that Mg deficiency *or* Mg excess directly affects fruit quality, even though the fruit trees suffering from Mg deficiency appear weak and unproductive. The authors indicate that results of most experiments with apples and other fruit crops do not clearly indicates Mg responses alone but more from the interaction of magnesium with other cations like Ca and K. As indicated by Gerendás and Führs (2013) an increase of Mg tends to increase quality but the ratios of Mg/Ca and Mg/K ae more reliable indicators of quality response that Mg alone. Furthermore, Bramlage et al. (op.cit.) state that Mg doses beyond those required for maximum yield rarely induce a further increase of quality, an example of the mentioned interaction are the results obtained by Fallali and Simons (1996) which in an experiment with two cultivars of apple found that fruit magnesium concentration and fruit potassium concentration were respectively negatively and positively correlated with **fruit color**

A negative effect of magnesium in apple skin colour was indicated by Marcelle (1995), and also indicated by Reay et al. (1998), who, investigating the effect of foliar urea and $MgSO_4$ sprays on chlorophyll, carotenoid and anthocyanin concentrations in apple skin, found that the Mg treatment of the tree canopy increased the chlorophyll and carotenoid concentration on the back side of the fruit (not facing the sun). These two components determine the 'backcolour' of the fruit ranging from light green to pale yellow and, in consequence, increase the green colour of the fruit because the 'greening effect' of Mg supply may be associated with increased chlorophyll formation or, more likely, decreased/delayed chlorophyll degradation and, as the authors indicate, this has a negative impact in a consumer-oriented approach to quality In fact, when using this colour for grading food maturity in export-oriented regions like New Zealand a greener colour means that less fruits are suitable for export at a given harvest date or the fruits need more time to reach the desired maturation.

Although results from the experiment done by Oosthuyse (1997) in South Africa with cvs. Tommy Atkins, Sensation, Kent and Heidi, did not show any relation between ground skin colour in mango and nutrient leaf concentration, information from Australia (QDAF, 2015) indicated a green effect in mango leaves and fruits of excesive Mg content. A negative effect on colour have also been reported by Amin et al., (2004) on cv. Samar Bahist Chausa where they found that applications of 4% $CaCI_2$ produced significantly higher fruit colour score while 1% $MgCl_2$ lowered colour score as compared with control. However, this effect was not observed, but the contrary, in trials done in Brazil which found an increase of skin colour in cv. Kent when 1-1.5% of magnesium sulphate was applied 30-45 days before harvest (Estrada, 2002; Mouco et al., 2005).

Other fruit quality parameters like **total soluble solids and acid content** can also be influenced by magnesium fertilization. In the case of citrus, Quaggio et al. (1992) investigating the effect of liming with dolomitic limestone in acidic and Mg-deficient Brazilian soils planted with citrus trees, found that the TSS and acid concentrations in fruits linearly increased with dolomitic limestone application for seven years. These increases were strongly correlated with the leaf Mg concentrations as already also observed by Koo (1971). Moss and Higgins (1974) conducting a sand experiment under greenhouse conditions for one season concluded that particularly the increase in fruit acidity (occurring at high Mg treatment) might be related to an increased Ca/Mg rather than an increased K/Mg ratio. Similarly, Zekri, and Obreza (2016) found that citrus fruits from Mg-deficient trees are lower in soluble solids, acidity, and vitamin C. A negative effect of Mg in fruit quality in apples was reported by Marcelle (1995) who found a negative relationship between the Mg concentration of the fruit and the Thiault index- which indicates the content of soluble solids and acids in fruits and is used as a quality parameter (Thiault, 1970). The author, however, explicitly states that the negative relationship between the Mg concentration of the fruit and the Thiault index- is not a direct consequence of high Mg but of an imbalanced cation (e.g. Ca and K) supply to the fruits underlining the already described importance of the cation ratios rather than the Mg concentration alone.

In the case of mangoes, however, results from the cited trial of Oosthuyse (1997) did not show any relation between nutrient content and TSS, pH or taste, but Amin et al., (2007) indicated that post harvest treatment of 1% $MgCl_2$ followed by 4% $CaCl_2$ produced significantly better taste that the control

Influence of Magnesium in Shelf Life

The only paper which, in accordance with what was said in the reports from Ecuador, Perú and Thailand, indicated a positive effect of Mg in shelflife was that of Alcaraz Lopez et al. (2003) stating that Mg foliar sprays improve flesh firmness on plums. By contrast, works on apples Marcelle (1995) indicate a negative impact in shelf life.This author provided an evaluation of favourable 'concentration ranges' of the macronutrients N, P, K, Ca, and Mg giving an idea about the complexity of the impact of mineral nutrient status on the various apple quality parameters, He also indicates, that the impact of Mg on 'good eating quality' is not well known except for a negative effect on fruit firmness which causes a reduction of Mg in apple storage quality. The competition of the main base cations K, Ca and Mg is discussed as causal factor responsible for this negative effect. According to his observations the optimal Mg concentration has to be relatively low for good storage properties. The physiological background underlying this recommendation was previously discussed in a review by Bramlage et al. (1980) arguing that the commonly described effects of various nutrients including N, P, K, Mg, and B on the quality of pome fruits are to certain extent a consequence of their interaction with Ca.

A positive effect of the impact of magnesium fertilization in shelf life was, however, reported in a paper by Garzón-Acosta et al. (2014) which in a trial with cape gooseberies (*Physalis peruviana* L.) found that fruit cracking was higher in the Mg-deficient fruits, than in the Ca-deficient and P deficient fruits. The explanation of this effect given by the authors is that Mg is very important in this species for maintaining pectic acids as insoluble in the cell wall, even more so than calcium, which is in accordance with the role of these two elements in maintaining plant tissue integrity (see section **GENERAL INFORMATION ABOUT THE ROLE OF MAGNESIUM IN PLANTS).**

The only bibliographic references found about the direct impact of Mg fertilization in shelf life of mangoes is that of the mentioned paper from South Africa (Oosthuyse, 1997) in which no any relation between mango shelf life and leaf magnesium concentration was found. However, Wangchai et al., 2012 indicated that the Ca+Mg/K ratio in the soil has a positive correlation with shelf life in a trial with 'Nan Doc Mai' mangoes and that the fruits grown in soils with values of this relation of 2,55 have better firmness, resisted better rot pathogens and had longer shelf life than those in soils with values of 1.55. Data shown by the authors about Mineral composition of the fruits also indicate that the presence of a higher Ca+Mg/K ratio in the fruits also are positively correlated with shelf life.

Influence of Magnesium in the Internal Fruit Breakdown

Although the mentioned paper by Oosthuyse (1997) reports a positive correlation between the incidence of IFB and leaf magnesium concentration, Amin et al (2007) reported that a significant reduction on soft nose incidence - one of the symptoms associated to IFB (Galán Saúco, 2009) - was observed in mango fruits cv. Samar Bahist Chausa sprayed 15 days before harvest with 4% $CaCl_2$ or 1%. Results of another brasilian experiment (Assis et al., 2004) also indicate that low levels of Ca and Mg together with high N/Ca and K/Ca relations, both in the flesh and in the skin, are observed in fruits of 'Tommy Atkins' with IFB. Similarly, to what was comented for shelf life, an increase of the Ca+Mg/K ratio has been found to have a positive effect in reducing jelly seed.

Influence of Magnesium in the Tolerance to Stresses

Many physiological treaties indicate that most plants under stress environmental conditions like excesive cold or warm temperature, draught or salinity receive more sunlight that can use in photosynthesis electron transport and $C0_2$ fixation causing photosynthetic damage which can even conduce to cell death. Furthermore, some plant species or cultivars within species have a particular sensitivity to Mg, becoming Mg deficient under moisture and/or temperature stress even though Mg may be at sufficient availability levels (Benton Jones, 2012).

As indicated by Barker and Pilbean (1937), citing several authors, conditions of the soil and rhizosphere, such as drought or irregular water availability poor drainage or excessive leaching, relatively cold or warm temperatures or low soil pH, will exaggerate magnesium deficiency symptomswhich can be explained by two reasons: Either magnesium is not physically available under these environmental conditions, or physiologically the plant roots are not capable of absorbing adequate magnesium to sustain normal plant growth. However, the degree of impact may be influenced by plant type and stage of plant development.

Influence of magnesium in the Tolerance to High Light Intensity

According to Cakmak and Yazici (2010) plants grown under high light intensity appear to have a higher requirement for Mg than those grown under low light intensity and as a consequence high light intensity increase the development of Mg deficiency symptoms. Since deficiency of Mg, like that of K, Zn and N, enhance the sensitivity of plants to photooxidative damage caused by impaired phloem loading of carbohydrates with the consequent apparition of leaf chlorosis, necrosis and disturbance of plant growth, adequate nutrition is absolutely necessary under stress conditions to reduce this damage (Cakmak,2005; Engels et al, 2012). Experimental work done in apples indicates that an adequate magnesium nutrition increases the tolerance of trees to high solar radiation because of a better foliar growth, as a result of the positive role of Mg in the phloem discharge process and the consequent increase of the photoquimic quenching. In practice, this results in better fruit quality in apples (bigger fruit size and less sunburn damage) (G Colavita. 2017.Personal communication.2017 Department of Fisiología Vegetal. Faculty of Agricultural Sciences. Universidad Nacional del Comahue, Argentina). Works on bean, wheat and corm indicate that ensuring a sufficiently high Mg supply is important for minimizing heat and radiation-related losses in crop production (Cakmak, 2013).

Influence of Magnesium in the Tolerance to Water Stress and Salinity

As in the case of tolerance to light intensity there are not specific experiments to evaluate the impact of Mg fertilization on the tolerance of mango or other fruit crops to water stress or salinity. As for many other plants an adequate level of this element in plant tissue will be beneficial but there is an experiment in sunflowers indicating that high leaf content of Mg (> 1.5%) may be critical because of an inhibition of phosphorylation and photosinthesis (Rao *et al.* 1987). Although this result can not be directly translated to mangoes, it is worth to indicate here that this value is much higher than that recomended as adequate both in the mango survey (0.15 to 0.60%) or in the literature review (0.35%).

Influence of Magnesium in the Tolerance to Cold Condition

Although there are authors that indicates that ‘it is not clear why magnesium has been associated with cold hardiness; it certainly is not based on available science’ (Chalker-Scott, undated), other reports show a clear relation of Mg with cold tolerance. In fact, in the case of citrus, Zekri and Obreza (2016) point out that magnesium-deficient trees are more susceptible to cold injury than non-deficient trees.

Influence of Magnesium in the Tolerance to Hot Water Treatment

Despite the existence of several papers dealing with hot water treatment in mangoes [(Yimyong et al., (2011); Zhang et al, (2012) Angasu et al., (2014)] or in other crops, we have not found reported any influence of magnesium in reducing any negative impact that this treatment can have in mangoes.

Influence of Magnesium in Disease Resistance

Magnesium nutrition and its impact on plant disease resistance have also been discussed by several authors, but, except in the mentioned paper by Wangchai et al. (2012) for the positive effect of Ca+Mg/K ratio in resistance to rot organisms (see impact on shelf life), not specifically for mangoes. Results of different experiments for other fruits can be, sometimes contradictory. In fact, Jones and Huber (2007) indicated that high levels of Mg reduce diseases such as bacterial soft root of potato, but, in contrast the same authors (Huber and Jones 2013) reported lately that high rates of Mg interfere with Ca uptake and may increase the incidence of diseases such as bacterial spot of tomato and pepper or peanut pod. (Benton Jones, 2012) also indicates that some fungus diseases, like powdery mildew incidence on greenhouse-grown cucumber are more likely to occur on plants that are marginally deficient in Mg.

According to Huber and Jones (2013) a specific mechanism of resistance to plant diseases enhanced by Mg includes the resistance of tissues to degradation by pectolytic enzymes of bacterial soft rotting pathogens which seems to indicate that the effect of Mg on disease resistance may be a consequence of its general effect on general plant health. The same authors indicated that Fusarium wilt pathogens tend to be less severe when adequate Mg is available. Since Fusarium spp are the causal agent of Mango malformation (Galán Saúco, 2009) it may be interesting to test the possible rol of Mg fertilization in reducing the incidence of this very importantdisease of very difficult field control.

In conclusion, management of Mg nutrition to reduce disease, in balance with other minerals, is still an underutilized tool for disease control in many crops in general and in mango in particular.

SUMMARY OF FINDINGS REGARDING MAGNESIUM FERTILIZATION AND ITS EFFECTS ON MANGO

- The great majority of the countries determine the **quantity of magnesium to apply** based on both leaf and soil analysis, complemented sometimes with traditional recommendations in the own country or literature recommendations from other countries.

- Almost all surveys reported a range of 0.15- 0.60 % as an **appropriate foliar level for Mg** with 0.20-0.40 % as optimum. Regarding **soil** analysis, the reports indicate an **optimum range** of 1.5-3 meq/100g (1-10 as extreme), around 60-90 ppm (48-200 as extremes) or in the proximity of 20% of the cation exchange capacity. These values, especially for leaf content, are similar to those indicated in the literature review as optimum for mangoes. The values reported also coincides *grosso modo* with those reported in literature as Mg concentrations required for optimal plant growth in many crops. By contrast, in the information received form K+S fertilizer company it is reported a critical leaf nutrient standard of 0.91 % Mg in India which is slightly higher than the value reported as excessive in one of the surveys received from that country and also than the range indicated as optimum in the other report of this country.

- A clear **interaction of magnesium uptake mainly with the presence of Ca and K but also with other elements** such as N, P, Mn, Fe, B and Zn and even Na is reported in the surveys, in the literature revision and also in the information received from the fertilisers companies. Optimum values for the relations Ca/Mg y K/Mg are reported but some of them are contradictory.

- Most countries use either **magnesium sulphate or dolomite as magnesium fertilizers** that are generally directly applied to the soil but also, in some of them, through foliar spray or via fertigation. Different organic fertilisers and biofertilisers, but also magnesium potassium sulphate, magnesium sulphite or dolomite, when approved for its use, are also applied for organic cultivation.

- Twelve (12) countries have reported that appropriate fertilization with Mg **improves yield** although none of them gives any quantitative data to support this statement. The report from Yara Company indicates the beneficial effect of Mg fertilization on increasing yield as well as the information gathered from one bibliographic reference from South Africa which states that tree yield was positively related to leaf Mg concentration goes in the same direction. Many other bibliographic references indicate that adequate levels of Mg increase plant yield in several fruit crops like apples or citrus, or the reverse, that low availability of Mg in an agricultural field leads to a decrease in yield.

- Ten (10) reports from the surveys indicated an **improve of fruit quality** through **appropriate magnesium fertilization** although they differ in relation to which parameters of fruit quality - skin colour, size and sugar content and taste - are improved. Increases in fruit size and sugar content by appropriate Mg fertilization are also mentioned in the information recorded from the fertilisers companies and, in the case of K+S, an increase of Vitamin C is also reported. The information obtained through the literature reviews indicates, however, that, at least in the case of apples, there is only very little evidence that Mg deficiency *or* Mg excess directly affects fruit quality. In the case of mangoes results form diferent trials are contradictory finding in some cases that **fruit color** was negatively correlated with Mg content, even causing a greening effect, but also that spraying SO_4Mg before harvest enhance fruit colour. This negative effect of greening of the fruit has been also reported for mangoes in Australia. Although the literature review showed that in the case of citrus and apples other fruit quality parameters like **total soluble solids and acid content** are also influenced by Mg content, positively for citrus and negatively for apples, the papers reviewed on mango dealing with these parameters did not show any relation between nutrient content and TSS, pH or even taste, except that for an improvement of taste obtained by some postharcvest tratments containing Mg and Ca.

- A positive ingfluence of Mg fertilization on **mango shelf life** is reported only in the surveys of three countries and in a trial reported by K+S Company. The information gathered through the literature review is contradictory regarding influence of Mg fertilization in shelf life with positive or negative influence depending on different fruit crops, but in any case, no any direct relation between mango shelf life and leaf magnesium concentration was found in the only paper dealing with this subject in mangoes, However the Ca+Mg/K ratio both in the soil and in the fruit can be a good predictor for mango shelf life.

- While the survey from Venezuela, one of the only three countries which mention this subject indicates, indicates a positive effect of Mg in the incidence of IFB, certain contradiction was found in the literature review. Both, a negative influence of Mg fertilization in the incidence of IFB and a positive influence of foliar sprays containing Mg, have been reported, with low levels of Mg also associated to IFB. The bibliographic review also indicates the relevant role of the levels of Ca and Mg as well as that of diferent cations ratios, N/Ca and K/Ca in the flesh and skin of the fruits in the incidence of this physiological disorder and also the positive effect of the Ca+Mg/K ratio in reducing the incidence of jelly seed.

- Although not any experiment has been specifically done in mangoes, nor any reference to this subject was reported in any of the surveys experimental work done in other species indicates that an adequate magnesium nutrition increases the **tolerance** of trees **to high solar radiation** and is beneficial regarding **tolerance** of mango **to water stress or salinity.**

- An increase on **cold resistance** associated to Mg fertilization has been reported as a well-known fact for avocados and mangoes in Florida and also in the surveys from Ecuador and Brazil, and, according to the literature review it holds true also for citrus, although some scientists has shown certain escepticism about this effect.

- Despite not any bibliographic reference cites any impact of Mg fertilization in reducing **damage** caused by **hot water treatment** in mangoes or in another crop, two of the main exporting mango countries to the USA, Brazil and Ecuador, indicated that an adequate Mg fertilization improves the tolerance of mango fruits to the HWT reducing the burning by excessive heat or cold during this treatment.

- Magnesium nutrition in balance with other minerals has a clear impact on **plant disease resistance** and its role in control of some important mango diseases like malformation merits to be studied.

GENERAL DISCUSSION

Although, as indicated in the surveys, most countries agreed regarding appropriate levels for magnesium content in leaves and soil, which also coincides *grosso modo* with those indicated in the bibligraphy consulted for other crops, like *Citrus*, the difference reported for mangoes in India may be explained by the use of cultivars different form those grown in other parts of the world as well as for different environmental and, particularly, soil conditions. No wonder the interaction cultivar/environment and its influence on many plant parameters is a well known common fact in mango and most other crops. Furthermore, Indian cultivars are also generally of green colour and increasing Mg levels, that as commented before may caused greening of the fruits, will not be detrimental for them as it may be for the more coloured cultivars dominating the western markets.

In the case of Ca and K, two of the elements which more influence Mg uptake, the contradictory values found in the relations Ca/Mg y K/Mg can also be due to the different soil types from which these values are reported, which explains that not a precise range can be established as a valid general rule for these relations to favour Mg uptake.

The beneficial role of Mg fertilization on yield as well as in the vigour and general growth of the mango plant is easily explained based on the role that this element plays in many plant processes (see section **General information about the rol of magnesium in plants).** Furthermore, since alternate bearing is a common well known fact of many mango cultivars around the world it is woth to indicate here that according to Zekri and Obreza (2016) alternate bearing is common in seedy citrus cultivars growing in an Mg-deficient condition, a reason more to maintain Mg levels in the adequate range for mango cultivation.

The contradictory influence on fruit colour reported for Mg can be also explained based in possible interactions with other elements like potassium which concentration in fruits of apples have been found positively correlated with fruit colour (Fallali and Simons (1996), illustrating once more that the effects of magnesium on fruit quality in apples, and probably in other fruits, are strongly influenced by the antagonistic effects on potassium uptake and accumulation. Another fact that explains the aparent contradiction of different trials dealing with the influence of Mg concentration and mango skin colour is the existence of an interaction with cultivar and environment. Similar comments may also apply to the influence of Mg in total soluble solids and acidity not investigated enough for mangoes and possibly, like in the case of apples (Marcelle, 1970) also more influenced by the cation ratios than by the Mg concentration alone.

The mentioned interaction of magnesium with other cations could also explains the contradiction found between the effect of Mg in shelf life, as clearly indicated by the positive correlation of Ca and (Ca+ Mg)/K ratio with storage life in the cv Nan Doc Mai grown under different soil conditions (Whangchai *et al.,* 2001).

Since IFB is caused by excesive N and/or low Ca in the fruit (Galán Saúco, 2009) the mentioned interaction Ca-Mg as well as difference between cultivars and environments may explain the contradiction found in the literature review regarding the influence of Mg in IFB. The above mentioned Ca+Mg/K ratio may serve as well as the Ca/N ratio as an indicator for the incidence of this disorder. The higher both ratios rhe lesser the incidence of IFB. Similar comments have been mentioned for 'bitter pit', a similar disorder of apples which, in addition of giving an undesirable appearance, reduces texture and taste of fruits, also caused by an insufficient Ca supply to the fruits). Although the incidence of this disorder has not been directly correlated with the Mg the Ca/Mg ratio serves also as an indicator of it (Askew et al. 1960). Despite the positive ffect of Mg sprays on IFB mentioned in the literature review, care should be taken in increasing much the Mg fruit content, since, as indicated earlier in this report (see section **GENERAL INFORMATION ABOUT THE ROLE OF MAGNESIUM IN PLANTS**), a clear interaction exists between Ca and Mg and, due to the scarce movility of Ca inside the plant - in contrast with the high movility of Mg - (White, 2012), excesive magnesium can reduce the translocation of this element to the fruit. The significant reduction in soft nose found by Amin et al., (2007) indicates that calcium and magnesium may prove to be good control measure for mango soft nose in future. So, it is suggested that in future, a series of higher concentrations of calcium and magnesium salts (particularly chlorides of Ca and Mg) should be evaluated in relation to different times of applications. As pre- and post harvest treatment of calcium and magnesium did not show any negative effects on the quality parameters (Table 1 and 2) of fruits and soft nose was found to be reduced in most of the treatments, so including calcium and magnesium in the orchard nutrition program will help to improve fruit quality.

Although not any experiment has been specifically published in mangoes, there is no doubt that the beneficial impact of an adequate Mg nutrition in increasing the tolerance of trees to high solar radiation found in apples and other crops can also be true for mangoes .

The beneficial effect of Mg on cold resistance can be easily explained. Caplan (1988) indicates that, by reducing N application in late summer, the carbohydrate reserves accumulates in the diferent tissues of the plant, acting like an antifreeze that reduces the temperature required for the tissue water to freeze. As conclusion he indicates that it is very important to maintain healthy foliage after the crop has been harvested which can permit the accumulation of sugars in the tree. As indicated by Cakmat and Yazici, (2010) the first reaction of Mg deficient plants is the accumulation of up to 4 times more sucrose in the deficient leaves compared with those well nutried with Mg which indicates a severe inhibition in sucrose transport through the phloem out of the deficient leaves. Because of this, there is no doubt that an adequate program of fertilization, particularly for N and Mg will be of great importance for the plant´s ability to withstand cold conditions.

The positive effect of Mg fertilization in reducing skin burning of mangoes during the HWT indicated in the reports from Ecuador and Brazil is attributed by them to a more reduced pigment formation, particularly chlorophyll. This explanation agreeds with was indicated in the previous section **GENERAL INFORMATION ABOUT THE ROLE OF MAGNESIUM IN PLANTS.** According to their observations (L. E. Ferraz. Clorofila. Agropecuaria & Consultoría. Personal Comunication. 2017) Mg content, both in fruit and leaf, decrease from flower-fruitset to ripening (see fig.1) and the chlorophyll initially synthetized during the early phases of fruit growing may be degradated during maturation to other red and yellow pigments, ceasing its protecting role and rendering fruits more sensitive to damage, either by cold, or by heat during the HWT. It should be noticed that the observations make reference only to 'Tommy Atkins' and 'Kent', cultivars in which both in the surveys and also in the literature review it is not reported any negative influence on colour, but the contrary in the surveys from Brazil. Care should however be taken before to extend this information to other cultivars like 'Palmer' or other less coloured cultivars such as 'Ataulfo', 'Nan Doc Mai', or 'Keitt' where an excess of chlorophyll in case of excesive Mg supply may enhance the green colouration of fruits, as indicated for apples (Gerendás and Führs, 2013) and also for mangos in Australia (QDAF, 2015) rendering fruits not well accepted by Western (Europe and North America) markets (Galán Saúco, 2017), except in the case of Keitt exported for the green unripe market well appreciated in the US.

As in other characteristics, the interaction with other elements plays a role on the resistance of mangoes to diseases which explains why well-known increases in susceptibility of plants to diseases under very high K supply have been associated with low tissue concentrations of Mg and Ca. The reason for this greater susceptibility may probably have its origin in the high accumulation of sugars in source leaves under Mg deficiency due to impaired phloem transportation which favours pathogen invasion and infection (Cakmak, 2013).

CONCLUSIONS AND FUTURE RESEARCH LINES TO DEVELOP

An appropriate Mg fertilization has the following effect in mango production:

1) Improvement of yield, vigour and general growth of the plant
2) A positive or negative effect on skin colour depending mainly in cultivars, causing greening of the skin of some of them. Within reasonable Mg. fertilization increases no problems seems to occur for 'Tommy Atkins' or 'Kent' which colour can be even improven
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 of the interaction with other elements, mainly with 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 mangoes during the HWT

Although not proven for mangoes, 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 recomendations about appropriate levels for this element because of the following facts:

1) The existance 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 explain also that it would be not possible that a precise range can be established for the relations Ca/Mg y K/Mg, also dependant from the soil types

In any case the following recomendation can be made:

Maintaining foliar level of Mg above 0.25% but being careful about increasing much this level, particularly in well coloured cultivars and, in any case do not exceed 1.0% even for green coloured cultivars. No clear indications can be made regarding Mg soil content, much dependant on soil type

To further clarify the role of Mg in mango and, particularly its benefits for mango production it will be necessary to do **experiments with different levels of Mg fertilization cultivars in different agroclimatic conditions and soil types.** Some particularly interesting new lines of research include the following:

1) Evaluate the effect of different concentrations of calcium and magnesium salts (particularly chlorides of Ca and Mg) in relation to different times of applications for control of IFB
2) Evaluate the impact of different levels of magnesium fertilization in the incidence of mango malformation

FIGURES

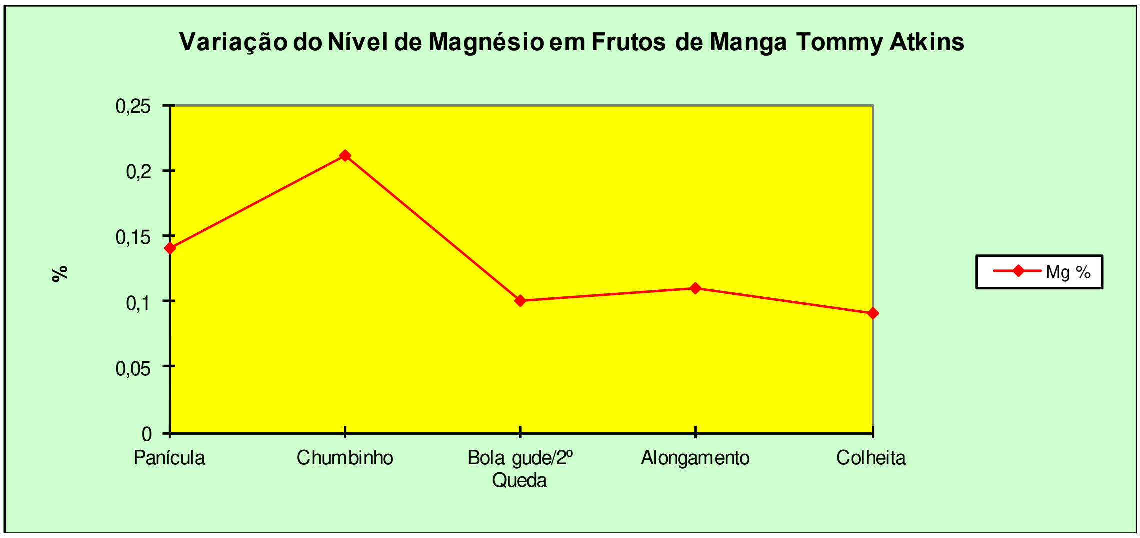

Fig.1 Variations of Mg levels in Tommy Atkins fruits

Legends: Panicula = Panicle; Chumbinho= Fruit set;
Bola gude 2ª queda = 2nd drop marble size; Alongamento = Fruit growth; Colheita = Harvest

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ANNEX 2. MANGO MAGNESIUM FERTILIZATION SURVEY

Name
Institution
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Air mail adress.
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1) How do you determine the quantity of magnesium to include in your fertilization program:
    - A) Based in leaf analysis
    - B) Based in soil analysis
    - C) Based on both
    - D) Following the traditional recommendations in your country
    - E) Following literature recommendations
    - F) By any other way
2) Indicate please the range and optimum levels of magnesium
    - A) In leaf analysis
    - B) In soil analysis
3) Indicate please any possible relation with other mango nutrients

4) Which fertilizers do you use to apply magnesium to mangoes?

    - A) In conventional cultivation
    - B) In organic cultivation
5) How do you apply magnesium?:
    - A) By foliar spray
    - B) To the soil
    - C) Through fertigation
6) Have you found that magnesium fertilization has any influence on:

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

7) Please indicate if you have any publication (scientific, extension or other) and/or lecture or powerpoint specific for magnesium fertilization in your country and, if available, please, email it to me or give the reference.
8) 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 magnesium fertilization, even for a different fruit crop than mango? If so, please indicate which one
    B) Are you (or somebody at your institution) interested in any line of research on magnesium fertilization in mango or other fruit crop? If so, please indicate the subject and reasons for it (i.e. any reason of those indicated in point 5).
    C) Are you interested in future cooperative trials inmagnesium fertilization in mango.

9) Add any comments you wish.

ANNEX 3. 'YARA TROPICAL FRUIT TREE PLANT MASTER'

Tropical Fruit Tree Plantmaster™

ANNEX 4. ‘KUMAR, N. MANGO IN INDIA MAXIMISING YIELD AND QUALITY THROUGH ADEQUATE CULTIVATION AND NUTRIENT MANAGEMENT’

ANNEX 5. 'INFORMACION MG-FRUTALES-MANGO'

Wachstum erleben.

K+S Group

5/09/2017

Informacion Mg-Frutales-Mango

CARLOS BAYON

ANNEX 6. 'BALANCED NUTRIENT MANAGEMENT INCLUDING MAGNESIUM AND MICRONUTRIENTS'

M. Andrea Gransee, K+S KALI GmbH.pdf

ANNEX 7. 'ESTA® KIESERITE A PRODUCT OF NATURE'


ESTA® Kieserit
A product of nature
KALI