7. Mango

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7.1. Introduction

The mango (*Mangifera indica* L.) belongs to the family Anacardiaceae, originally from southern Asia, more precisely from India, where it has been cultivated for more than 4,000 years from the Malay Islands. The number of species in the genus Mangifera is controversial. Mukherjee (1985) describes 35 species, while Bompard (1993) reports the existence of 69 species, with *Mangifera indica* as the most commercially important.

In Brazil, large areas of sexual origin (non-grafted) mangos are cultivated. They show considerable genetic variability as a result of intra- and inter-species breeding between the two species originally introduced by the Portuguese. These were the Indian breed, with oblong to rounded fruits, red skin and monoembryonic seeds, represented by the "Florida Tommy Atkins", "Haden" and other cultivars, and the Philippine breed with long fruit, red to green skin, polyembrionic seeds, normally used as a rootstock.

Mango flowering is polygamous, generally of the terminal type, however, lateral buds may also emerge (Campbell and Mallo, 1974), with the number of flowers varying from 500 to 4,000 per panicle. The fruit is a berry whose pulp is rich in sugars, low in acids and considerable quantities of Vitamin A (2.75 to 8.92 mg/100 g pulp), Vitamin C (5 to 178 mg/100 g pulp), thiamine (B1) and niacin (Alves *et al.*, 2002).

The roots are extremely long with small quantities of lateral rootlets. The fine roots constitute 77% of the root system and are found concentrated at depths between 20 to 40 cm and up to 60 cm from the trunk (Laroushilhe, 1980). In commercial plantations, where grafted mangoes are grown with irrigation, the

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root system is concentrated around the wet areas, highlighting the need for fertilization in this area.

The worldwide-cultivated area of mangoes in 2003 was approximately 3 million ha with a production of around 24 million mt. India is the primary producer with 43% of the total. Brazil, with an area of around 70,000 ha and a production of 600,000 mt, has 2.3 to 2.5%, respectively, of the worldwide area and production.

In Brazil, mango is one of the principal tropical fruits produced. The south-east and north-east regions have 51.4 and 42.6% of the total area of cultivated mango and are also the most important from a commercial and export perspective (Souza *et al.,* 2002). Although the total area grown has declined, there has recently been an increase in yield per unit area and exports. Between 2002 and 2003 the cultivated area of mango decreased from 67,661 to 67,591 ha, but total production increased from 782,300 to 842,300 mt. Exports in 2003 were about 133,300 mt, resulting in 73.4 million US dollars of fruit agro-business for Brazil (Anuário Brasileiro da Fruticultura, 2004).

There is a large potential to increase mango production in Brazil, principally in the south-east and north-east regions where soil and climate conditions are favorable. However, there are problems with not only disease but also inadequate nutrient and fertilizer management that result in small yields, and quality not acceptable for either domestic or export markets.

7.2. Climate and soil

The growth of mango depends on its response to the environment and the occurrence of vegetative and reproductive flushes of growth that are typical characteristic of this fruit tree.

7.2.1. Climate

In general, mango adapts and produces very well in an environment with mild temperatures (25°C day and 15°C night) and a drought period before flowering. At temperatures around 30°C during the fruit forming phase if water is available, by irrigation or rain, mango also produces well (Chacko, 1986). At temperatures below 15°C and/or above 30°C fertilization may be inhibited and without fertilization the embryo is aborted. Some monoembryonic cultivars like Haden do not produce any fruit at all when the climatic conditions, especially when temperatures are above 35°C. These climatic conditions cause the inhibition or degeneration of zygote embryonic development, accompanied by the premature falling of fruits (Mukherjee, 1953 and Sturrock, 1968).

Solar radiation is very important for mango growth and production because of its direct relationship to photosynthesis and carbohydrate production. However, the quantity of radiation depends on the time of year and the presence of clouds (Allen *et al.*, 1998). Data presented by Lima Filho *et al.* (2002) show that in mango producing regions, maximum radiation occurs in October (528 cal/cm^2/day), which corresponds to the flowering and fruit forming periods, respectively. The fact that mango is grown between latitudes of 27° N and 27° S, seems to suggest that it is a plant of neutral photoperiod, that is, flowering does not respond physiologically to changes in light intensity.

7.2.2. Soil

Although the mango has been grown, especially for commerce, in red or yellow Latosols, it adapts to a wide variety of soil types, including Quartz Neosols (Sandy Quartz) and Argisols (Podzolics) of low fertility, in most regions, including Brazil, where it is produced. However, its growth and production are influenced by the physical and chemical characteristics of the soil. It grows best in soils deeper than >2 m, which are well drained and without salinity problems. The soils most recommended are sandy clays, rich in organic matter, that are deep and flat (Magalhães and Borges, 2000).

7.3. Soil and crop management

Many factors are involved in the growth of a high quality mango tree, the most important of which is the preparation and fertilization of the growth medium on which the seedlings are grown. This varies greatly from one region to the next and depends on the fertility of the soil used in the mixture. In some regions, nurseries successfully use a mixture of 3 parts soil with one part cured manure, with the addition of 3 kg of single superphosphate and 500 g of potassium chloride per m^3 (Castro Neto *et al.*, 2002).

Mango propagated primarily by direct germination of the seed in the growth medium contained in black plastic bags, 30-35 cm high, 20-25 cm diameter and 200 microns thick, with perforations along the base and on the sides to facilitate drainage of excess water. In Petrolina, Pernambuco state, a semi-arid region, fertilization of the seedlings with macro-nutrients is done only via fertigation and the micro-nutrients are applied via foliar spray (Paulo Sérgio Nogueira, personal communication; Fazenda Boa Fruta, 2003).

Before planting the soil is ploughed and amendments, fertilizers and lime, added. Cultivation should be done to a depth of about 30 cm and at least 30 days before the rainy season (Pinto and Ramos, 1998). In the case of acidic soils, especially the Latosols in Central Brazil, corrective liming is required to increase soil pH to 6.0-6.5, the best range for mango, and also to increase the base saturation to between 60-70% (Pinto, 2000). Chalking is especially recommended when there are acidic subsoils with aluminium saturation >20% and Ca <0.5 $cmol_c/dm^3$ in any soil layer up to 60 cm deep (Andrade, 2004). Corrective fertilizer application is generally recommended for soils deficient in phosphorus (P) and potassium (K) (Tables 7.1 and 7.2). The fertilizers are broadcast over the entire area or in the planting row, followed by incorporation (Andrade, 2004; Sousa *et al.*, 2004).

Table 7.1. Amounts of phosphorus to apply according to clay percent and availability of phosphorus in the soil.

	Phosphorus availability in the soil		
Clay (%)	Low	Medium	Adequate
	P_2O_5 (kg/ha)		
≤15	60	30	0
16-35	100	50	0
36-60	200	100	0
>60	280	140	0

Source: Andrade, 2004; Souza, 2004.

Table 7.2. Amounts of potassium to apply according to the availability of potassium in the soil and the CEC (pH 7) or the percent clay.

Available K	Analysis interpretation	Amount K_2O
mg/dm^3	CEC at pH 7 <4.0 $cmol_c/dm^3$ or clay <20%	kg/ha
<15	Low	50
16-40	Medium	25
>40	Adequate	0
mg/dm^3	CEC at pH 7 >4.0 $cmol_c/dm^3$ or clay >20%	kg/ha
<25	Low	100
25-80	Medium	50
>80	Adequate	0

Source: Andrade, 2004; Souza, 2004.

Mangoes are usually planted in pits measuring 60 x 60 x 60 cm. Fertilization of the pit varies from region to region. The amount of fertilizer applied is based on the chemical analysis of the soil and the volume of the soil in the pit. For the acidic soils of the Cerrados, Andrade (2004) suggested the following quantities of corrective and of mineral and organic fertilizers per pit: 22L of cured bovine manure or 5 L of poultry manure, 151 g P_2O_5, 1.0 g boron, 0.5 g copper, 1.0 g manganese, 0.05 g molybdenum, 5.0 g zinc, 216 g calcareous dolomite (PRNT 100%) and the best surface soil. In addition, 100 g of F.T.E. formula BR-12 has been used as a source of micro-nutrients.

Raij *et al.* (1996) reported that in Sao Paulo the following fertilizers are used for mango: 10-15L bovine manure or 3-5L chicken manure, 200 g P_2O_5 as soluble phosphates or thermophosphates and 5 g Zn as zinc sulphate.

After planting, management is crucial to ensure that the seedling is firmly established in the pit to prevent it falling in the wind. Having a layer of organic mulch serves to prevent water loss by evaporation and allows better absorption of mineral or organic nutrients and, consequently, better establishment of the seedling in the field. The mulch also liberates certain chemical alleles, like phenolic composites, which control some weeds that compete with the mango for water and nutrients. Growing a surface cover of certain legumes, like mucuna and the pork bean, promotes the fixation of N and the cycling of nutrients (Carvalho and Castro Neto, 2002). However, growing legumes when the tree reaches the adult phase should be well planned to avoid an excess of N and possible problems of collapse of the cells in the pulp.

Plant density directly affects the availability of light between and within the plant crowns, and on orchard productivity and the quality of the fruit, especially better fruit coloration. Plant density also affects the cost of maintenance, especially fertilizers. In dry conditions, as in south-east and central-east Brazil, plant density is usually about 100 plants/ha (spacing 10 x 10 m), whereas in the semi-arid north-east a density of 250 plants/ha (8 x 5 m spacing) is not uncommon. At such a high density, pruning is necessary to eliminate excessive foliage and permit a better distribution of the nutrients and products of photosynthesis in the tissues within the crown. Pruning also allows the preparation of the plant for use of "paclobutrazol" (plant growth retardant, also known as "pestanal" or "bonsai" or "cultar").

7.4. Mineral nutrition

7.4.1. Uptake and export of nutrients

The mango is relatively tolerant of low soil fertility, consequently an adequate supply and uptake of nutrients gives a good response in plant growth and nutrient export via the fruit. Stassen *et al.* (1997), working with cv. 'Sensation' grafted onto 'Sabre' rootstock, observed that 29.6% of the total P in the plant was in leaf dry matter when the trees were six years old. Of the remaining P, 17.9% was in the roots, 16.6% in new branches, 14.9% in the fruits, 11.7% in the wood and 9.3% in the bark. Although the leaves contained the greatest proportion of P in the plant, a significant proportion (70.4%) is in the rest of the vegetative parts. Thus, a large percent P in the leaves does not necessarily indicate a high availability of P in the soil.

There are a few particularities with respect to the concentration of nutrients in mango fruit from different sources. Laborem *et al.* (1979) observed that the Haden cultivar fruits exported less than half the N (0.86 kg N/mt) compared to the fruits of Tommy Atkins (2.01 kg N/mt). Calcium in the fruit coming from Venezuelan orchards (Laborem *et al.*, 1979) is about six times greater (1.25 kg Ca/mt) than that in fruits harvested in Brazil (0.15 kg Ca/mt). On average, macro-nutrients occur in mango pulp in the following decreasing order of magnitude: K>N>P>Mg>Ca>Na and micro-nutrients: Fe>Mn>B>Zn>Cu. In the skin, the nutrients are in a different sequence to that in the pulp: for the macro-nutrients the order is N>K>Ca>Mg>P>Na and for micro-nutrients, Mn>Fe>B>Zn>Cu (Pinto, 2002).

7.4.2. Functions and importance of nutrients

Nitrogen (N): Nitrogen is one of the most important nutrients for the growth of mango and it has a relevant role in the production and quality of the fruits. Its effects are seen principally in the vegetative phase of growth, and considering the relationship that exists between vegetative and reproductive flushes (development of floral buds and fruit formation), N deficiency may adversely affect yield. Mangoes adequately nourished with N regularly develop shoots, which when they reach maturity have viable panicles able to bear fruit (Silva, 1997). Lack of N causes retarded development, less vegetative growth and reduced production of fruit (Jacob and Uexkull, 1958; Geus, 1964). Excess of N causes excessive vegetative growth, difficulty at floral differentiation, loss of yield and fruit quality, and an increased susceptibility to disease. In South Africa, McKenzie (1994) showed that mango leaves with more than 1.2% N were associated with fruits that had greenish spots on reddish skin. These same symptoms where observed by Pinto (2000) in mature fruits of cv Tommy Atkins in the Cerrados when leaf percentage N exceeded 1.3% (see appendix of chapter 7, Plate 7.1).

Phosphorus (P): Phosphorus favors root system development, production of a strong stem/trunk, and retention and maturation of fruits (Samra and Arora, 1997). Deficiency of P may result in a weaker root system, restricting the uptake of water and nutrients, slowing the maturation of the fruits, which acquire a course texture. Slowing growth, premature falling of leaves, drying and death of

branches and substantial decreases in yield are other symptoms of the P deficiency (Childers, 1966).

Potassium (K): Potassium deficiency symptoms occur in the oldest leaves as small red spots, irregularly distributed. The leaves are smaller and thinner than normal. With a more pronounced shortage of K, the spots coalesce and the leaf suffers necrosis along the edges. The leaves fall only when they are completely dead (Childers, 1966; Koo, 1968). An excess of K may cause an imbalance in the levels of Ca and Mg, which also causes browning along the edges and apex of the older leaves. The quality of the fruits, especially coloration of the skin, aroma, size, and shelf life, is improved when there is adequate K, which also increases the ability of the plant to withstand stress conditions, such as dry, cold, salinity and attacks of diseases and pests (Samra and Arora, 1997).

Calcium (Ca): Calcium is important in the assimilation of N and transport of carbohydrates and amino acids. Calcium plays an important role in the structural functions in the cellular membranes and walls throughout the entire plant. The fruits have an increased demand for Ca to maintain pulp consistency during growth. Generally, the fruits are firmer, with a better appearance, better resist handling and transport and have a lower incidence of physiological disturbance that causes the internal collapse of the pulp. Calcium is taken up more efficiently by the roots than it is from foliar applications. The greatest demand for Ca occurs during the post-harvest flush and the initial development of the fruits. In this period the demand for Ca increases and it should be readily available in the soil for uptake by the roots. Leaf applications are not efficient at reducing the incidence of fruit pulp collapse. Pinto *et al.* (1994) reported that one of the more serious problems related to quality is collapse of the internal pulp, attributed to an imbalance between low Ca and high N. These authors tested the effects of different Ca:N ratios in the soil and leaves. During the establishment of an orchard and before applying N fertilizer, they applied gypsum at 291 g m^{-2}, and maintained a ratio of Ca:N of 20:1 in the soil. Plants with a minimum ratio of Ca:N of 2.2:1 in the leaves produced an average yield of 245 fruits per plant with 97% of the fruits free from internal pulp collapse. On the other hand, plants with a Ca:N ratio in the leaves of 1:1, yielded only 139 fruits per plant, of which 60% had internal pulp collapse.

Magnesium (Mg): Magnesium occurs in the chlorophyll molecule and in enzymes that induce the formation of amino acids for protein synthesis. It also participates in P transport within the plant. Deficiency of Mg reduces development, causes premature shedding of leaves and decreases yield. Application of excess amounts of Ca and K decrease the uptake of Mg.

Sulphur (S): Sulphur is the principal component of amino acids and vegetable proteins. It is an enzyme activator and participates in chlorophyll synthesis. When deficient, mango growth is slowed and leaf loss is provoked. Its availability is reduced by the continuous use of fertilizers that do not contain S (Silva, 1997). Deficiency of S causes necrotic spots on a green background on the youngest leaves, there is also premature leaf shedding.

Boron (B): The symptoms of B deficiency first occur in the youngest parts of the plant, while its toxicity is seen at the extremities of the oldest leaves. Boron deficiency causes death of the apical bud, which results in an excessive number of lateral buds that develop tuft-shaped secondary branches (Agarwala *et al.*, 1988). The floral panicles are smaller and have fewer hermaphroditic flowers and consequently produce fewer fruits than plants well supplied in B (Singh and Dhillion, 1987). Rossetto *et al.* (2000) observed that, in the northern region of Sao Paulo state, B deficiency in cv. "Van Dyke" (average of 7.2 ppm B in the leaves) caused less abortion of fruits and a greater fruit yield compared to B deficiency in cv. "Haden" 2H (8.2 ppm B in the leaves).

Copper (Cu): Symptoms of Cu deficiency are seen frequently in young plants getting large amounts of N, or in the young shoots of adult plants. Copper deficiency in mango orchards in Sao Paulo state caused long, tender and "S"-shaped branches and leaves with downward curls, both on the lamina and the central vein. On the branches, Cu deficiency causes boil-like eruptions on the bark that, at times, weeps sap. Progressive terminal branch death may occur where new shoots were curved or "S"-shaped in the previous year (Quaggio and Piza Jr., 2001).

Iron (Fe): Iron deficiency is manifest by typical chlorosis in new leaves, which have a mesh of green veins contrasting with the yellow of the lamina. Severely affected leaves may be pale yellow, with little or no green in the veins. Young leaves are always affected first. In situations of acute deficiency branches and twigs may dye (Childers, 1966). Iron deficiency is associated with soils derived from calcareous material or acidic soils with very high levels of manganese (Mn). In Brazil, with the exception of a few soils in the north-east, Fe deficiency is rare in most regions. Sometimes excessive amounts of Mn in poorly drained soils can induce Fe deficiency in plants. Associated with an excess of Mn applying large amounts of P fertilizer may also induce Fe deficiency in mango.

Manganese (Mn): Mn deficiency causes reduced growth, similar to deficiencies of P and Mg. New leaves have a yellowish green lamina, with a noticeable green mesh between the veins, which are thicker than those associated with Fe deficiency. Manganese deficiency reduces tree growth. The first symptoms

appear on new leaves, which have a yellowish green background. When the deficiency is severe, the new leaves become chlorotic, with necrosis along the extremities of the lamina (Agarwala *et al.*, 1988). Liming and the application of large amounts of P decrease the availability of Mn in the soil.

Zinc (Zn): The principal symptom of Zn deficiency is the production of small narrow leaves. There is less branching and the branches have short internodes, resulting in reduced plant growth. Leaves are small, curled, thick and inflexible, and there is either more or less incidence of chlorosis between veins with a mottled aspect. Floral deformation or "dolling" and vegetative deformation or "witch's broomstick" are perhaps associated with Zn deficiency. Deficiency of Zn may be more serious in calcareous soils or in those that receive large amounts of lime and P fertilizers (Ruele and Ledin, 1955 and Geus, 1964).

7.5. Fertilization

Soil analysis: No recommendation for liming or fertilization should be implemented without first doing a soil and leaf analysis (Quaggio, 1996). The soil sample should represent, in the best way possible, the average composition of the soil in the area exploited by the mango root system. The latter depends on the cultivar, the soil, the irrigation system, the water regime, as well as crop management. There are two occasions one which to take soil samples. The first is to sample the whole area on which the orchard will be planted and the other is to sample orchards already planted. For the first, the samples are taken randomly from at least twenty locations to form a composite sample representing the whole area. For the second type of sampling twenty cores are taken from random positions within the area covered by the crown of the tree, avoiding recently fertilized soil. Soil samples are taken from the 0 to 30 and of 30 to 60 cm depth of soil. Calibration curves are used to relate soil analysis data to the response of a crop to each nutrient.

Leaf analysis: Leaf analysis is of fundamental importance in evaluating the nutrient requirements of the mango tree. This is because although soil analysis might indicate sufficiency of a nutrient, the roots may not be able to take up enough of the nutrient. Additionally, soil pH, salinity or antagonism between elements may influence nutrient uptake. Thus soil analysis may not provide a satisfactory index of nutrient availability.

Perennial plants maintain a large quantity of nutrients in their biomass, especially those responsible for vegetative growth, flowering and fruit formation. Such plants do not respond quickly to fertilization, except to that of N. Nutrients added in the vegetative phase will usually be taken up during the next production cycle. For mango this fact is very relevant because the leaves remain on the tree for a period of at least four years (Young and Koo, 1971). Also the ratio of nutrients may be important not only for production but also for fruit quality. Nutrient concentration in mango leaves is affected by several factors: a) leaf age; b) variety; c) leaf position on the twig; d) branches with or without fruit; e) height of sample on the plant; f) position of branches in relation to points of origin; g) soil type. The concentration of each nutrient in the leaves undergoes marked changes with age (Koo and Young, 1972; Chadha *et al.*, 1980).

At the age of 6 to 8 months the leaves, although still young, are already fully expanded and nutrient concentration are close to the optimum level for the sample. Catchpoole and Bally (1995) noted that between one and two months before flowering is the best time for taking leaf samples. When taking samples from an orchard the following procedures are recommended. a) Divide the orchard into separate sections of no more than 10 ha with trees of the same age and productivity growing on similar soil; b) collect whole, healthy leaves from the middle of the tree crown, from the four cardinal points, from normal branches recently matured from the previous flush of growth and not less than four months old; c) take four leaves per plant, from 20 plants selected randomly before the application of nitrates or other foliar fertilizer applied to break the dormancy of the floral buds.

Using all available results, Quaggio (1996) proposed limits of classifying the results of leaf analysis to define deficient, adequate and excessive nutrient levels (Table 7.3). An alternative method of interpreting leaf analysis data is the Diagnosis and Recommendation Integrated System (DRIS). This system evaluates the nutritional state of the plants by considering the balance between nutrients (Sumner, 1999).

Pinto (2002), using the DRIS method, found that in orchards with high productivity, nutrients limited yield in the following sequence: Mg>Cu = K = Fe>Ca = B>Mn = Zn = N = P. In orchards with low productivity the order was different: B>Cu = Zn>Ca>N>Fe>Mn>P>K = Mg. Where nutrients were in excess they limited yield in the following order: Fe>K = Mg = Cu = Zn>Ca = B>Mn>N = P in the highly productive orchards and Fe>P>Cu>Zn>Mn = K>B>Mg>N>Ca, in the poorly productive orchards.

Fertilization for initial growth: In general, the quantities of N, P_2O_5 and K_2O applied during the initial stage of establishment and growth vary according to the age of the plants and the level of P and K in the soil. For dryland orchards in Sao Paulo and in Central Brazil (Table 7.4) the amounts are different to those for irrigated orchards in the semi-arid north-eastern region (Table 7.5). As often as possible, simple superphosphate should be used as a source of P and ammonium sulphate as a source of N, aiming to also supply S.

During the early stages of growth in dryland orchards, K and N should be divided into three applications: at the start and then during and at the end of the rainy season. In irrigated orchards, the amounts required should be divided into six applications per year on clayey soils and in twelve applications on sandy soils, beginning with 10 g of N per plant at 30 days after planting. Phosphorus should be divided into two applications starting from the second year.

Table 7.3. Ranges of mango leaf nutrient composition.

Nutrients	Ranges of compositions		
	Deficient	Adequate	Excessive
Macro-nutrient		g/kg	
N	<8.0	12.0-14.0	>16.0
P	<0.5	0.8-1.6	>2.5
K	<2.5	5.0-10.0	>12.0
Ca	<15.0	20.0- 35.0	>50.0
Mg	<1.0	2.5-5.0	>8.0
S	<0.5	0.8- 1.8	>2.5
Micro-nutrient		mg/kg	
B	<10	50-100	>150
Cu	<5	10-50	-
Fe	<15	50-200	-
Cl	-	100-900	>1600
Mn	<10	50-100	-
Zn	<10	20-40	>100

Source: Quaggio, 1996.

Table 7.4. Amounts of N, P_2O_5 and K_2O recommended in the initial phase and growth of the mango orchard in dryland conditions, by plant age and available P and K in the soil.

Age	N	P-resin (mg/dm^3)				K-exchangeable (mmol$_c$ dm^3)			
		0-5	6-12	13-30	>30	0-0.7	0.8-1.5	1.6-3.0	>3.0
yr	g/plant	P_2O_5 (g/plant)				K_2O (g/plant)			
0-1	80	0	0	0	0	40	20	0	0
1-2	160	160	100	50	0	120	90	50	0
2-3	200	200	140	70	0	200	150	100	60
3-4	300	300	210	100	0	400	300	200	100

Source: Raij *et.al.*, 1997.

Table 7.5. Amounts of N, P_2O_5 and K_2O recommended for the initial phase and growth of irrigated mango in the semi-arid Brazilian regions.

Age	N	P-Mehlich-1 (mg/dm^3)				K-exchangeable (mmol$_c$/dm^3)			
		<10	10-20	21-40	>40	<0.16	0.16-0.30	0.31-0.45	>0.45
months		------------ P_2O_5 (g/plant) ----------				---------- K_2O (g/plant) ------------			
At planting (g/pit)									
0-1	-	250	150	120	80	-	-	-	-
1-2	150	-	-	0	0	40	0	0	0
2-3	210	160	120	80	40	120	100	80	60
3-4	150	-	-	-	-	80	60	40	20

Source: Silva *et.al.*, 1996.

Fertilization for production: When the orchard is producing fruit the amounts of fertilizer applied depend on the expected yield and the results of soil, leaf and, more recently, fruit (dry matter) analysis. Productivity determines, as a function of nutrient export via the fruits at harvest, the minimum quantity of nutrients to be replaced and also the potential economic return from applying fertilizers (Quaggio, 1996).

Liming and chalking: In production orchards, soil analysis is recommended at least every two years and lime application when the base saturation of the soil is less than 60%. Chalk is usually applied at the end of the rainy season while there is still sufficient moisture in the soil for the lime to be incorporated and the acidity to be corrected. In irrigated plantations in semi-arid regions, chalk should be applied shortly after harvest.

Gypsum may be applied with lime to help meet the large demand for Ca by the mango plant. This is especially so in Cerrado soils poor in Ca to avoid collapse of the pulp (Pinto *et al.*, 1994). The quantity of gypsum applied depends on the texture of the soil and its chemical analysis. The amount varies from 0.5 mt/ha in sandy textured soils to 2.5 mt/ha in clayey soils. When leaf Ca exceeds 30 g/kg there is no need to apply gypsum.

7.5.1. Organic fertilization

The application of organic manures for maintenance and to prepare for the next production phase is usually done soon after harvest, primarily to replenish the N exported by the fruits. The application of 10 to 30 L/plant/yr of cured bovine manure or 3 to 5 litres of chicken manure is recommended. Goat manure is used in place of bovine manure in the semi-arid region because of its greater availability.

In organic mango production, the use of organic compost, such as worm compost, bio-fertilizers and organic acids (humic substances) are already quite common. Another alternative approach, used as much in organic as in conventional cultivation, is orchard management with mixed species. These are used to cover the soil and/or act as a green fertilizer (legumes and non-legumes) and are known as cocktail vegetables. However much care needs to be taken in order to avoid the availability of excessive amounts of N.

7.5.2. Mineral fertilization

Mango responds well to N but its use is difficult to manage because the rate of growth of the adult plant, which is affected by N supply, is inversely proportional to its productivity. Trees that produce excessive vegetation have more difficulty with floral differentiation and produce few fruits.

The excessive application of P, besides being not economic, may promote antagonism with other nutrients and effect plant metabolism. Raij *et al.* (1996) recommend the application of NPK in the production phase of the mango in dryland conditions in Sao Paulo, based on productivity and on the levels of nutrients available in the soil (Table 7.6). For irrigated mango plants in Brazilian semi-arid regions, Silva *et al.* (2002) recommended fertilization using the same parameters (Table 7.7).

Boron is the micro-nutrient that most effects mango productivity and fruit quality (Ram and Sirohi, 1989; Coetzer *et al.*, 1984). Rossetto *et al.* (2000) observed that the application of 2.0 kg/ha of B (as borax) to the soil promoted significant increases in the production of the cultivars "Van Dyke", "Haden" and "Tommy Atkins". Boron can also be applied as a foliar spray during the production of new vegetation or before or during the flowering period. Quaggio (1996) recommended the application of a 0.2% solution of boric acid in two annual applications, the first a little before flowering, when the primordial flowers are already visible and the second during the period of plant growth. The latter application should be done when there is a flush of new buds, because the young leaves absorb the nutrient more easily.

Manganese and Zn deficiencies are also frequent in the mango. Pereira *et al.* (1999) observed that 68% of the orchards examined in the Submedio San Francisco showed severe Zn deficiency.

Table 7.6. Fertilizer recommendations for dryland mango production, as a function of plant productivity and availability of nutrients in Sao Paulo.

Productivity expected	N in leaves (g/kg)			P-resin (mg/dm³)				K-exchangeable (mmol$_c$/dm³)			
	<12	12-14	>14	<6	6-12	3-30	>30	<0.8	0.8-1.5	1.6-3.0	>3.0
mt/ha	N (kg/ha)			P_2O_5 (kg/ha)				K_2O (kg/ha)			
<10	20	10	0	30	20	10	0	30	20	10	0
10-15	30	20	0	40	30	20	0	50	30	20	0
15-20	40	30	0	60	40	30	0	60	40	30	0
>20	50	40	0	80	60	40	0	80	60	40	0

Source: Raij *et al.*, 1996.

Table 7.7. Quantities of N, P_2O_5 and K_2O recommended for production in irrigated mango orchards in a semi-arid region, as a function of productivity and of availability of nutrients.

Productivity expected	N in leaves (g/kg)				P-Mehlich-1 (mg/dm³)				K-soil (mmol$_c$/dm³)			
	<12	12-14	14-16	>16	<10	10-20	21-40	>40	<1.6	1.6-3.0	3.1-4.5	>4.5
mt/ha	N (kg/ha)				P_2O_5 (kg/ha)				K_2O (kg/ha)			
<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	80	40	0	150	100	50	0	250	150	75	0

Source: Silva *et al.*, 2002.

Pre-harvest fertilization: In non-irrigated orchards, P should be applied in a single dose, before flowering, and incorporated with a medium-weight plough. Of the N and K, 40% should be applied at the beginning of the rains, and the remainder after flowering and at the start of fruit bearing. In irrigated conditions, around 40% of the P should be applied before flowering and 50% of the N applied pre-harvest, after the start of fruit setting. For K, applications should be distributed throughout the entire cycle of production, giving a greater proportion after the start of fruit bearing.

Post-harvest fertilization: Of the total N and K applied, 40% should be after harvest and 20% at the end of the rainy season, generally at the beginning of March in the conditions of Sao Paulo state and Central Brazil. In irrigated conditions, half of the N, 60% of the P and 25% of the recommended K are applied post-harvest.

7.6. Irrigation

Irrigation is important in the management of mango orchards because it increases productivity and improves fruit quality (Coelho *et al.*, 2002). With irrigation yields of up to 40 mt/ha are possible, without irrigation average production varies from 8 to 12 mt/ha.

7.6.1. Irrigation methods

Success in using irrigation technology depends on the method and the strategy of water management adopted throughout the whole cycle of growth. In general, any irrigation method such as furrow, flooding, dripping and spraying with fixed or moveable laterals may be used for the application of water. The choice of method depends on soil and water availability, and economic factors. Soil and water characteristics include topography, salinity, water availability and climate characteristics like temperature, wind speed, evaporation etc. Economic factors include the cost of installation, operation and maintenance, and profitability. There are also human factors like the quality of available labour, tradition and level of education (Silva *et al.*, 1996).

In the north-eastern semi-arid zone, where there is a shortage of water resources, irrigation is essential and the efficiency of its use is very important. Therefore, surface irrigation is least recommended because of its low efficiency compared to pressurized methods of micro-irrigation like drip and jets. The initial cost of installation of a micro-irrigation system per hectare of mango varies from R$ 3,800 to R$ 4,500 (US$ 1,366 to US$ 1,618). Conventional sprinkler irrigation has disadvantages, including greater energy consumption and a lower efficiency (50 to 75%), mainly under high wind conditions, indicating that there is a higher water loss (Allen, 1992). Other disadvantages are related to the impacts on flower and fruit loss, and reduced numbers of pollinating insects. The drip system is very efficient (70 to 95%), requires less energy but has a high start-up cost. For mangos spaced at 8 x 5 m, a total of 5 to 6 drip emitters per plant are sufficient to attain a wetting of 16% of the area occupied by the roots (Coelho *et al.*, 2001). Using jets is also a very efficient method (70 to 95%), and is widely used in mango orchards. It wets a larger area of soil compared to the drip system and has a discharge rate that varies from 15 to 200 L/h with pressures in the range of 8 to 35 m water column (Silva *et al.*, 1996).

7.6.2. Water requirements

The amounts of water required depend on climatic conditions but also vary between the non-productive period (juvenile phase) that goes from planting until the beginning of production and the productive phase from flowering to harvest (Coelho *et al.*, 2002).

It is recommended that the initial planting is done at the beginning of the rains, because soil moisture provides sufficient water for the seedling to take root and for its initial growth. In the years before the productive period, water is applied primarily in the dry season to meet the demand of the growing plant.

In sub-humid regions water stress is necessary for approximately 60 – 70 days, after the application of paclobutrazol to favor flowering. The greatest demand for water is during fruit growth especially the period between the fourth and sixth week after setting the fruits. In this phase, a period of only 30 days without irrigation is sufficient to reduce the size of the fruits by 20% in comparison to an irrigated crop (Schaffer *et al.*, 1994).

7.6.3. Fertigation

Fertigation, the method of applying fertilizer with the irrigation water, has been a common practice in orchards producing fruit for export. This practice has numerous advantages, besides greater productivity and better quality of the fruit (Pinto *et al.,* 2002). Water is used more efficiently and nutrients can be applied at the right time and in the correct quantity, employing less manual labour. Fertilizer is distributed more evenly where there is water and there is less risk of environmental contamination. However, there are some limitations such as non-uniform application of fertilizer when the irrigation system is poorly laid out, possibility of precipitation of chemical products causing blockage of the emitters and the danger of contaminating the water source (Silva *et al.*, 1996).

Fertilizer solubility and compatibility are important factors in deciding which fertilizers should be used in fertigation systems. Urea and ammonium nitrate, for example, are highly soluble fertilizers and compatible with all other fertilizers,

however ammonium sulphate is incompatible with calcium nitrate and cannot be used in fertigation (Pinto *et al.*, 2002).

7.7. References

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