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Fertilizing for High Yield and Quality

Tropical Fruits of Brazil

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Tropical Fruits of Brazil

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Introduction

This discusses the cultivation, mineral nutrition and fertilization of 11 widely grown tropical, perennial fruits. Many of the data are from Brazil, with cross-references to production systems in other tropical climates, so that the observations are applicable to other parts of the world.

The International Potash Institute (IPI) considers that this topic is very important because the vast range and variety of tropical fruits offer great potential for the diversification of human nutrition. Tropical fruits are rich in vitamins, and have high nutritive value and very special, individual flavors: characteristics that ensure an ever-increasing demand for them. The boom in banana production for the U.S. and European markets in the early 20th century was soon followed by increasing orange juice consumption, and increasing demand for these two commodities stimulated expansion of banana and citrus plantations in Central America and the Caribbean. Since then, fruits from the tropics have become part of the everyday diet for many of those living in the developed countries, however, as their value is ever more appreciated in the less-developed countries demand continues to increase.

From the beginning of tropical fruit production worldwide, Latin America has been one of the most important producers, and it is now becoming an important exporter as a result of the globalization of trade in food. For fresh fruits, rapid delivery “from the field to the table” relies on modern transportation systems, storage infrastructure, and processing technologies. Expansion of this segment of the food production chain presents consumers with diversity and choice, and often introduces them to fruits with which many are not familiar. The increasing number of people aware of the need for healthy eating should guarantee the further expansion and successful development of this market in the near future. The diversification of agriculture into fruit production will also have environmental benefits through sustaining biodiversity in the landscape.

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The increasing worldwide demand for tropical fruits and their processed products requires the increased yields that can be achieved through improvements in cultivation and production techniques, and fruit processing and storage. In many cases, the widely adopted, traditional methods of production result in small yields, poor fruit quality and a very short shelf life. Better mineral nutrition of these tropical fruits is one of the principle keys to improving this situation, because most tropical soils on which these fruits are grown are deficient in nutrients, and perennials usually require larger amounts of nutrients than do annual crops. Another factor that boosts the need for larger amounts of fertilizer is the increasing use of irrigation as another means to improve yields.

Many of the data presented in this crop bulletin are from Brazil, for two reasons. First, Brazil is one of the world's major producers of tropical fruits. Historically, the production of many tropical fruits has spread or migrated from the region where they originated. Consequently, countries currently in the top rank of world production are often not those where the fruit was originally introduced into agriculture. Brazil is a case in point, as shown in Table 1.

Second, the yields of tropical fruits in Brazil are mostly above the world average (see Fig. 1)[2]. Brazilian government bodies and other research and development institutions in the agricultural sector recognize the importance of tropical fruit production. In the 1990s, the Ministry of Agriculture and Food Supply launched the special PROFRUTA program to support research and extension regarding tropical fruits, and this program became one of the strategic priorities in national agricultural development; its benefits are already perceptible. Tropical fruit production has become an important source of revenue for the national economy: in 2004, exports of fruit juices (including concentrates) generated US$ 1.1 billion, and exports of fresh fruits and nuts brought in US$ 592 million (including US$ 115 million from exports of cashew nuts[3]). In Brazil, the revenue from fresh fruit exports has nearly doubled during the last 10 years, and there are positive prospects for further increases in the future.

Tropical fruits are planted throughout Brazil, wherever the climate is suitable (see Table 2 and Fig. 2), with some states specializing in specific crops. For example, São Paulo has 71% of the total national planted area of citrus, Ceará has 53% of the cashew trees, and Bahia has 43 and 27%, respectively, of the papaya and coconut areas. The federal and state governments' promotion of tropical fruit production has caused some changes in the areas planted in the

[2] Banana is an exception because banana production in Brazil is mostly for the domestic market, and the varieties differ from those grown for export in Ecuador, Costa Rica, etc.

[3] Data published by the Secretaria da Politica Agricola at www.agricultura.gov.br.

various states. The main natural factor restricting production, especially in the regions near the equator (except Amazonia), is water deficiency, caused by insufficient rainfall and high evaporation. Consequently, recently planted areas are associated with irrigation projects. In the north-eastern states, more than 30 areas being developed for agricultural production are on irrigated land. The largest one, specializing in tropical fruits, is the Petrolina-Juazeiro region, near the Sobradinho hydroelectric power station and dam on the São Francisco river. Most of the mangoes and other fruits exported from Brazil originate from this region.

The production of tropical fruits in Brazil has benefited from cooperation between the IPI and the Brazilian Corporation of Agricultural Research (EMBRAPA). Among the activities fostered by this cooperation was a joint research program on the fertilization of tropical fruits, which was launched jointly by IPI and EMBRAPA in 2001. Some of the data presented here are based on the results of field experiments in the north-eastern region of Brazil during 2001–2005.

Each of the 11 chapters in this Crop Bulletin is devoted to one of the following fruits: Acerola, or West Indian cherry *(Malpighia emarginata)*, Banana *(Musa spp.)*, Cashew *(Anacardium occidentale)*[4], Citrus[5], Coconut *(Coco nucifera)*[6], Guava *(Psidium guajava)*, Mango *(Mangifera indica)*, Papaya *(Carica papaya)*, Passion-fruit *(Passiflora alata)*, Pineapple *(Ananas comosus)* and Soursop *(Annona muricata)*. Each chapter has a brief overview of the geography of the area where the fruit is grown, the characteristics of the climate and soil, and recommendations for soil preparation and amelioration, if required. In general, the soils where tropical fruits are grown in Brazil are red or yellow Latosols with tropical Podzols in the inner regions and sandy soils in the coastal zone. All these soils tend to be acidic, with aluminum and iron oxides, therefore, liming before planting is a common practice. To increase the base saturation of a Latosol and bring the soil pH up to 6.0–6.5, producers usually apply $CaCO_3$ at 5–6 mt/ha. The water requirement of each fruit type is discussed in its chapter, together with the amounts of nutrients removed in the harvested produce, the function of each nutrient, and a description of the visible symptoms caused by their deficiency. The authors emphasize fertilization practices for the various

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[4] Cashew trees in Brazil are grown mostly for their nuts, or fruit pistils, called "apple". The "apple" itself is also used to produce juice and jam.

[5] Mostly oranges. The climate in Sao Paulo state, the major producer of oranges in Brazil, is tropical.

[6] Coconut in Brazil is produced mostly for its "milk", and not for copra, as in Asian and Pacific countries.

phases of plant development from nursery to production, with attention to irrigation (including fertigation).

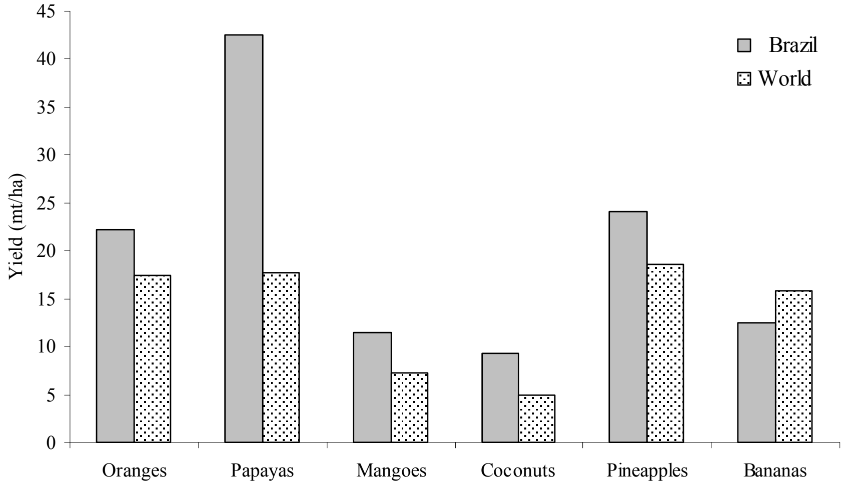

Fig. 1. Average 2000-2005 yield of some tropical perennial fruits in Brazil and the world, mt/ha (*Source:* FAOSTAT, 2004; www.fao.org).

Table 1. Countries of origin of some tropical fruits, and the major producing countries.

Plant	Botanical name	Origin	Major producing countries[1]	Brazil's rank	Harvested Area, 2004 (1,000 ha)		Production, 2004 (1,000 mt)	
					World	Brazil	World	Brazil
Avocado	*Persea gratissima*	Central America	Mexico, Indonesia, United States, Brazil, Colombia	4	417	13	3,078	173
Banana[2]	*Musa spp.*	South-east Asia, Pacific Ocean islands	India, Brazil, China, Ecuador, Philippines	2	4,446	485	71,343	6,603
Cashew	*Anacardium occidentale*	South America (Brazil)	Nuts: Viet Nam, India, Nigeria, Brazil, Indonesia	4	3,078	682	2,292	212
			"Apples": Brazil, Guyana, Madagascar	1	626	600	1,678	1610
Oranges	*Citrus*[3]	South-east and East Asia	Brazil, USA, Mexico, India, Spain	1	3,601	820	62,814	18,257
Coconut	*Coco nucifera*	South-east Asia or South America	Indonesia, Philippines, India, Brazil, Sri Lanka	4		275	54,737	2974
Lime[4]	*Citrus aurantifolia*	South-east Asia	Mexico, India, Argentina, Iran, Brazil	5	802	52	12,339	1,000
Mango	*Mangifera indica*	South and South-east Asia	India, China, Thailand, Mexico, Pakistan, Indonesia, Philippines, Brazil	8	3,690	68	26,574	850
Papaya	*Carica papaya*	Central and South America	Brazil, Mexico, Nigeria, India, Indonesia	1	375	37	6,709	1,650
Pineapple	*Ananas comosus*	South America (Brazil, Bolivia, Paraguay)	Thailand, Philippines, Brazil, China, India	3	843	55	15,288	1,435

(1)Five major producers in order of gross production volume (except mangoes).
(2)Dessert varieties only.
(3)Genus.
(4)Also known as Key Lime. Statistical data for lemons and limes, the last predominant in Brazil.

Source: FAOSTAT, 2004.

Table 2. Planted areas of the main tropical fruits in Brazil by state, 2003 (1,000 ha and % of the total national area).[(1)]

State	Avocado		Banana		Cashew		Coconut		Guava		Mango		Orange		Papaya		Passion fruit		Pineapple	
	1,000 ha	%	1,000 ha	%	1,000 ha	%	1,000 ha	%	1,000 ha	%	1,000 ha	%	1,000 ha	%	1,000 ha	%	1,000 ha	%	1,000 ha	%
North (Amazonia)																				
Amazonas (AM)	0.5	4.5	35.0	6.8	0.0	0.0	0.6	0.2	0.1	0.4	0.4	0.6	2.8	0.3	1.2	3.2	0.5	1.5	3.1	5.3
Roraima (RR)	-	-	4.6	0.9	0.0	0.0	-	-	-	-	-	-	0.3	0.0	0.6	1.6	-	-	0.2	0.3
Pará (PA)	0.1	0.5	54.5	10.6	2.1	0.3	22.4	8.0	0.1	0.6	-	-	12.4	1.5	1.1	2.9	3.5	9.9	9.7	16.7
Tocantins (TO)	0.0	0.1	5.3	1.0	0.2	0.0	0.7	0.2	0.0	0.0	0.4	0.6	0.2	0.0	0.0	0.0	0.1	0.4	1.9	3.3
North-east																				
Maranhão (MA)	0.0	0.0	11.8	2.3	13.4	2.0	1.7	0.6	-	-	0.9	1.4	1.4	0.2	0.1	0.4	0.0	0.1	1.9	3.2
Piauí (PI)	0.0	0.3	2.5	0.5	154.7	22.7	1.5	0.5	0.1	0.3	1.8	2.6	0.6	0.1	0.0	0.1	0.0	0.1	0.0	0.1
Ceará (CE)	0.4	3.9	42.1	8.2	364.6	53.4	39.5	14.0	0.5	2.6	4.5	6.6	1.6	0.2	1.6	4.5	2.5	7.0	0.0	0.1
Rio Grande do Norte (RN)	0.1	1.4	6.3	1.2	113.8	16.7	33.5	11.9	0.4	2.2	3.1	4.5	0.4	0.0	0.8	2.3	0.3	0.7	3.7	6.3
Paraíba (PB)	0.1	1.1	16.3	3.2	7.6	1.1	11.9	4.2	0.6	3.2	2.5	3.6	0.8	0.1	1.2	3.3	0.7	2.1	9.1	15.6
Pernambuco (PE)	0.2	1.9	39.6	7.7	5.5	0.8	15.0	5.3	4.7	26.7	7.2	10.6	0.9	0.1	0.6	1.6	0.7	2.0	0.9	1.5
Alagoas (AL)	-	-	4.1	0.8	0.2	0.0	14.1	5.0	0.0	0.1	1.0	1.5	3.8	0.5	0.1	0.2	0.9	2.7	0.7	1.2
Sergipe (SE)	-	-	4.6	0.9	-	-	40.0	14.2	0.2	1.0	1.4	2.0	51.1	6.1	0.4	1.1	4.1	11.6	0.5	0.8
Bahia (BA)	0.0	0.3	53.7	10.4	19.5	2.9	76.4	27.1	2.7	15.3	18.1	26.5	48.3	5.8	16.0	43.8	8.1	23.0	4.7	8.0
South-east																				
Minas Gerais (MG)	0.9	8.5	39.1	7.6	-	-	2.3	0.8	0.6	3.5	5.0	7.3	40.8	4.9	0.8	2.2	2.6	7.4	9.1	15.6
Espírito Santo (ES)	0.8	7.4	19.5	3.8	-	-	10.5	3.7	0.4	2.0	0.5	0.7	2.5	0.3	10.5	28.6	2.9	8.3	1.9	3.3
Rio de Janeiro (RJ)	0.0	0.4	25.6	5.0	-	-	4.1	1.5	0.6	3.5	0.3	0.4	7.1	0.8	0.1	0.3	2.1	6.0	2.4	4.2
São Paulo (SP)	4.6	45.2	57.2	11.1	-	-	2.6	0.9	4.9	27.5	19.4	28.4	600.1	71.7	0.2	0.5	2.8	7.9	3.5	6.1
South																				
Paraná (PR)	1.5	14.8	9.8	1.9	-	-	0.1	0.0	0.3	1.6	0.6	0.8	14.9	1.8	0.1	0.2	0.6	1.7	0.4	0.6
Santa Catarina (SC)	-	-	29.7	5.8	-	-	-	-	0.0	0.0	-	-	9.6	1.2	0.0	0.0	0.6	1.8	0.1	0.1
Rio Grande do Sul (RS)	0.7	6.6	10.8	2.1	-	-	-	-	0.7	4.2	0.1	0.2	27.1	3.2	0.3	0.9	-	-	0.3	0.5
Center West																				
Mato Grosso (MT)	-	-	11.7	2.3	0.9	0.1	2.3	0.8	-	-	0.3	0.4	1.0	0.1	0.1	0.2	0.3	0.9	1.0	1.8
Goiás (GO)	0.1	0.5	13.1	2.5	-	-	0.9	0.3	0.6	3.5	0.3	0.4	6.1	0.7	0.2	0.5	1.0	2.9	2.0	3.4
Brazil	10.1	100	514.5	100	682.5	100	281.6	100	17.8	100	68.5	100	836.7	100	36.6	100	35.1	100	58.2	100

[(1)]Only states with 1% and more of national planted area of each of 10 selected fruits.

Source: IBGE, Produção Agrícola Municipal, 2005.

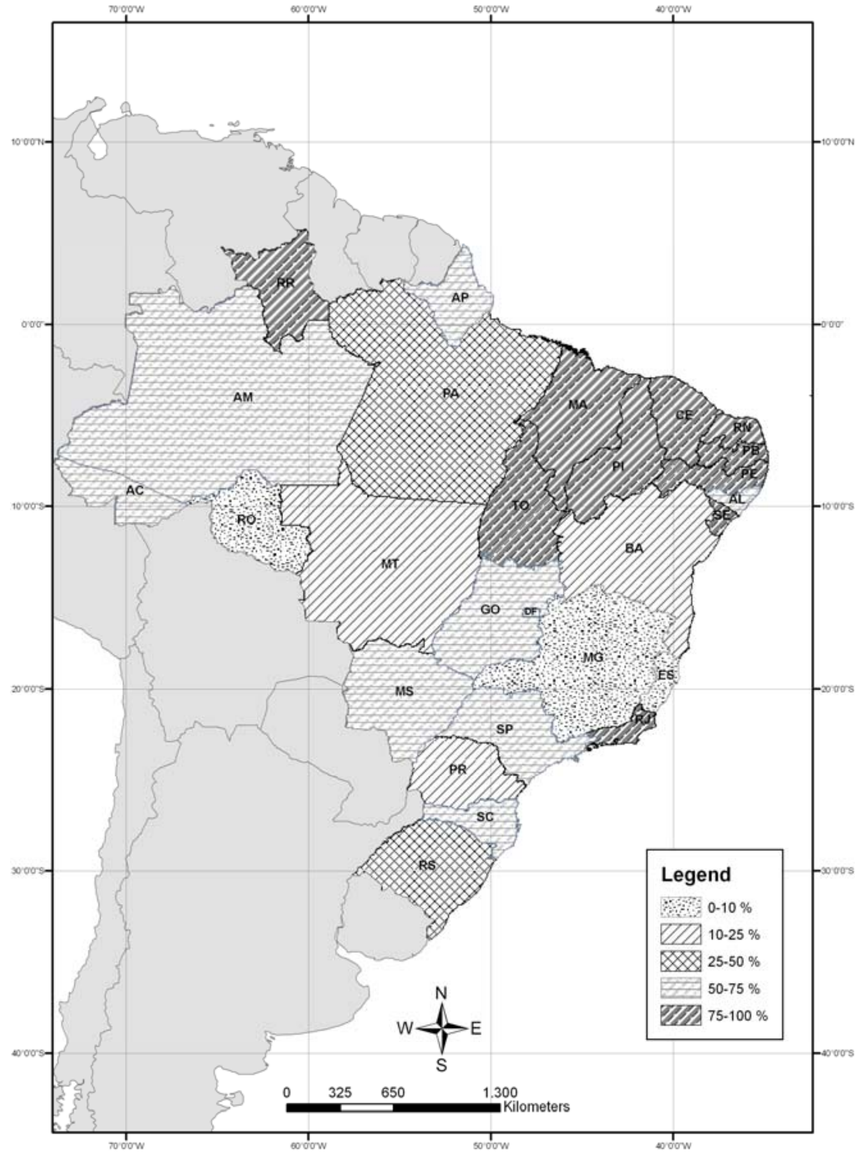

Fig 2. Share of tropical fruits: avocado, banana, cashew, citrus (oranges and others), coconut, guava, mango, papaya, passion fruit in the total planted area of permanent crops by states of Brazil, 2003 (*Source:* IBGE, Produçao Agrícola Municipal, 2005; www.ibge.gov. Map design by Dr. R.B. Prado, Embrapa National Soils Research Center).

1. Acerola

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Fábio Rodrigues de Miranda[1]
Humberto Silva[2]

1.1. Introduction

The acerola shrub (*Malpighia emarginata*; see appendix of chapter 1) is a tropical plant that produces fruit with a large concentration of vitamin C. It is native to the Caribbean Islands, Northern South America, Central America and Southern Mexico. In Brazil, its cultivation has increased from 1988 to 1992, owing to the discovery of its importance to human nutrition as a result if its richness in vitamin C, estimated at between 1,200 and 1,900 mg/100 g of pulp (Paiva *et al*., 2003).

Brazil has seen a considerable expansion of the area cultivated with acerola, principally because of its nutritional qualities, ease of cultivation and appropriate climatic conditions. These factors were responsible for the large increase in commercial plantations and, as a result, the emergence of pests and diseases.

Table 1.1 shows that the total area of acerola in Brazil is more than 10,000 ha, with Bahia state, followed by Pernambuco and Ceará as the greatest producers of this fruit shrub. The production is estimated at 33,000 mt of fruit, principally originating from the north-eastern region and from Sao Paulo state (IBGE, 2004).

The export of acerola, which is largely destined for the USA, Germany, France and Japan, is estimated to be about 37 to 43% of the total production (Manica *et al*., 2003), i.e. around 12,800 mt.

In spite of its current elevated status as an economically important crop for many regions, as shown by the annual increase in the planted area, it can be

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assumed that little attention has been given to the considerable nutritional benefits of acerola.

Table 1.1. Area harvested and quantity of acerola produced in the principle states of Brazil in 1996.

State	Area harvested	Production
	ha	mt
Bahia	1,881	3,458
Pernambuco	1,467	7,625
Ceará	1,358	4,724
Paraíba	1,156	2,686
São Paulo	956	3,759
Pará	935	1,814
Paraná	620	1,751
Rio Grande do Norte	584	2,683
Minas Gerais	443	978
Maranhão	317	593

Source: IBGE, Censo Agropecuário, 2004.

1.2. Climate, soil and plant

1.2.1. Climate

The acerola shrub grows as well in tropical as in subtropical climates, the ideal temperature is around 26ºC (Simão, 1971; Ameida and Araújo, 1992; Teixeria and Azevedo, 1995).

Although adapted for cultivation in semi-arid regions, the largest production occurs in regions with an evenly distributed annual average precipitation of between 1,200 and 1,600 mm (Gonzaga Neto and Soares, 1994). In regions with less precipitation, the leaves fall from the shrubs in the dry season, but grow again during the rainy season.

The quality of acerola fruit is largely influenced by solar radiation, and there is a positive correlation between the composition of ascorbic acid and the intensity of solar radiation (Nakasone *et al*., 1968).

1.2.2. Soil

The acerola shrub can be grown on a range of soil types, from sandy to clay-based soils, as long as the fertilization and drainage requirements are met (Gonzaga Neto and Soares, 1994). However, soils of medium fertility and sandy clay texture are the most productive due to their increased capacity to retain water (Simão, 1971).

1.2.3. Plant

The acerola shrub has a low basic water potential. In 12-month-old plants grown in polyethylene pots in clay soil, under a mesh canopy, the leaf water potential before dawn is around –1.0 MPa (Oliveira, 1996). Non-irrigated adult plants (seven years old) have a pre-dawn leaf water potential of –0.4 MPa during the rainy season and –1.5 in the dry season (Nogueira *et al*., 2000).

Stomatal conductance and transpiration of this species are very small, compared to other fruit trees (Oliveira, 1996; Nogueira *et al*., 2000). Despite this, a deficit in vapour pressure is more strongly correlated with the leaf water potential than with the stomatal resistance. This, on the other hand, seems to depend more on solar radiation, especially in the dry season. The stomatal system does not seem to be very efficient in avoiding water loss through the leaves and the low basic water potential acts principally as an internal adjustment for the plant.

Nogueira *et al*. (2000) found maximum rates of photosynthesis in the range of 6.0 to 6.40 µmol CO_2 m^{-2} s^{-1}, values that are within the accepted limit for deciduous fruit plants (6.5 to 20 µmol CO_2 m^{-2} s^{-1}) (Korner *et al*., 1979).

1.3. Soil and plantation management

The propagation of the acerola shrub may be sexual (by seeds) or vegetative (budding and grafting). Seeds can be germinated in beds or in soil in bags or plastic jars. In budding propagation, it is recommended to use buds with a stem of about 30 cm, taken from vigorous branches on young plants. The stems should be treated with indolbutyric acid (IBA) and put in sandy soil or vermiculite to develop roots. Propagation by grafting favors the formation of a more vigorous root system.

Similarly to what is done for other fruit plants, preparation of the soil includes ploughing, harrowing, liming and fertilization, when necessary, and preparing the planting holes.

Liming of the soil is extremely beneficial, increasing the depth and density of the root system, and the growth and production of the plants (Ledin, 1958; Landrau Júnior and Hernández-Medina, 1959; Hernández-Medina *et al*., 1970). Preferably, calcareous dolomite should be applied over the whole area and incorporated to the greatest depth possible. The operation ought to be completed before ploughing and two to three months before planting. In established plantations, most of liming material should be applied at the base of the plant, because of the acidification produced by the addition of fertilizers.

Kavati (1995) recommended that liming, should aim to establish a base saturation of about 70% and that this should be repeated when soil analysis reveals a base saturation of less than 60%. For this and other crops it can be recommended to use liming principally in soils with a Mg content of less than 5 $mmol_c/dm^3$ (Federal University of Ceará, 1993). In Porto Rico, when Hernández-Medina *et al*. (1970) increased soil pH from 4.5 to 6.5 with liming there was a 170% increase in fruit production.

The planting holes or pits should be spaced at 4.0 m x 4.0 m or 4.0 m x 3.0 m. The pits should be opened about one or two months before planting. This operation may be manual or mechanical and the size can be from 40 to 60 cm in all three dimensions. The slips or young plants are transplanted when they are 30 cm to 40 cm tall. In non-irrigated areas this operation should be done during the rainy season.

Careful supervision is essential after planting during the initial growth of the plants. Until the slip reaches 30 cm to 40 cm in height it should be supported by a stake or pole to ensure an upright trunk. Then three to four branches should be left dominant until the plant reaches 50 cm to 60 cm in height, at which point it is pruned for breaking the apical dominance. Any suckers should be removed and the bush pruned after each production cycle to maintain the plants at an adequate height.

Weed control is an indispensable practice, because weeds decrease the availability of nutrients and water and also favor the dissemination of pests and diseases in addition to making maintenance of the irrigation system difficult (especially drip systems). Finally, the presence of weeds makes harvesting difficult, besides reducing the production of fruit.

Generally, weeds can be controlled by mechanical or manual harrowing and by using herbicides. Currently, the primary form of weed control is manual harrowing around the base of the plants (crowning) along with the use of a mower between the rows. In some regions ploughing is used between the rows, however this practice is not recommended during the period of initial establishment of the plants, and even in older plants the use of a plough can harm the root system, which is concentrated in the top 60 cm of the soil (Musser, 1995). In areas with drip irrigation systems the use of herbicides is recommended, because it reduces the damage caused to the irrigation system like cutting of the hoses. The use of a mulch is also recommended at the base of the plant, because it not only controls the formation of weed growth, but it also preserves the moisture in the soil.

1.4. Mineral nutrition

Although a large number of new acerola orchards have been established in areas of low soil fertility, the literature on nutrition and fertilization is still scarce. Thus, discussions about this subject need to be very cautious, because fertilization cannot safely be recommended based on other plant cultures.

Leaf analysis as a method of evaluating a plant's nutritional state started in the 1930's as a technique to interpret the effects of and estimate the requirement for fertilization. However, it is essential to establish a positive correlation between the quantities of nutrients supplied, the composition of the leaves and the production of the plants (Malavolta *et al*., 1967). Even then the results of leaf analysis alone does not permit a precise and thorough calculation of the quantities of fertilizer to apply, given that it is a complimentary technique and not exclusive.

There is very little data in the literature on the methodology of leaf sampling for the acerola shrub. For research, it is recommended to collect an average of 100 mature leaves per plant, from the same height, the middle of the crown (±1.5 m above the ground) and from all sides of the plant.

1.4.1. Uptake and export of nutrients

The nutrient requirement of the acerola plant has been assessed by the export of nutrients through the fresh fruits, at the time of harvest. This data was obtained by various researches in the team SF/DF/CCA/UFPB, in Areia, Paraíba, Brazil, who studied fruits coming from orchards situated in different localities in Paraíba (Table 1.2). This data, shows that the order of exportation of the primary macro-nutrients by the fruits is K>N>P and that the variations between the different data sets are due to the local conditions and the nonuniformity of the orchards from which the fruits were obtained, especially the sexual origin of the plants.

Regarding the remaining nutrients, Alves *et al*. (1990) found the following order of export: K>N>Ca>P>Mg>S>Fe>Zn>Mn>Cu. These authors observed that in the fruit, the concentrations of N and Ca were highest in the seed, while those of P and K were in the pulp. Silva (1998) found the order of export was similar in one year old plants: K>N>Mg>S>P>Mn>Zn>B.

Regarding the quantities of minerals found in the leaves and branches, Tables 1.3 and 1.4, respectively, give values of N, P and K found in plants cultivated in the greenhouse and under field conditions. In general, it is observed that N was most prevalent in the leaves, followed by K and P. In the branches, the sequence was found to be the same as that in the fruit, i.e. N>K>P. It is observed, therefore, that K is of great significance to the mineral nutrition of this crop, as much in young plants as in those already in production.

Table 1.2. Composition (%) of N, P and K in acerola fruit parts: skin and pulb (S + P) and seed (S) from different sources from different regions of Paraíba state.

Source	Region	Part	Nutrients (%)		
			N	P	K
1	Marsh	S + P	0.10	0.25	2.60
		S	1.60	0.15	0.72
2	Costal	S + P	1.22	0.22	2.55
		S	1.35	0.20	0.97
3	Costal	S + P	1.94	0.30	3.52
		S	1.57	0.21	1.09
4	Cariri	S + P	1.41	0.23	2.82
		S	1.47	0.20	1.35
5	Cariri	S + P	1.00	0.16	2.64
		S	1.27	0.19	0.90
	Cariri	S + P	1.14	0.22	2.62
		S	1.33	0.21	1.33
	Costal	S + P	1.86	0.30	2.56
		S	1.44	0.20	1.02
	Forest	S + P	1.16	0.19	2.48
		S	1.48	0.20	0.89
	Rural	S + P	1.57	0.20	2.59
		S	1.72	0.19	1.00

Sources: 1. Alves *et al.*, 1990; 2. Silva Júnior *et al.*, 1989; 3. Nascimento, 1995; 4. Cunha, 1992; 5. Freire, 1995.

Table 1.3. Composition (%) of N, P and K contained in acerola leaves cultivated in a greenhouse and in field conditions, in different regions of Paraíba state.

Source	Region	Age (years)	Nutrients (%)		
			N	P	K
1	Greenhouse	-	2.46	0.97	2.73
2	Marsh	>10	2.20	0.11	1.72
3	Coastal	2	2.70	0.31	1.63
4	Cariri	1	2.44	0.15	1.27
	Cariri	3	1.78	0.15	1.23
	Cariri	4	1.65	0.15	1.54
	Marsh	4	2.06	0.21	3.02
5	Coastal	1	2.68	0.26	0.21
	Coastal	2	2.40	0.28	2.20
	Coastal	3	2.66	0.32	2.23
6	Coastal	4	2.98	0.25	1.61
	Forest	5	2.86	0.19	2.77
	Rural	5	3.00	0.21	2.55
	West Cariri	3	3.11	0.20	2.18
	West Cariri	4	2.71	0.21	1.69
	West Cariri	5	3.18	0.24	2.18

Sources: 1. Cibes and Samuels, 1955; 2. Alves *et al.*, 1990; 3. Silva Júnior *et al.*, 1990; 4. Nascimento, 1995; 5. Cunha, 1992; 6. Freire, 1995.

Table 1.4. Composition (%) of N, P and K found in branches of acerola cultivated in field conditions, in different regions in Paraíba state.

Source	Region	Age (years)	Nutrients (%)		
			N	P	K
1	Marsh	>10	0.90	0.08	2.21
2	Coastal	2	1.03	0.24	1.48
3	Cariri	1	1.00	0.14	1.29
	Cariri	3	1.35	0.15	4.36
	Cariri	4	1.06	0.16	1.43
	Cariri	4	0.47	0.10	1.25
4	Coastal	1	0.90	0.19	1.35
	Coastal	2	0.85	0.18	1.30
	Coastal	3	0.90	0.18	1.40
5	Cariri		0.55	0.12	1.19
	Cariri		0.56	0.11	1.44
	Cariri		0.67	0.12	1.56
	Coastal		0.62	0.15	1.03
	Forest		0.60	0.08	1.27
	Rural		0.64	0.10	1.31

Sources: 1. Alves *et al.*, 1990; 2. Silva Júnior *et al.*, 1990; 3. Nascimento, 1995; 4. Cunha, 1992, 5. Freire, 1995.

It should be pointed out that the concentration of N, P and K in the leaves and branches and, consequently, the demands of the plant for these nutrients, vary according to the season (Cunha *et al.*, 1993).

1.4.2. Functions and importance of nutrients

Nitrogen (N): Nitrogen is of fundamental importance in the plant's nutrition and is required in large amounts. Oriented around the current prices of fertilizers, it is important to know the point at which N becomes effective for production.

When deficient, N accumulated in the oldest organs, principally the leaves, is redistributed to the young organs. Consequently, deficiency symptoms appear initially as a yellowing or chlorosis in the oldest leaves. Nitrogen deficient plants develop less than those well supplied with N because proteins are not produced. On the other hand, excess of N in the soil produces vegetative growth, producing few fruits and storing less sugar and carbohydrate (Malavolta, 1989).

Cibes and Samuels (1955) working in a greenhouse with acerola in Porto Rico determined that the omission of N contributed most to the decrease in plant development and production. The complete yellowing of the leaves, with premature leaf fall was the principal symptom of acute deficiency. Plants deficient in N had an increased concentration of P, Ca, Mn, Fe and S in the leaves. Landrau Júnior and Hernández-Medina (1959) increased production with the application of N up to 185 kg N/ha. Miranda *et al*. (1995) studied the effect of N, P, K, Ca, Mg and Fe omission in a nutrient solution experiment. The omission of N caused a reduction in the height of the plants and in the production of aboveground dry matter.

Phosphorus (P): Phosphorus has been considered the element that most limits production in tropical and subtropical regions. In many Brazilian soils, the total P is small.

Although essential, plants in production take up smaller quantities of P, compared to those of N and K. This can be observed in the production of the acerola shrub (Table 1.2). Similarly to what occurs with N, P is easily distributed in the plant, especially when there is a deficiency, which causes the emergence of typical symptoms in the oldest leaves.

In acerola seedlings 90 days old, the application of increasing amounts of P linearly increased plant height, number of leaves and amount of dry matter amongst the roots and aboveground parts (Corrêa *et al*., 2002). The presence of mycorrhizal fungi on the roots of slips results in an increased absorption of P, increasing their growth (Chu, 1993). Cibes and Samuels (1995) report that the omission of P in the nutritive solution produces symptoms not specific to this nutrient. Acerola plants submitted to treatment without P did not show significant differences regarding the production of dry matter, height or diameter (Miranda *et al*., 1995).

Potassium (K): Potassium is the nutrient most in demand and that which is assimilated most by the fruits (Table 1.2). Fertilization with K and N, both quantity and balance, in the production phase, is fundamental, because much K is exported in fruits and seeds.

The transport of carbohydrates produced in the leave for the other organs is done inefficiently when the plant is deficient in K.

Potassium is highly mobile in the plant, and is transported from the oldest organs to the youngest ones. Consequently the symptoms of K deficiency are first manifest in the older leaves (Malavolta, 1989).

Cibes and Samuels (1995) observed that the absence of K is characterized by the formation of a large number of small spots on the leaf cuticle and in this condition the composition of both Ca and Mg was increased because there was also a decrease in the composition of P in the leaf. These authors also reported that the absence of K reduced the diameter of the crown and that although large quantities of fruits were produced, they were small.

In six-month-old slips cultivated in a nutritive solution, Barbosa *et al.* (1995) observed that the absence of K in the nutritive solution caused an increase in the concentration of N in the leaves.

Calcium (Ca): The deficiency of Ca provokes leaf loss, with symptoms in the remaining leaves characterized by a yellowing at the tips and edges. When the deficiency is acute, there is severe burning at the leaf tips (Cibes and Samuels, 1995; Lugo-López *et al.*, 1959). On the other hand, Ledin (1958) noticed that the leaves in Ca deficient acerola plants showed yellowing starting from the apex and going towards the edges. Miranda *et al.* (1995) observed a significant reduction in the production of aboveground dry matter of acerola cultivated with the omission of Ca.

The application of calcium in the form of lime, proven beneficial to the root system, accelerates the growth and increases the production of the plants (Landrau Júnior and Hernández-Medina, 1959; Hernández-Medina *et al.*, 1970).

Magnesium (Mg): Besides making up part of the chlorophyll molecule, Mg is known as the activator of numerous enzymes, especially the "activators" of "amino acids" which catalyse the first step in protein synthesis. Magnesium is also important for the absorption of P (Malavolta, 1979). With very large concentrations of K in the soil or in solution, there could be a deficiency of Mg. Deficiency symptoms appear first in the oldest leaves. The symptoms of deficiency are characterized by yellowing along the edges of the oldest leaves, extending to between the veins, in the case of acute deficiency (Cibes and Samuels, 1955).

Sulphur (S): Held in the soil in the form of sulphate, sulphur participates in the composition of some of the amino acids and proteins, it also serves as an enzyme activator, besides participating in the synthesis of chlorophyll and the absorption of CO_2, among other functions. In situations of deficiency, its low phloem mobility results in an emergence of symptoms initially in the youngest leaves (Malavolta, 1989). Conditions of low availability of sulphur are observed in soils with a lack of organic material, soils with a high ratio of C/N, which hinders mineralization, periods of drought and constant use of fertilizers without S. The symptoms of deficiency are similar to those of nitrogen deficiency (Cibes and Samuels, 1955).

Boron (B): Deficiency of B is common in Brazilian soils, principally in those that are sandy and deprived of organic material or where there has been excessive liming, in regions with long droughts or also where B has been leached from the soil by rain or irrigation water.

The element is practically immobile in phloem and in the acerola shrub the symptoms of its deficiency emerge first in the youngest leaves, with yellowing and later death of upper the extremities of the leaves (Cibes and Samuels, 1955).

Iron (Fe): In acidic soils a lack of Fe could be induced by an excess of Mn, which inhibits the competitive absorption of the former. Excessive liming that increased soil pH to above 7.0 could make Fe insoluble, leading to its deficiency.

The presence of this micro-nutrient is crucial for the plant because amongst other functions, it is an enzymatic activator, participating in the constitution of some co-enzymes and of molecules that participate in the transport of electrons in the processes of photosynthesis and respiration. Owing to its immobility in phloem, the symptoms of its deficiency in the acerola emerge first in the youngest leaves, characterized by a yellowish-green color. With the intensification of Fe deficiency, only the veins remain greenish, while the leaf cuticle is yellow (Cibes and Samuels, 1955).

Manganese (Mn): Since Mn is poorly distributed in the plant, the symptoms of its deficiency emerge first in the young leaves. The symptoms of deficiency include leaf chlorosis with a background of light green, contrasting with the dark green veins (Cibes and Samuels, 1955).

Copper (Cu): The visual symptoms of Cu deficiency in the acerola shrub may be seen in plants developed in sandy soils and also in conditions where there has been an application of a large quantity of organic material, lime and of phosphate. Symptoms may also occur as a consequence of N fertilization, by the “dilution effect” of the cuticle composition. Its low level of distribution by the phloem results in the symptoms of its deficiency first appearing in the young leaves.

Zinc (Zn): The deficiency of Zn in Brazilian soils is just as common as that of boron, being principally in acidic and sandy soils. It is worth stressing that in any soil excessive liming may also reduce the availability of Zn to the plants. Ledin (1958) comments that Zn deficiency results in a general yellowing of young leaves and a retarded growth of acerola shrubs.

1.5. Fertilization

Acerola is a rugged plant that has the capacity to obtain nutrients from most of the soils where it grows (Ledin, 1958; Couceiro, 1985), and, in consequence, there is a lack of information on its nutrient requirements.

In treating it as a perennial plant, fertilization should offer survival conditions in an ideal situation to guarantee the physical and economic maximum in production and productivity. For this, it is necessary to have knowledge of the orchard's situation, and beyond a visual assessment of the nutritional state, soil analysis and leaf analysis.

1.5.1. Fertilization in the nursery phase

The nursery phase is the period transpires between germination and the time when the slip can be planted in the orchard.

The substrate for filling the plastic bags should be two to three parts fertile soil mixed with one part cured bovine manure. To every cubic meter of this mixture, 3.0 to 5.0 kg of single superphosphate (SSP) should be added as well as 0.5 to 0.7 kg of potassium chloride (KCl) (São José and Batista, 1995). Subsequently it is convenient to supply nutrients with a weekly or biweekly addition of the following solution: 100 g of $(NH_4)_2SO_4$, 100 g of SSP and 50 g of KCl in 100 L of water, with every square meter of surface receiving 3 to 4 L of solution.

For acerola slips cultivated in jars, Miranda *et al.* (1995) noticed a significant effect of P on the height of the plant, the number of leaves and the root and aboveground dry matter.

1.5.2. Fertilization in the planting phase

When preparing the planting pits it is generally recommended to apply a manure which has been well cured (chicken, bovine, goat and sheep), principally on light textured soils where nematodes can occur. The quantities vary from 10 to 20 L of manure per pit (Simão, 1971; UFC, 1993; Musser, 1995). Besides manure, P, K and even lime should be applied (Musser, 1995). Recommendations vary between 400 and 500 g of SSP, 300 to 400 g of KCl and 200 g of calcareous dolomite (Gonzaga Neto and Soares, 1994; Kavati, 1995).

1.5.3. Fertilization in the growing phase

During the growing phase, which is until three years old, there are many recommendations in the literature (Table 1.5). For example, Simão (1971), suggests that the plants require fertilization with a mixture of 400 g of $(NH_4)_2SO_4$ or $Ca(NO_3)_2$, 400 g of SSP and 200 g of KCl per plant at the initiation of fruit bearing. Gonzaga Neto and Soares (1994) recommend 20 L of cured bovine manure to be supplemented by addition of mineral fertilizers (Table 1.5).

Table 1.5. Recommendations for fertilizing acerola.

Year	Fertilizer	g/plant	Reference
	Nitrogen		
1	8-8-15	500	Simão, 1971; UFC, 1993
2	14-4-10	1,300	Marty and Pennock , 1965
2	8-8-15	500	Araújo and Minami, 1994
12	Urea	30–40	Gonzaga Neto and Soares, 1994
1	Urea	53	Musser, 1995
3-4	N	20	Kavati, 1995
	Phosphorus		
1	8-8-15	500	Simão, 1971; UFC, 1993
2	14-4-10	1,300	Marty and Pennock, 1965
1	SSP	250	Musser, 1995
2	8-8-15	500	Araújo and Minami, 1994
	Potassium		
1	8-8-15	500	Simão, 1971; UFC, 1993
2	14-4-10	1,300	Marty and Pennock, 1965
2	8-8-15	500	Araújo and Minami, 1994
12	K_2SO_4	30–40	Gonzaga Neto and Soares, 1994
1	KCl	33	Musser, 1995

1.5.4. Fertilization in the production phase

In the fruit bearing phase the application of 60 to 100 g of $(NH_4)_2SO_4$ or of $Ca(NO_3)_2$ and 375 to 500 g of KCl/plant is recommended (Simão, 1971). This fertilization, which is recommended for rainfed areas, should be divided into two equal doses, with the first being applied at the start of the rainy season and the other at the end of the rainy season, in a circular band about 20 to 40 cm from the trunk. Kavati (1995) recommends for production plants from two to five years old, an annual fertilization with about 200 g of N, 180 g of P_2O_5 and 250 g of K_2O/plant, divided into eight monthly applications, applied during the fruit bearing period, in moist soils at the base of the plant.

It should be stressed that fertilization during fruit bearing, the average productivity of the orchard should be considered, taking into account nutrient export harvest, so that the nutrients lost will be replenished by the addition of fertilizers.

1.6. Irrigation

In non-irrigated crops the production of acerola normally begins 30 to 35 days after the start of the rainy season. The large production of acerola in this rainy season floods the market and increases the difficulties of selling the fruit. Irrigation permits an increase in productivity, increases the period of harvest and increases the size of the fruit. In regions where the average temperature remains above 20ºC, irrigation permits an increase in the yield up to 100% and an average of eight to nine harvests per year (Gonzaga Neto and Soares, 1994). In the region of Nova Alta Paulista, Sao Paulo state, Konrad (2002) confirmed that the use of irrigation gives a better distribution of production, facilitating the flow of production and increasing the gross income of the producer up to 98% in relation to a non-irrigated crop.

1.6.1. Methods of irrigation

Acerola adapts well to the following methods of irrigation: conventional and sprinkling, jet, drip, sub-superficial drip, laser perforated hose and ditches. The choice of system of irrigation should take into account the availability of water, land topography, climate, soil and the financial resources of the producer. Irrigation by ditches may be used in locations with level topography, with limitations of water resources, and clay based soils. In medium to sandy soils, where there is a limitation of water resources, localized systems of irrigations (drip or jet) are best because water is used more efficiently. When using jet it is recommended to use one unit per plant and in dripping it is recommended to use four drippers per plant. In using laser perforated hoses one hose could be used for every two rows of plants, depending on row spacing.

Comparing different systems of irrigation for the acerola crop, Konrad (2002) concluded that there was no difference between the systems of irrigation concerning the composition of vitamin C and the quality of the fruits. Amongst the systems of irrigation evaluated, the laser perforated hose, drip and sub-superficial drip where those which produced the best results. Using one jet for two plants was not adequate for the crop.

1.6.2. Water requirements

The water requirements for the acerola shrub vary according to the climate, the size of the plants (leaf area and height), the frequency of irrigation and the percentage of soil surface wetted by irrigation. Water consumption tends to be greater in conditions of high evapo-transpiration demand, frequent irrigation and wetting of more than 60% of the soil surface.

In the climatic conditions of Ceará state, Martin Neto *et al.* (1998) observed values of evapo-transpiration of the acerola crop (ET_c) varying from 4.4 to

8.0 mm/d, with an average of 5.1 mm/d and an average crop coefficient (Kc) of 0.98. According to Konrad (2002) the use of a Kc value of 1.0 and a soil evaporation reduction coefficient (Kr) of 0.8 proved adequate for irrigation management of an acerola orchard in the production phase. Table 1.6 presents average values of ET_c and volume of water recommended for irrigation of mature acerola plants, as a function of evapo-transpiration in reference (ETo) to the local plantation.

In an experiment conducted in sandy soil of Paraipaba, Ceara state, using irrigation with jet emitters, Bandeira *et al.* (1998) applied average volumes of 21 to 27 L/plant/d to acerola plants at the start of production (two to three years old), obtaining an average production of 20 mt/ha. The authors did not observe significant differences in production between frequencies of irrigation varying from one to eight days.

Table 1.6. Values of evapo-transpiration of an acerola cultivar (ET_c) and volume of water to be applied per plant as a function of evapo-transpiration of reference (ET_o).

ET_o	ET_c	Volume of water[1]
mm/d	mm/d	L/plant/d
2.0	1.6	26
3.0	2.4	38
4.0	3.2	51
5.0	4.0	64
6.0	4.8	77
7.0	5.6	90

(1)Considering spacing between plants to be 4 x 4 m.

Source: Miranda, F. R. de., 2005; unpublished data.

1.6.3. Fertigation

The use of localized irrigation systems in acerola cultivation makes possible the application of fertilizers through the irrigation system (fertigation), which has as primary advantages the increased efficiency of fertilizers and the reduction of costs like labour and machinery used for its application. Fertigaion permits application of nutrients to the soil with a greater frequency, without increasing the cost of application, minimizing the losses by volatilization and leaching and optimizing uptake by the roots. Konrad (2002) showed a reduction in consumption of fertilizers of about 35% with fertigation, without a reduction in the productivity of the acerola.

The recommended procedures for the application of the fertilizers with the irrigation water consist of dividing the operation into three steps. In the first step the irrigation system operates only with water, until the pressure and discharge rate in all of the emitters is stabilized. In the second step the fertilizer solution is injected into the system. After injection, the irrigation system should operate with only water for about 20 or 30 minutes more, in order to remove all the fertilizer solution from the tubes.

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2. Banana

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2.1. Introduction

The banana belongs to the family *Musa* and is grown in most tropical countries. It is an important food consumed world-wide and it can be eaten unripe or ripe, raw or processed (cooked, fried, roasted or processed). The fruit contains vitamins (A, B and C), minerals (calcium, potassium and iron) and has few calories (90 to 120 kcal/100 g). The fruit is approximately 70% water; the solid material is principally carbohydrates (23 to 32 g/100 g) with little protein (1.0 to 1.3 g/100 g) and fat (0.37 to 0.48/100 g).

In 2004, world banana production was approximately 73 million mt. The largest producer was India (23%), followed by Brazil (9%), then China and Ecuador (8% respectively). World production of plantains and bananas was 33 million mt. While the African continent, had the lowest production of plantains per unit area (5.72 mt/ha), it was nevertheless responsible for 70% of this total production. Major producing countries are Uganda (30% of the world production), Columbia (20%) and Rwanda (8%) (FAO, 2006).

In Brazil the banana is cultivated in the north and south on approximately 500,000 ha of land, ranging from the coastal region to the plateaus of the interior. In 2004, national production in Brazil was 6.5 mt, of which the south-eastern and north-eastern regions produced two-thirds. Ninety-nine percent of this production was for the internal market.

The banana tree is a herbaceous monocotyledon (after harvest the aboveground part is cut). It has a subterranean stem (rhizome) from which sprout the primary roots, in groups of three or four, to give a total of about 200 to 500 roots each about 5 to 8 mm wide. The roots are white and tender when young and healthy, turning gradually yellow and hard. The roots can grow horizontally up to 5 m, although more commonly 1 to 2 m, depending on the cultivar and the soil conditions, and about 40% are at a depth of 10 cm and 60 to 80% are concentrated in the top 30 cm layer of soil.

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The pseudostem is formed by overlapping leaf sheaths, closing around a cup of wide and long leaves, each leaf with a developed central vein. One plant may produce 30 to 70 leaves, with the appearance of a new leaf every 7 to 11 days. The inflorescence grows out from the centre of the cup, presenting reddish ovate bracts, from these axils appear the flowers. Each set of flowers becomes a cluster of fruit (usually 7 to 15 clusters), containing a variable number of fruits per cluster (40 to 220), depending on the cultivar.

Both internal and external factors influence growth and production. The internal factors are related to the genetic characteristics of the variety while the external factors include climate, soil, pests and diseases and human activity (Borges *et al.*, 2000).

2.2. Climate and soil

2.2.1. Climate

The best temperature for the normal development of commercial bananas is about 28ºC, but they can be grown within the range 15 to 35ºC provided that there is sufficient water and nutrients for maximum growth of the plant.

Below 15ºC plant growth ceases and below 12ºC there is a physiological disturbance called “Chilling”, which compromises the maturation process and damages the fruit, especially the peal. “Chilling” may occur in subtropical regions where minimum night temperatures reach 4.5 to 10ºC. This phenomenon occurs more commonly in banana plantations, but may also occur during transport of the fruit, in the acclimatization chambers or soon after the fruit turns yellow. Low temperatures also cause compaction of the flower rosette, making difficult the start of inflorescence or provoking its “choking”, which deforms the cluster, making it commercially unacceptable. At 0ºC, frosting occurs, causing serious damage, as much for the plant that will follow as for the current one.

In temperatures above 35°C, the development of the plant is inhibited, principally because of dehydration, especially the leaves (Borges *et al.*, 2000).

The banana is cultivated at altitudes varying from 0 to 1,000 m above sea level. The plant cycle changes with altitude. Bananas of the subgroup Cavendish, cultivated at low altitudes (0 to 300 m), have a growth cycle of 8 to 10 months, whereas above 900 m 18 months are required to complete the cycle. When the same cultivar is grown in the same soil and similar rain and humidity conditions, the production cycle increases by 30 to 34 days for every 100 m increase in altitude. Altitude influences temperature, rain, relative humidity and luminescence and this affects growth and production (Borges *et al.*, 2000). Low relative humidity results in drier leaves with a shorter life (Borges *et al.*, 2000).

The banana plant develops best in areas with an average annual humidity above 80%. At this humidity, the production of leaves is accelerated and their longevity increases. Also, the development of flowers and uniform fruit color is favored. However, when associated with rain and elevated temperatures, there is increased risk disease and fungal attack, especially yellow Sigatoka.

Wind damage is proportional to wind speed and ranges from minor effects to complete destruction of the plant. Effects range from "chilling", due to cold winds; tissue dehydration as a result of intense evaporation; splitting of the secondary veins; cutting the leaves, diminishing of the leaf area; ripping out the roots; breaking the plants and causing them to fall over. Losses by wind have been estimated at between 20 and 30% of total production.

The majority of the cultivars can withstand winds of up to 40 km/h. Speeds between 40 and 55 km/h cause damage ranging from moderate to severe depending on the age of the plant, the variety, its development and its height. When wind speed exceeds 55 km/h, the destruction of the plant may be total. However, varieties with low stature, like Enano, may be able to withstand winds up to 70 km/h, compared to varieties of medium stature (Giant Enano and Grand Nain). In areas subject to wind it is recommended to use windbreaks: bamboo curtains of *Musa balbisiana*, *Musa textilis* or other plants.

The banana requires high light intensity, even though day length, apparently, does not influence its growth and fruit bearing. In regions with high light intensity the period required for the cluster to reach the point of commercial harvest is about 80 to 90 days after its emergence. In regions with low light intensity during part of the year, this period varies between 85 and 112 days. Where light intensity is medium, the harvest occurs between 90 and 100 days from the emergence of the cluster.

Photosynthetic activity accelerates quickly when light intensity, measured on the underside of the leaves where the stomata are more abundant, ranges from 2,000 to 10,000 lux, and then slows in the range 10,000 to 30,000 lux. Low values (less than 1,000 lux) are insufficient for the plant to develop well. At the other extreme, excessively high levels of sunlight may cause leaf burn, especially if this happens when the cluster has freshly opened or inflorescence has started (Borges *et al.,* 2000).

Banana has a large, constant requirement for water due to its morphology and tissue hydration. The largest yields are associated with total annual precipitation of 1,900 mm when it is well distributed throughout the year, *i.e.* 160 mm/month and 5 mm/day. The lack of water is most serious in the phases of flower differentiation (floral period) and at the commencement of fruit production. When water is severely deficient the leaf rosette tightens, inhibiting or even stopping the production of an inflorescence. Consequently, the cluster could lose its commercial value.

When irrigating, the amount of water applied is closely related to the ability of the soil to retain water. On deeper soils well able to retain moisture, adding 100 mm/month would be sufficient but on soils with a lower water retention, 180 mm/month would be required. It is therefore essential that the water source is sufficient to supply not less than 75% of the water retention capacity of the soil. On the other hand, soils should not become saturated because this inhibits aeration (Borges *et al*., 2000). Thus, the effective annual precipitation would be from 1,200 to 2,160 mm/yr.

2.2.2. Soil

In all areas of Brazil there are favorable soil conditions for growing bananas. However, the best soils are not always used and on the less suitable soils yields tend to be small and quality poor. Given that the banana has a superficial root system within the top 30 cm, it is important that the soil is deep, and at least the top 75 cm should be without any obstacles for root growth. Soils with a depth of less than 25 cm are considered unsuitable. In compact soils, the banana roots rarely reach a depth greater than 60 to 80 cm, and the plants are prone to falling over. On soils with a compacted layer at 30 to 35 cm, which the root system does not penetrate, subsoiling can be beneficial. Thus the nature of the whole soil profile, not just the superficial layers, is important. For good development of the plant, it is recommended that the soil does not contain an impermeable layer (rocky or compacted) and that the water table be less than one meter deep (Borges *et al*., 2000).

In general, when the climate is favorable, the plants may be established on hillsides as well as on flat ground. However, areas with gradients of less than 8% are recommended; soils with gradients between 8 and 30% being used with some restrictions; and gradients above 30% considered unsuitable. Ground with gently sloped hills (gradients less than 8%) is ideal, facilitating crop management, mechanization, maintenance operations, harvest and soil preservation.

On slopes with gradients in the range 8 to 30%, other than the need to control erosion, irrigation is more difficult. High-powered pumps with greater energy consumption and pressure compensated systems are required due to the topography. In the principal banana producing regions in the world, workable soils in the lowlands and depressions within the landscape, have been used successfully to grow bananas, especially those destined for export (Borges *et al.*, 2000).

The availability of an adequate oxygen supply in the soil is of fundamental importance for the good development of the root system. When oxygen is lacking, the roots lose their rigidity, acquire a pale blue-grey color and decompose quickly. Poor aeration may be the result of soil compaction or flooding. To improve soil aeration in areas with a tendency to flood, a good drainage system should be established. If the soil is water logged for more than three days there can be irreparable damage to the root system, with almost certain loss of yield. For this reason, soils used to grow bananas should be of a good depth and internal drainage, so that excess moisture drains away quickly and the water table can be maintained below 1.80 m (Borges *et al*., 2000).

2.3. Soil and crop management

The banana plant does little to induce soil degradation, but this does not dispense with the need to choose suitable sites for growing it. Other than this, it is important to ensure adequate soil preparation to promote root growth both in volume and depth. The use of organic mulches is recommended to keep the soil covered, reduce the effects of flash flooding and recycle nutrients (Souza and Borges, 2000).

In general, soil preparation aims to improve the physical condition of the soil for root growth, by increasing aeration and water infiltration and reducing the resistance of the soil to root expansion. The following precautions are recommended in soil preparation. Alternate the type of implement used and the depth of working to minimize the risk of forming compact layers and excessive disintegration of the soil. Invert the soil as little as possible, work the soil in conditions of adequate moisture, preserve maximum amounts of plant residues on the soil surface. Soil preparation for planting may be done manually or with machines.

Liming, when recommended, should preferably be done at least 30 days before planting using calcareous dolomite. This avoids an imbalance between potassium (K) and magnesium (Mg), which can lead to the physiological disorder called "blue banana" (deficiency of Mg induced by an excess of K). Liming should aim to achieve a base saturation of 70% with Mg^{2+} being 8 $cmol_c$ kg. With acidic soils (pH in water less than 6.0) add 300 g of lime in the planting pit (Borges *et al*., 2002).

Bananas are quite sensitive to weed competition during establishment, and require weeding at about monthly intervals to stimulate quick growth (Chambers, 1970), especially during the first five months after planting (Alves and Oliveira, 1997). After this period, the banana is less sensitive to weed competition (Belalcázar Carvajal, 1991). Weeds can be controlled mechanically or chemically. Manual weeding – using a hoe, taking care to avoid damaging the root system and mechanical weeding – using a discer or a rotary tiller between the rows of plants, can lead to soil compaction and damage the root system. Five months after planting it is recommended to do the weeding manually or with a mechanical mower rather than a rotary tiller to avoid turning the soil and cause damage to the root system. The choice of herbicide or mixture of herbicides for chemical weeding will depend on the types of weed in the orchard and the cultivar being grown (Carvalho, 2000).

Integrated control, using a mechanical method (mower between the rows) with a chemical method (post-emergence herbicide), is used in certain periods of the year, being combined with the planting of legumes between the rows, which are harvested in the dry season (Carvalho, 2000).

2.4. Mineral nutrition

Banana plants grow quickly and require, for their development and production, adequate quantities of available nutrients in the soil. Although part of the nutrients required can be supplied by the soil itself and by plant residues, it is usually necessary to apply lime and organic manures and/or chemical fertilizers to obtain economically viable yields. The amount of nutrients required depends on the cultivar, its yield potential, plant population density, the phyto-sanitary state and, principally, the balance of nutrients in the soil and the uptake by the roots. The amounts of mineral fertilizers required are usually large because large quantities are removed in the harvested produce (Borges *et al.,* 2002).

2.4.1. Uptake and export of nutrients

Banana requires a large quantity of nutrients to maintain good growth, large yields and profitability (López M., 1994; Robinson, 1996). Potassium (K) and nitrogen (N) are needed in the largest amounts followed, in order, by magnesium (Mg) and calcium (Ca) sulphur (S) and phosphorus (P) (Table 2.1).

Of the micro-nutrients, boron (B) and zinc (Zn) are taken up in the largest amounts, especially the by “Terra” variety, followed by Cu (Table 2.1). The variation between genotypes highlights the larger nutrient uptake by the “Terra” variety, undoubtedly because of the greater production of dry matter and the different climatic conditions under which it is grown (Table 2.1).

Besides knowledge of total nutrient requirement, it is important to quantify the total exported in the harvested crop, aiming to replenish the amounts by fertilization and by returning the plant residues to the soil. At harvest, the nutrients are exported through the bunch (fruits + stalk + female rachis + male rachis + heart). The vast majority of research has shown that the removal of macro-nutrients in the bunch occurs in the following order: K>N>Mg, and varying the order for the quantities of S, P and Ca (Table 2.1). Cultivars with the largest amount of dry matter in the bunch remove the largest quantities of macro-nutrients. The offtake of nutrients in the bunches of the subgroup Cavendish are, in kg/mt, 1.7 of N; 0.2 of P; 5.0 of K; 0.2 of S (IFA, 1992). In Sao Paulo, the amount of nutrients removed for the cultivar "Nanicão", is, in kg/mt, 2.1 of N; 0.3 of P; 5.0 of K and 0.1 of S (Raij *et al.*, 1996). For "Prata Ana", grown in Reconcavo da Bahia, the amount removed, in kg/mt is: 2.3 of N; 0.24 of P; 5.5 of K; 0.28 of Ca; 0.35 of Mg and 0.12 of S (Faria, 1997).

The export of micro-nutrients in the bunch in relation to the quantity absorbed is approximately 28% for B, 49% for Cu and 42% for Zn (calculated from Table 2.1).

Although banana requires a large quantity of nutrients during growth, a considerable proportion is recycled in the pseudostem, leaves and rhizome, which are 66% of the vegetative growth at harvest and are returned to the soil. For example, for the cultivar "Terra" the quantities recycled in residues can be, in kg/ha, 170 of N; 9.6 of P; 311 of K; 126 of Ca; 187 of Mg and 21 of S (Borges *et al.,* 2002).

Nutrient losses by leaching, volatilization and erosion depend on the physical and chemical conditions of the soil and rainfall. To decrease these losses, the root system should be vigorous and the fertilizers applied in small quantities at a time (Borges *et al.*, 2002).

2.4.2. Functions and importance of nutrients

Nitrogen (N): Nitrogen is important for vegetative growth, especially in the first three months, when the plant is developing. It favors the production and development of slips and increases the quantity of dry matter. Its deficiency reduces the number of leaves, increases the number of days for the emergence of a new leaf, and fruit bunches are stunted and less numerous. Compared to a treatment without N, adding 400 kg of N/ha/yr increased the number of leaves and bunches by 8% and 11%, respectively, (Oliveira *et al.,* 1998).

Nitrogen deficiency results in a generalized chlorosis of the leaves, reddish stems, stunted clusters and a smaller number of bunches. Deficiency normally occurs in soils with little organic matter, where there is a less mineralization of organic matter, and also in soils with considerable leaching and where there is a prolonged drought. Deficiency can be corrected by applying 50 to 300 kg N/ha, depending on the concentration of N in the leaves. Excessive N results in production of weak clusters with widely spaced bunches (Borges *et al.,* 2002).

Table 2.1. Quantities of macro- and micro-nutrients absorbed (AB), exported (EX) and recycled (RE) to the soil for different banana cultivars at harvest.

Cultivar	Macro-nutrients (kg/ha)																	
	N			P			K			Ca			Mg			S		
	AB	EX	RE	AB	EX	RE	AB	EX	RE	AB	EX	RE	AB	EX	RE	AB	EX	RE
Caipira	146.9	52.9	94.0	9.8	3.9	5.9	313.9	124.7	189.1	53.0	2.8	50.2	58.0	5.2	52.8	9.3	3.0	6.3
Prata Anã	136.5	44.4	92.1	10.1	4.6	5.5	418.5	107.1	311.4	71.6	5.5	66.1	61.6	6.9	54.7	5.8	2.4	3.4
Pioneer	116.7	29.7	87.0	8.5	3.2	5.3	371.1	100.0	271.1	73.2	3.6	69.6	70.8	5.0	65.8	5.3	1.1	4.2
FHIA-18	144.1	50.9	93.2	11.2	5.2	6.0	382.4	142.4	240.0	74.1	4.8	69.3	64.5	7.0	57.4	7.5	2.8	4.7
Terra	227.9	57.9	170.0	15.5	5.9	9.6	459.2	156.2	303.0	131.0	5.5	125.5	193.2	6.5	186.7	35.9	14.9	21.0
Average	154.4	47.2	107.3	11.0	4.6	6.5	389.0	126.1	262.9	80.6	4.4	76.1	89.6	6.1	83.5	12.8	4.8	7.9

Cultivar	Micro-nutrients (g/ha)								
	B			Cu			Zn		
	AB	EX	RE	AB	EX	RE	AB	EX	RE
Caipira	295.5	98.8	196.7	52.1	11.7	40.4	132.9	40.5	92.4
Prata Anã	309.5	70.1	239.4	26.9	5.4	21.5	148.1	52.4	95.7
Pioneer	222.3	50.3	172.0	30.1	4.9	25.2	120.5	33.2	87.3
FHIA-18	237.7	81.9	155.8	34.7	10.2	24.5	115.7	43.5	72.2
Terra	482.7	132.6	350.1	239.9	155.4	84.5	662.0	324.2	337.8
Average	309.5	86.7	222.8	76.7	37.5	39.2	235.8	98.8	137.1

Source: Borges *et al.*, 2002.

Phosphorus (P): With a deficiency of P, the plants are stunted and have poorly developed roots. Other than this, the oldest leaves show a marginal necrosis in the shape of saw teeth, with dark green coloration and stem breakage. The fruit may be smaller and with a lower sugar content. Deficiency is likely where there is little P in the soil, and especially on acid soils. Deficiency can be corrected by applying 40 to 100 kg of P_2O_5/ha, the actual amount depending on the composition of the soil and the leaves (Borges *et al.,* 2002).

Potassium (K): Potassium is the nutrient taken up in the largest quantity by the banana plant. Potassium plays several vital roles in plants. It is involved in translocating photosynthates within the plant, in the water balance of the plant, and the production and quality of the fruit by increasing total soluble solids and sugars and decreasing the acidity of the pulp. Rapid yellowing and withering of the oldest leaves characterize K deficiency; the lamina bends at the tip of the leaf, which appears cracked and dry (see appendix of chapter 2, Plate 2.1 - 2.3). The cluster is the part of the plant most affected by K deficiency, reducing the production of dry matter. When the supply of K is limited, the translocation of sugars from the leaf to the fruit decreases and, even when the sugars reach the fruit, their conversion into starch is restricted, producing small fruits and clusters, with irregular maturation and almost tasteless pulp which makes them unsuitable for sale. Potassium deficiency occurs in nutrient poor soils, especially where there is intense leaching, and also where excessive amounts of lime are applied, because of the antagonism between Ca and K decreases K uptake. Potassium deficiency can be corrected by applying 150 to 600 kg K_2O/ha, depending on the soil type, %K in the leaves and the yield expected. (Borges *et al*., 2002).

Calcium (Ca): The visual symptoms of Ca deficiency are seen principally in the newest leaves and are characterized by discontinuous chlorosis along the edges, thickening of the secondary veins and reduction in leaf size. The fruits can mature irregularly and rot and green fruits that form along with mature ones have no aroma or sugar. Deficiency occurs in soils with little Ca and also where there has been excessive amounts of K applied. Calcium deficiency is corrected by application of lime or gypsum. The quantity required is a function of the calcium content in the soil and leaves. (Borges *et al.,* 2002).

Magnesium (Mg): Deficiency of Mg occurs in acid soils low in fertility, and also following excessive K fertilization. This is an important aspect because banana is very demanding of K. The amount of Mg in the soil should be sufficient to prevent the occurrence of “blue banana”, a deficiency of Mg induced by excess K and characterized by brownish-violet spots on the stems.

Deficiency occurs in the oldest leaves and is characterized by yellowing parallel to the edges of the leaf stem, by deformation and irregularities in the emergence of flowers. Rotting of the lamina leads to a bad smell and separation of the sheath from the pseudostem. The most common symptom in the field is chlorosis in the internal part of the lamina, also known as magnesia chlorosis, with the central vein and the edges remaining green. When the deficiency is severe and reaches the clusters they become stunted and deformed, the fruit and pulp mature irregularly, and the pulp becomes soft, viscous, tastes bad and rots quickly.

Deficiency can be corrected by applying calcareous dolomite or 50 to 100 kg/ha magnesium sulphate, depending on the level of Mg in the soil and the leaves. Excess Mg gives a bluish color to the stem and irregular chlorosis followed by death of the leaves (Borges *et al*., 2002).

Sulphur (S): Sulphur deficiency is characterized by a generalized chlorosis of the lamina of the newest leaves, which disappears with age, as the root system develops and exploits a greater volume of soil. When the deficiency persists the edges of the lamina die, there is a slight thickening of the veins, similar to that with Ca deficiency, and the clusters are small.

Sulphur is normally applied in ammonium sulphate and single superphosphate (Borges *et al*., 2002).

Boron (B): The first signs of boron (B) deficiency is seen in yellowish-white lines, which spread over the leaf's surface parallel to the main vein, followed by death of the tissue. The leaves may remain deformed and the lamina may be decreased. These symptoms are similar to those of S deficiency. In serious cases, a gum appears on the pseudostem, which reaches the flower and may even prevent its emergence, the inflorescence being retained within the pseudostem.

Copper (Cu): The deficiency of Cu is often confused with that of N, owing to the generalized chlorosis and reduced stature of the plant, which has an umbrella shape. The plant becomes very prone to attacks by trips, fungus and mosaic virus and the fruits contain rust stains (Cordeiro and Borges, 2000). According to Dechen *et al*. (1991), Cu is involved in the defence mechanism against fungal diseases, therefore in its absence the plants are less protected physically, which facilitates the penetration of the pathogen.

Iron (Fe): Plants deficient in iron have chlorosis along the edges of the lamina of the youngest leaves, quickly reaching the middle by way of the interveinal spaces, with the potential to become almost completely white.

Manganese (Mn): The deficiency of Mn normally occurs in the middle leaves, with the lamina displaying a chlorosis in a comb-like shape along the edges. Eventually the fungus *Deightoniella torulosa* develops on the leaf lamina and contaminates the fruit (Cordeiro and Borges, 2000).

Zinc (Zn): An essential element in the synthesis of tryptophan, a precursor of indoleacetic acid (IAA), which induces the production of tilose. The latter is involved in the plant's resistance to Panama Sickness, showing that there is a positive correlation between Zn deficiency and the incidence of Panama Sickness (Cordeiro, 1984).

Deficiency slows the growth and development of the plant. The leaves are small and lanceolate and have yellowish-white stripes between the secondary veins and red pigmentation on the under side of the leaves. Besides being small, the fruits may be curled, with light green tips and the apex in the shape of a nipple in bananas of the Cavendish subgroup. Such symptoms are often confused with a viral infection (Cordeiro and Borges, 2000).

Leaf analysis is an important technique in fruit growing but to be used successfully it is necessary to know the position of the leaves sampled and the characteristics of the growing season. For banana, it is recommended to sample the third leaf counting from the apex, with the inflorescence having all female rachises (without bracts) and no more than three male rachises of the male flowers (Fig. 2.1). Collect 10 to 25 cm in the inner middle of the lamina, eliminating the central vein. For this state of development there are standard nutrient compositions, which may be used as reference. The ranges of nutrients adequate for some cultivars are found in Table 2.3 (Borges *et al.*, 2002).

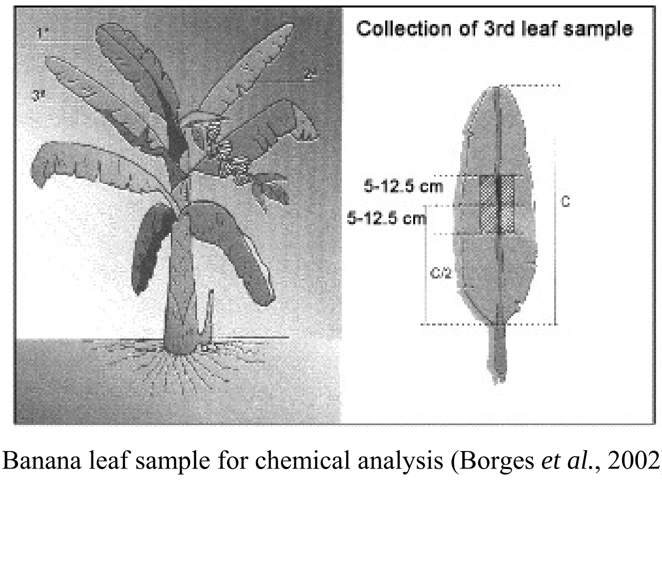

Fig. 2.1. Banana leaf sample for chemical analysis (Borges *et al.*, 2002).

2.5. Fertilization

2.5.1. Organic fertilization

Organic manures are the best way of supplying N, especially when conventional seedlings are used because N losses are minimal and root growth is stimulated. Therefore, such manures should be applied in the plant pit: For example, bovine manure (10 to 15 L) or chicken manure (3 to 5 L) or castor bean pie (2 to 3 L) or other manures available in the region or on the property. It is worth noting that the organic manure, irrespective of the source, should be well composted. If available, add 20 m^3/ha of bovine manure annually. Covering the soil with banana plant residues (leaves and pseudostems) is a viable alternative for small producers. This practice increases the content of nutrients in the soil, principally K and Ca, besides improving the physical, chemical and biological characteristics of the soil (Borges *et al*., 2002).

2.5.2. Mineral fertilization

Nitrogen is very important for vegetative growth and it is recommended to apply 200 kg mineral N mineral/ha/yr in the development phase and 160 to 400 kg/ha/yr in the production phase of the banana, depending on the anticipated yield. The first application should be made around 30 to 45 days after planting. Ammonium sulphate, calcium nitrate and ammonium nitrate are recommended as N fertilizers.

Potassium is considered the most important nutrient for the production of superior quality fruits. The recommended quantity varies from 200 to 450 kg of K_2O/ha in the development phase and 100 to 750 kg of K_2O/ha in the production phase, depending on the K content of the soil. The first application should be made in the second or third month after planting. If the soil K content is less than 1.5 $mmol_c/dm^3$ the first application should be given at 30 days, along with the first application of N (Tables 2.2 and 2.3). Potassium can be applied as potassium chloride, potassium sulphate and potassium nitrate, although because of the price the chloride is almost always used. On soils with a K content above 6.0 $cmol_c/dm$ it may be possible to dispense with applying K fertilizer (Borges *et al.,* 2002).

Although necessary, banana needs only small quantities of P but if P is not applied the development of the root system is compromised and consequently production is affected. The total quantity recommended after soil analysis (40 to 120 kg of P_2O_5/ha) should be put in the planting pit. The application should be repeated annually after soil sampling for analysis. If a soil contains more than 60 mg P/kg (resin extraction) there is no need to apply P fertilizer (Table 2.2) (Borges *et al*., 2002).

Table 2.2. Fertilizer recommendations for N, P and K at planting, and during the development and production phases of irrigated banana.

Development Phase	N	P-resin (mg/dm^3)				K-exchangeable (mmol$_c$/dm^3)			
		0-12	13-30	30-60	>60	0-0.15	0.16-0.30	0.31-0.60	>0.60
	kg/ha	---------------- P_2O_5 (kg/ha) ------------------				------------------ K_2O (kg/ha) ------------------			
Planting	70[1]	120	80	40	0	0	0	0	0
Days after planting									
30	20	0	0	0	0	20	0	0	0
60	20	0	0	0	0	30	30	0	0
90	30	0	0	0	0	40	30	20	0
120	30	0	0	0	0	60	40	30	0
120-180	100				0	300	250	150	0
Production									
Expected yield (mt/ha)									
<20	160	80	60	40	0	300	200	100	0
20-40	240	100	80	50	0	450	300	150	0
40-60	320	120	100	70	0	600	400	200	0
>60	400	160	120	80	0	750	500	250	0

[1]Nitrogen in organic form (bovine manure).

Source: Natale *et al.*, 1996a.

Table 2.3. Range of macro- and micro-nutrients from various sources considered adequate for banana (IFA, 1992) and irrigated banana (Silva *et al.*, 2002; Borges and Caldas, 2002).

Nutrient	Source		
	IFA, 1992.	Silva *et al.*, 2002. *cv. Prata Anã*	Borges and Caldas, 2002. *cv. Pocovan*
Macro-nutrient	------------------------------	g/kg	------------------------------
N	27-36	25-29	22-24
P	1.6-2.7	1.5-1.9	1.7-1.9
K	32-54	27-35	25-28
Ca	6.6-12	4.5-7.5	6.3-7.3
Mg	2.7-6.0	2.4-4.0	3.1-3.5
S	1.6-3.0	1.7-2.0	1.7-1.9
Micro-nutrient	----------------------------	mg/kg	------------------------------
B	10-25	25-32	13-16
Cu	6-30	2.6-8.8	6-7
Fe	80-360	72-157	71-86
Mn	200-1,800	173-630	315-398
Zn	20-50	14-25	12-14

Boron and zinc are the micro-nutrients most commonly deficient in banana. As a source, apply 50g of F.T.E. Br-12 (see composition of F.T.E. Br-12 in footnote of Table 2.4) or similar material to the plant's base. If the soil B content is less than 0.21 mg/kg (hot water extract) 2.0 kg of B/ha should be applied; for soil Zn content of less than 0.6 mg/kg (DTPA extract) 6.0 kg Zn/ha is recommended (Table 2.4) (Borges *et al.*, 2002).

Whether or not to split fertilizer applications will depend on soil texture and the cation exchange capacity (CEC) of the soil, as well as on the rain pattern and management adopted. In sandy soils with low CEC, fertilizers should be applied weekly or bi-weekly. In soils with a larger clay content, fertilizer applications may be made monthly or bi-monthly, especially when applied to the soil (Borges *et al.*, 2002).

Table 2.4. Quantities of boron (B) and zinc (Zn) applied at the plant base of irrigated banana, based on soil analysis.

Nutrient	Soil test (mg/kg)	Fertilization (kg/ha)
	Hot water[(1)]	
B	0-0.21	2.0
	>0.21	0
	DTPA[(1)]	
Zn	0-0.60	6.0
	>0.60	0

[(1)]Determine annually the availability of boron and zinc in the soil, and if necessary, apply fertilizers containing B and Zn, according to the table above, or add 50 g/plant of F.T.E. Br-12 (9% Zn, 1.8% B, 0.8% Cu, 3.0% Fe, 2.0% Mn and 0.1% Mo).

Source: Borges *et al*., 2002.

When applying fertilizers under the leaf canopy they should be put in a circular band 10 to 20 cm wide and 20 to 40 cm from the base of the plant, increasing the distance with the age of the plant. In an adult banana plantation, the fertilizers are distributed in a half moon in front of the plant's sucker and secondary sucker (Fig. 2.2). On sloping land, the application should be made in a half moon on the upper side of the planting hole and then lightly incorporated into the soil. In dense plantations and on flat lands, the fertilizer can be thrown from the paths (Borges *et al.,* 2002).

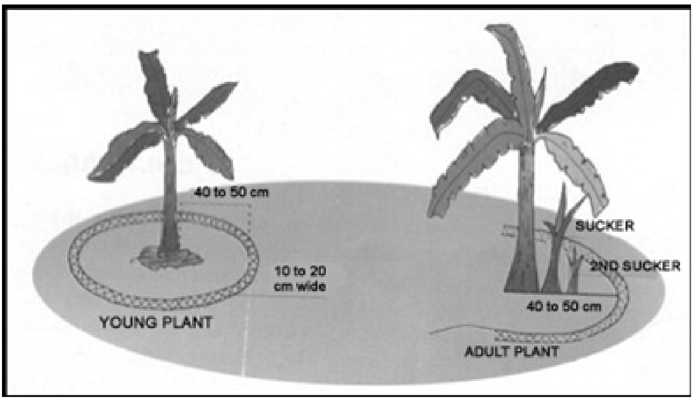

Fig. 2.2. Banana leaf sample for chemical analysis (Borges *et al*., 2002).

For the first cycle of the cultivar ‘Grand Nain’, Borges *et al*. (2002) reported that the fruits did not meet export requirements (22 to 26 cm long and 32 to 36 mm in diameter), but the application of 300 kg of N and 550 kg of K_2O/ha/yr resulted in a larger yield (81 mt/ha), heavier (251.8 g) and longer (20.4 cm) fruits. For the first cycle of the cultivar for ‘Prata Anã’ grown on a Red-Yellow Agrisol, with a K content of 19.5 mg/kg, Sousa *et al.* (2003) found no effect of N and K other than increased production (24.3 mt/ha) with 570 kg N and 770 kg K_2O/ha/yr.

2.6. Irrigation

Banana requires a large quantity of water, because it has a large leaf area and 87.5% of the total weight of the plant is water. Water deficiency can affect the production and quality of the fruits. The water requirements of the plant depend on its age. It has been estimated that on sunny days with low relative humidity of the air and for a foliar area of approximately 14 m^2, the plant consumes about 26 L/day, 17 L/day on partly cloudy days, and 10 L/day on completely cloudy days.

2.6.1. Irrigation methods

There are no restrictions on the method of irrigation for the majority of banana varieties. The chosen method will depend on the local conditions including soil type and its topography, the cost of installation, maintenance and operation, as well as the quantity and quality of the water and the labour available. The preference is for methods that promote:

(i) Uniform distribution of water in the soil, that is, a high coefficient of water distribution;

(ii) Greatest efficiency in water use;

(iii) Maintenance of a stable average relative humidity under the canopy (Oliveira *et al*., 2000).

Localized irrigation, with a greater efficiency and a lower consumption of water and energy, is generally recommended, especially in regions where water is limiting. Between the systems of jet and drip, the former generates a larger wet area, permitting greater development of the roots. In spraying the nozzles used should have spray rates greater than 45 L/h, and have one jet per four plants to get the largest wet area. In dripping, attention should be given to the number and position of the drippers, establishing a wet area adequate for the development of the roots. The drippers may be installed in one or two lateral rows per row of plants, making a continuous long wet line along the lateral row. This reduces the problem of possible incompatibilities of localization of the drippers in relation to the pseudostems, which change for every cycle. The irrigation interval for spray and drip systems can vary from one day for medium texture and sandy soils to every third day for medium to clayey textured soils (Coelho *et al.*, 2000).

2.6.2. Water requirements

The response of banana to different levels of irrigation depends on the local meteorological conditions, which result in different evapo-transpiration conditions, and heat constant, associated with the characteristics of the cultivar, such as: ruggedness, plant height and foliar area, which directly influence aerodynamic resistance. Other factors include cultivar spacing, irrigation method and management practices like mulching.

2.6.3. Fertigation

In irrigated plantations, nutrients may be applied with the irrigation water, fertigation. This practice, employed in irrigated agriculture, is a more efficient way of applying nutrients. This practice is adapted more for localized irrigation systems (spray and drip), in order to take advantage of the characteristics of the method, like low pressure, high frequency of irrigation and possibility of application of the solution to the root area, making more efficient use of the nutrients. The frequency of fertigation could be every two weeks on soils with high clay content; on more sandy soils a weekly frequency is recommended. For monitoring fertigation, chemical analysis of the soil is recommended, including the electrical conductivity of the saturated soil, every six months (Borges and Coelho, 2002).

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3. Cashew – Dwarf Variety

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3.1. Introduction

The largest number of varieties of the genus *Anacardium* is found in north-eastern Brazil. For this reason Johnson (1973) considered that Ceará state was where the cashew originated. Now about 98% of cultivated cashew is grown in the north-east Brazil (Paula Pessoa *et al.,* 1995).

In Brazil, there are two groups of cashew. The most prevalent is the common type (giant), which grows to heights ranging from 5 to 8 m, but able to reach 15 m. The diameter of the crown generally varies from 12 to 14 m and, in exceptional cases is up to 20 m (Barros, 1995). The other group, the dwarf cashews grow up to 4 m, on average, with a crown diameter of 6 to 8 m. This group of dwarf cashew flowers between 6 and 18 months (Barros *et al.,* 1998).

The flowers are small, polygamous, bunched in large terminal panicles. The fruit is an achene (nut) hanging from a fleshy and juicy peduncle of varying color and size. The cashew nut is rich in vitamins, non-saturated fatty acids and proteins. The peduncle contains large amounts of vitamin C, sugars and minerals (calcium, iron, phosphorus and fibres. Currently less than 20% of the total peduncles produced are used, mainly to consume fresh or made into sweets, jams and diverse drinks. Generally, the ratio of nut to peduncle is 1:10 (w/w).

The root system of the young dwarf cashew is one very well developed main root that branches many times and can grow to 10 m or more in deep sandy soils. Lateral roots develop in the upper soil layers between 15 and 32 cm deep. The length of the superficial roots may reach twice the diameter of the crown in dry-land conditions (Barros, 1995). When irrigated the lateral roots are concentrated around the wet area of soil. The characteristics of the tap and lateral roots are of importance in relation to the fertilization of cashew. Falade

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(1984) when studying the effects of topography, soil texture, stoniness and the presence of a hardened soil layer on the development of the cashew root system, reported great variation in the depth of the main root and distribution in depth and length of the lateral roots.

3.2. World production and trends

In 2004, the total world area occupied by cashew was 3.09 million ha and production was 2.27 million mt, providing a yield of 0.73/ha (Table 3.1). The principle producing countries responsible for 83.9% of world production are Vietnam, India, Nigeria, Brazil, Indonesia and Tanzania. In 2002, the largest yields were produced in Vietnam and Tanzania, with 2,920 and 1,250 kg/ha. The smallest yields were generated in Brazil and Benin, with 1,350 and 220 kg/ha respectively.

Table 3.1. Production, harvested area and yields of cashew nut, 2004.

Countries	Production	Harvested Area	Yield
	mt	ha	kg/ha
Vietnam	825,696	282,300	2,920
India	460,000	730,000	630
Nigeria	213,000	324,000	660
Brazil	182,632	691,059	260
Indonesia	120,000	260,000	460
Tanzania	100,000	80,000	1,250
Côte d'Ivoire	90,000	125,000	720
Guinea-Bissau	81,000	212,000	380
Mozambique	58,000	50,000	1,160
Benin	40,000	185,000	220
Worldwide	2,265,473	3,089,078	730

Source: FAO, 2006.

The small yields in Brazil are in part, related to the area under old cashew trees relative to that of clones of the more productive premature dwarf cashew.

From 1995 to 2004, world production of cashew nut doubled as a result of government incentives in the producing countries and expansion of consumer markets. This trend, though still growing, has been increasing more slowly in the last seven years (Fig. 3.1). The greatest increase in production and the area planted to cashew occurred in Vietnam, where cashew nuts production grew four-fold during 1995–2004.

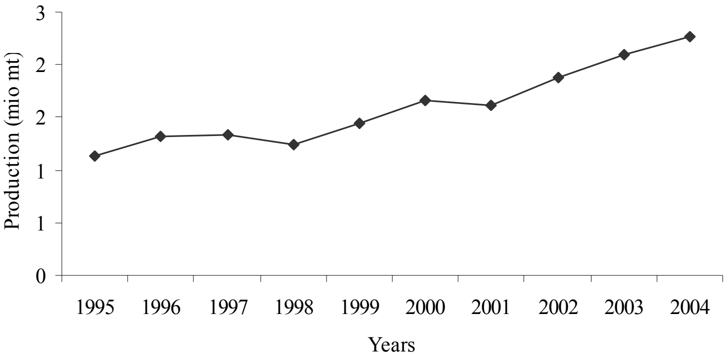

Fig. 3.1. World production of cashew nut, 1995-2004 (FAO, 2006).

During this period, world exports of cashew nut grew 2.5 times fold. Although exports remained reasonably constant between 1995 and 1999, they started increasing in 2000 (FAO, 2006). In 2002, the principle exporters were India, Vietnam and Brazil (with 46.35%, 24.36% and 13.18% respectively) of nuts exported in 2002. In Europe, most of the cashew nuts imports are redistributed through the port of Rotterdam, which makes the Netherlands the fourth major exporter for this commodity.

In 2002, the total value of the crop was US$ 240.9 million, with a variation in price ranging from US$ 3.12/kg for Vietnamese cashew nuts to US$ 4.10/kg for nuts re-exported by the United States. At that time, the Brazilian cashew nut traded on average at US$ 3.38/kg.

In 2002, the principal importers of cashew nuts were the United States (approximately half of the total worldwide volume of exports), the Netherlands, England and Germany. The considerable participation of the North American market in cashew nut trade has meant that this market has become a regulator of world market prices. It is likely that worldwide consumption of cashew nuts will continue to increase.

3.3. Climate and soil

3.3.1. Climate

The cashew tree is an evergreen plant, although a partial replacement of the leaves can occur. Owing to its sensitivity to low temperatures, it geographic distribution is confined to regions between 27ºN and 28ºS (Frota and Parente, 1995). In spite of being a tropical fruit in origin, the cashew develops well in temperatures varying from 22 to 40ºC, although Parente *et al.* (1972) cite 27ºC as the ideal average temperature for normal development and fruit bearing. Owing to the influence of altitude on temperature, cashew plantations may be found at altitudes up to 1,000 m close to the equator. In higher latitudes and altitudes above 170 m, the yield is negatively affected (Aguiar and Costa, 2002).

The cashew develops well between 70% and 85%, relative humidity. Trees will grow in regions where the relative humidity is 50% for a long period of time if the soil contains a good reserve of moisture or irrigation is used. In regions where the air relative humidity is above 85%, fungal diseases of the leaves, flowers and fruits increase.

Wind has little influence on a cashew plantation. However, at velocities of 7 m/s or higher, Aguiar and Costa (2002) reported an increase in loss of flowers and fruits and trees being blown over.

According to Aguiar and Costa (2002), trees are established successfully when the annual precipitation is within the range 800 to 1,500 mm, distributed over 5 to 7 months along with a 5 to 6 month drought that coincides with the flowering and fruiting phases. Frota *et al.* (1985, cited by Aguiar and Costa, 2002) reported successful cultivation in regions with annual precipitation of up to 4,000 mm; however, if there is a drought of 4 to 7 months, then this rainfall is not always well distributed.

3.3.2. Soil

In Brazil, especially in the north-east, the majority of cashew plantations grow on Quartzarenic Neosols (Quartz Sands), Latosols and Argisols (Podzolics). These are deep soils with good drainage, and with no stones or impervious layers, but with poor chemical fertility (Crisóstomo, 1991). In India, the cashew is cultivated on soil that is infertile, leached, acidic and sometimes containing excess changeable aluminium (Al) (Hanamashetti *et al.,* 1985, Gunn and Coks, 1971; Falade, 1984; Badrinath *et al.,* 1997). On the other hand, Menon and Sulladmath (1982) reported that satisfactorily prosperous plantations existed on soils that are volcanic, iron-rich, lateritic rusty, alluvial, clayey, and those with a high water table, at times subject to flooding. According to Latis and Chibiliti (1988), the cashew requires fewer nutrients than other fruit trees, and for this reason many plantations are found on soils of marginal fertility. However, research has shown positive responses to mineral fertilizers. (Falade, 1978; Maamashetti *et al.,* 1985; Sawke *et al.,* 1985 and Grundon 1999). Falade (1984) concluded that the physical and chemical characteristics of the soil influence the height of the plant as well as the diameter of the crown, and the morphology of the root system. He concluded that light textured soils, free from stones and without an impervious layer or horizon within the top 100 cm are the best for growing cashews.

Before establishing a plantation, the soil should be sampled and analysed to determine the need for soil amendments and fertilizers. In already established orchards, soil and leaf analysis provide supplementary information as to the recommendations for fertilizers and soil amendments. Table 3.2 gives data used to evaluate the fertility of the soil.

3.4. Soil and plantation management

3.4.1. Soil preparation and seedling planting

For new plantations, existing surface vegetation and roots, especially around the area where the pit will be prepared, should be removed to minimise competition from other plants. For soil preparation, the use of heavy machinery should be avoided, to diminish the risk of soil compaction.

Liming, when necessary, should be performed in two steps, the first before aeration and the second at ploughing. The quantities should be sufficient to increase base saturation to 60% and the levels of exchangeable calcium (Ca) and magnesium (Mg) to a minimum of 3 and 4 mmolc/dm^3, respectively (Crisóstomo *et al.,* 2003).

The seedlings should be planted into pits, 40 x 40 x 40 cm for sandy soils and of 50 x 50 x 50 cm for medium texture soils with the pits spaced at 7 x 7 m or 8 x 6 m. At the bottom of the pit apply calcareous dolomite at the required amount. The pit should then be filled with a mixture of surface soil, 10 L of cured corral manure, phosphate according to soil analysis, and 100g of Frits[1], 30 days before the seedlings are transplanted. Bovine manure, in general, substantially increases the electrical conductivity of the soil, sometimes causing irreversible damages to the transplants. Kernot (1998) considers that it is undesirable for the electrical conductivity of the saturated water extract to exceed 0.30 dS/m.

[1] F.T.E. Br-12 9% Zn, 1.8% B, 0.8% Cu, 3.0% Fe, 2.0% Mn, 0.1% Mo

3.4.2. Plant management

The transplants should remain upright and lateral shoots should be removed up to 1 m in height, with the object of leaving three or four of the most robust branches, aiming to obtain plants with good crown architecture. It is recommended to remove the flowers in the first year so that the plants will grow more vigorously. Pruning, generally, is limited to removing sick, dry and poorly growing branches. Removing the lower branches should be minimized because the fruit is borne at the edges of the branches occupying the lower two thirds of the plant (Oliveira and Bandeira, 2002).

Soil disturbance to control weeds when necessary, should be not deeper than 15 cm (20 cm maximum) to avoid cutting or damaging the roots. To preserve the soil from erosion (wind or water), mechanical or manual mowing is recommended in between the rows of the plants, and using chemical or manual weeding to keep the soil under the crown clear of weeds. This procedure reduces the competition of weeds for water and nutrients and even facilitates harvesting of the nuts.

To reduce the cost of planting and maintaining an orchard, it is desirable to inter-crop with plants of a short growth cycle (maize, beans, cassava, sorghum) until the third/fourth year. If this practice is adopted, a space of at least one meter should be kept between the tree and the inter-crop. Fertilization of the latter may be necessary to reduce the competition between it and the cashew for nutrients.

3.5. Mineral nutrition

3.5.1. Uptake and export of nutrients

Erroneously, the cashew is considered to require low levels of plant available nutrients because many plantations are found in soils of low natural fertility to which no fertilizers are applied. However, yields do increase with the addition of fertilizers (Ghosh and Bose, 1986; Ghosh, 1989; Grundon, 1999). After germination the cotyledons meet the demand for nutrients but at approximately 45 days this supply is exhausted and development of the root system is induced (Ximenes, 1995).

In each growth cycle, the nutrients are removed from the soil to supply the vegetative parts of the plant (leaves, branches, trunk and roots) and for export in the harvested fruits and pseudo fruits. Thus plant growth and satisfactory harvests are only possible by replacing the nutrients exported by the harvested parts. Some values for exported nutrients are shown in Table 3.3.

Table 3.2. Recommended physical and chemical soil attributes for the interpretation of soil analysis in Brazil and Australia.

Brazil (Crisóstomo, 2003; Raij *et al.*, 1997)			Australia (Kernot, 1998)		
Attribute	Class	Level	Attribute	Class	Level
pH (1:2.5) $CaCl_2$ 0.1 M	Satisfactory	5.5–6.0	pH (1:5) Water (1:2.5)	Satisfactory	6.0–6.5
Electrical Conductivity (dS/m)			Electrical Conductivity (dS/m)	Good Elevated	<0.15 >0.30
P-resin (mg/dm^3)	Low Adequate Elevated	<12 13–30 >30	Phosphorus (mg/dm^3) sodium bicarbonate	Low Adequate Elevated	<30 30–50 >50
Potassium ($mmol_c$/ dm^3)	Low Adequate Elevated	<1.5 1.6–3.0 >3.0	Potassium ($mmol_c$/kg)	Low Adequate Elevated	<0.1 0.2–0.4
Calcium ($mmol_c/dm^3$)	Low Adequate Elevated	<3 4–7 >8	Calcium ($mmol_c$/kg)	Low Adequate Elevated	<1.5 1.6–1.8 >1.9
Magnesium ($mmol_c/dm^3$)	Low Adequate Elevated	<4 4-7 >8	Magnesium ($mmol_c$/kg)	Low Adequate Elevated	<0.2 0.2–0.3 >0.4
Copper (DTPA) (mg/dm^3)	Low Adequate Elevated	<0.2 0.3–0.8 >0.8	Copper (mg/kg)	Low	<0.3
Zinc (DTPA) (mg/dm^3)	Low Adequate Elevated	<0.5 0.6–1.2 >1.2	Zinc (mg/kg)	Low Marginal Elevated	<0.5 0.5–1.0 >1.0

Sources: Raij *et al.*, 1997; Kernot, 1998; Crisóstomo *et al.*, 2003.

Table 3.3. Export of nutrients by cashew nuts and the pseudo fruit.

Source	Nut					
	N	P	K	Ca	Mg	S
	g/kg					
Mohapatra *et al*. (1973)	31.36	4.15	6.30	-	-	-
Haag *et al*. (1985)	6.76	0.70	3.28	0.24	0.67	0.27
Fragoso (1996) CCP 76 [(1)]	11.79	1.28	6.16	0.38	2.23	0.60
Fragoso (1996) CCP 09 [(1)]	11.35	1.47	7.25	0.27	2.19	0.66
Kernot (1998)	13.80	2.00	6.50	1.00	1.60	0.70
	Peduncle					
	N	P	K	Ca	Mg	S
	g/kg					
Mohapatra *et al*. (1973)[b]	6.16	0.85	3.90	-	-	-
Haag *et al*. (1985)[a]	7.14	0.66	2.93	0.14	0.64	0.26
Fragoso (1996) CCP 76[a (1)]	0.90	0.10	1.16	0.01	0.13	0.04
Fragoso (1996) CCP 09[a (1)]	0.81	0.11	1.32	0.01	0.12	0.06
Kernot (1998)[b]	8.50	1.30	8.50	0.90	0.90	0.80

[a]fresh weight; [b]dry weight.

[(1)]CCP: Cashew Clone "Pacajus" 09 or 76.

3.5.2. Functions and importance of nutrients

Nitrogen (N): Reddy *et al.* (1981) and Ghosh (1986) report impressive increases in production by increasing the amount of nitrogen applied. Ghosh (1989) showed that increasing the amount of N applied significantly increased the duration of flowering and the number and weight of nuts. The symptoms of N deficiency are seen initially in the older leaves, characterized by chlorosis in the apex region of the lamina, but because N can be mobilized and redistributed within the plant, the young leaves remain green (Plate 3.1). Generally, plants deficient in N have: (a) low stature, fewer branches and fewer leaves; (b) pale leaves due to less chlorophyll (Plate 3.1); (c) when deficiency is severe leaves fall and branches die.

Chemical analysis of the leaves together with soil analysis is used to evaluate the nutritional state of the orchard and formulate fertilizer recommendations. Haag *et al*. (1975) (Table 3.4) consider 13.8 g N/kg of dry matter as insufficient, in agreement with a suggestion of Kernot (1998). These authors considered that adequate levels of N were between 24.0 to 25.8 and 14 to 180 g/kg of dry matter, respectively. Such a large difference may be attributed to the genetic material used by the two authors.

Phosphorus (P): Phosphorus is required in a smaller amount than either N or K. Table 3.3 shows the quantity of P exported by the fruit ranging from 0.7 to 4.15 g/kg and the pseudo fruit from 0.11 to 1.30 g/kg. Such differences are due to the form of expression of the results, fresh weight and dry weight. The visual symptoms of P deficiency are characterized, initially, by dark green coloration of the leaf, which in the more advanced stages, turns an opaque green before the leaves fall prematurely. In general, plants deficient in P have smaller leaves than well-nourished plants. Due to nutrient redistribution, the visual symptoms are observed in the leaves on the lower third of the crown.

Chemical analysis of the leaves together with soil analysis indicates the nutritional state of the plant on which P fertilizer recommendations can be based. Table 3.4 shows foliar P composition reported in Australia, Brazil and Zambia, which are very similar.

Table 3.4. Comparative compositions of nutrients found in mature cashew leaves in Australia, Brazil and Zambia.

Nutrient (in DM)	Richards (1993)	Haag *et al.* (1975)	Latis & Chibiliti (1988)
	Australia	Brazil	Zambia
Macro-nutrient	----------------------------	g/kg	----------------------------
N	15.0	22.9	17.2
P	1.08	1.4	0.2
K	0.62	8.9	0.9
Ca	3.8	2.1	1.2
Mg	2.6	3.4	0.7
S	-	1.8	-
Micro-nutrient	--------------------------	mg/kg	----------------------------
B	-	51.7	12.6
Cu	-	12.7	-
Fe	-	83.1	78.8
Mn	-	139.0	73.2
Zn		25.0	8.7

Potassium (K): At harvest, 1,000 kg cashew nut and 10,000 kg of fresh peduncle contains about 115 kg K (Fragoso, 1996). The symptom of K deficiency is similar to that of N and P, starting in the oldest leaves, which show light chlorosis on the edges. In the advanced stages, the chlorosis reaches the centre of the leaf lamina, remaining green only at the base, in appearance like an inverted “V”. Remembering that visual symptoms only become evident when the deficiency is in an advanced stage, chemical analysis permits a more accurate diagnosis. Kernot (1998) considers an adequate leaf K is between 7.2

and 11.0 g/kg (Table 3.4). On the other hand, the values found by Haag *et al.* (1975) are much larger and vary between 11 and 20 g/kg. This difference, possibly, may be attributed to the genetic material used because the latter author worked with the Giant Cashew.

Calcium (Ca): The initial symptoms of Ca deficiency, according to Avilán (1971), are seen as ripples in new leaves (Plate 3.2). Because Ca has little mobility in the plant, it has to be applied frequently.

Magnesium (Mg): The quantity of Mg absorbed by the cashew plant is generally less than that of Ca and K. In general, Mg deficiency is due to competition with other ions like Ca^{2+}, K^+ and NH_4^+ for uptake by roots (Mengel and Kirkby, 1978). Most of the Mg in the plant is in chlorophyll but it is also an enzyme activator, especially those involved in the transfer of phosphate radicals rich in energy and the synthesis of nucleic acids. The characteristic symptom of Mg deficiency is interveinal yellowing which starts from the main vein and develops to the edges (Plate 3.3). It is usually seen in the lower leaves, due to the ease of translocation to regions of active growth.

Sulphur (S): The symptoms of S deficiency are seen at the beginning of plant growth. The older leaves become chlorotic and, at the same time, become rigid (Plate 3.4). Necrosis appears at the apex accompanied by curling of the affected tips and torn edges. Sulphate is readily translocated within the plant.

Boron (B): The points of active development above ground and in the roots cease to elongate when boron is deficient, and, if the deficiency persists, become disorganized, lose their normal color and die. With death of the buds and the youngest leaves, the adjacent ones become leathery. In general, plants deficient in boron over-produce shoots, with a duplication of the symptoms on the new shoots.

Copper (Cu): Copper deficiency results in a darkening of the green areas of the leaves. The young leaves are longer and curled down, as though they lack water. Growth seems to be unaffected, at least in the first months of the plant's life.

Iron (Fe): Cashew tree growth is seriously compromised in the absence of iron. In just one month, the visual symptoms of it deficiency appear, characterized by severe chlorosis in young leaves. With increasing deficiency, the leaves become translucent, remaining light green only in the oldest leaves.

Manganese (Mn): In the cashew, Mn deficiency symptoms appear initially in the youngest leaves, characterized by pale green coloring, developing later into greenish-yellow and, in some leaves, the edges become brown. Plants deficient in manganese have a small number of leaves and growth slows down although there is a great development of lateral branches. The occurrence of large clusters of small leaves in the shape of a rosette is common followed by the leaves drying, and falling prematurely.

Zinc (Zn): In the absence of zinc, the plants have short internodes and few lateral branches. In deficient plants, the youngest leaves appear small, elongated, and with a color varying from green to pale green, but the veins remain green. The lower mature leaves develop normally.

3.6. Fertilization

Ghosh and Bose (1986) evaluated the effect of fertilization with N, P and K singly and in combination with other minor and micro-nutrients. They showed that larger yields of cashew nuts were obtained with a combination of N, P_2O_5 and K_2O equivalent to 200, 75 and 100 g/plant/yr, respectively. Later, Ghosh (1989), working with seven-year-old plants for three consecutive years, concluded that the best yield was obtained with N, P_2O_5 and K_2O equivalent to 500, 200 and 200 g/plant/yr. Mahanthesh and Melanta (1994) found that only 100 g P_2O_5 was necessary when they tested 0, 200, 400 and 600 g N/plant/yr. With P_2O_5 and K_2O at 200 and 400 g/plant/yr, respectively, Ghosh (1990) concluded that the weight of the nut, number of nuts, height and vigour of the plants were increased and reached a maximum with 600 g N/plant/yr. Grundon (1999), during three consecutive years found, for four year-old plants, substantial increases in nut production with the application of up to 288 g P and up to 176 g S/plant/yr, but there was no increase in yield from applying up to 3,000 g K_20/plant/yr. Best yields from fifteen year-old plants was with 250, 125 and 125 g/plant/yr of N, P_2O_5 and K_2O, respectively, when the fertilizer was applied in a circular band 1.5 m wide and 1.5 and 3.0 m from the trunk (Subramanian *et al*., 1995). Crisóstomo *et al.* (2004) reported that the maximum yield of cashew nut (1,536 kg/ha), in the sixth year of cultivation on dryland, was obtained with 700 and 45 g/plant/yr of N and K_2O, respectively. Overall, from the economic point of view, doses of N and K_2O recommended were 107 and 41 g/plant/yr with an economic return of US$ 355.36 ha/yr. When evaluating dry matter production, Vishnuvardhana *et al.* (2002) observed that the largest yields were obtained with 1000, 250 and 250 g/plant/yr of N, P_2O_5 and K_2O, respectively, but economically, 500, 250, 250 g/plant/yr N, P_2O_5 and K_2O produced the best results.

Generally, little or no emphasis has been given to the economic evaluation of fertilizer use for cashew. In field experiments during six years in India, Vidyachandra and Hanamashetti (1984), tested 127, 181 and 108 g N, P_2O_5 and

K_2O/plant/yr, alone or in combination with minor and micro-nutrients. The profit was Rs 19.10 (US$ 0.42)/plant when micro-nutrients were added. In Australia, according to Grundon (1999), fertilizing normally with N and K generated costs varying from US$ 0.16 to US$ 0.32 plant/yr. This author also reported that using larger amounts of fertilizer generated costs varying from US$ 169 to 468 ha/yr, when compared to the amounts used traditionally.

3.6.1. Fertilizer recommendations in dryland cultivation

Post-planting fertilization (first year): Fertilizers containing N and K should be applied during the rainy season in three or more equal parts, in a circular groove 10 to 15 cm deep and 10 to 15 cm wide, at a distance of approximately 20 to 30 cm from the stem of the plant and covered with soil, to reduce the loss of ammonium by volatilization.

Fertilization for growth and production: Nitrogen and K rich fertilizers are recommended starting from the second year (Table 3.5) and should be applied in three or more equal applications. On the other hand, P fertilizers should be applied all in one application. The depth and width of the fertilization groove are the same as for post-planting, except the distance from the stem should be increased such that it is situated under the external third of the crown canopy (Crisóstomo *et al.,* 2003).

3.6.2. Fertilizer recommendations in irrigated cultivation

Post-plantation and fertilization for growth and production: In irrigated cultivation, soluble N and K-rich fertilizers, solid or liquid, are applied in the irrigation water, improving their distribution and penetration to the root system. Fertilizers supplying P also may be applied via irrigation water provided the necessary precautions are taken to avoid clogging the emitters (spray and drip). The recommended amounts for the different plant growth phases are outlined in Table 3.5.

3.7. Soil analysis and fertilizer recommendations

3.7.1. Brazil

The criteria for interpreting soil analysis results for fertilization recommendations for cashew (Table 3.5) permit separation of areas with high probability of reaction to a certain nutrient, those of medium and those of low reaction. Other than this, expected productivity, the age of the plant and the plantation system (irrigated or rain-fed) are also considered.

Table 3.5. Fertilization recommendations for pre-mature dwarf cashew in planting, growth and production phases in both irrigated and dryland conditions.

Fertilization	N	P-resin (mg/dm^3)			K-soil (mmol$_c$/dm^3)		
		0-12	12-30	>30	0-1.5	1.6-3.0	>3.0
Year	g/plant	--------------- P_2O_5 (g/plant) --------------			-------------- K_2O (g/plant) --------------		
Planting	0	200 (180) [(1)]	150 (140)	100 (90)	0	0	0
Growth							
0-1	60 (45)	0	0	0	60 (50)	40 (30)	20 (20)
1-2	80 (70)	200 (160)	150 (140)	100 (90)	100 (90)	60 (50)	40 (30)
2-3	150 (120)	250 (220)	200 (180)	120 (110)	140 (120)	100 (90)	60 (50)
3-4	200 (150)	300 (290)	250 (230)	150 (140)	180 (170)	140 (130)	80 (70)
4-5	300 (220)	300 (290)	250 (230)	150 (140)	180 (170)	140 (130)	80 (70)
Production							
Expected yield (kg/ha)							
<1,200	400 (300)	200 (160)	100 (80)	100 (80)	150 (120)	100 (80)	80 (80)
1,200-3,000	700 (520)	300 (240)	200 (160)	150 (120)	300 (240)	200 (160)	150 (120)
>3,000	1,000	400	300	200	450	300	200

[(1)]Values in parenthesis refer to cultivar in dry land.
Apply 50 g de F.T.E. BR-12 plant/yr for years 2 to 4 and 100 g starting from year 5.

Source: Crisóstomo *et al*., 2002; Crisóstomo *et al*.2003.

3.7.2. Australia

Table 3.6 presents suggestions for cashew fertilization from the second year, without taking into consideration soil analysis.

Table 3.6. Fertilization suggestion for cashew.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year >5
Macro-nutrient	------------------------------- g/plant/yr -------------------------------					
N	-	200	400	600	800	1,200
P	-	30	80	100	140	170
K	-	150	400	600	800	1,200
Ca	-	100	100	200	300	400
Mg	-	100	100	200	250	300
S	-	5	10	20	30	45
Micro-nutrient						
B	-	0.1	0.2	0.3	0.4	0.5
Cu	-	0.1	0.2	0.2	0.3	0.4
Fe	-	1	2	4	6	8
Mn	-	0.2	0.4	0.5	0.7	1.0
Mo	-	0.001	0.001	0.001	0.001	0.001
Zn	-	0.2	0.4	0.6	0.8	1.2

Source: Kernot, 1998.

3.8. Irrigation

Although the cashew may grow and produce in regions with an annual precipitation above 600 mm and with a drought of 4 to 5 months, irrigation allows maximum productivity, increasing the harvest period and improving the quality of the peduncle and the nut. Studies in Brazil and other countries have shown that irrigation could increase productivity by up to 300%, depending on the region.

3.8.1. Irrigation methods

It is recommended to use micro-irrigation (spray or drip), because it has the following advantages over other methods of irrigation: decreased incidence of leaf sickness and weeds, water saving by decreasing losses by evaporation and greater efficiency of water use. Micro-irrigation can also be adapted to different soil and topographies; there is a saving in labour costs and efficient application of fertilizers via irrigation water (fertigation). The initial cost of a system of micro-irrigation for cashew varies from R$ 3,000 to R$ 4,500 (US$ 1,000 to US$ 1,500) per hectare.

Where spraying is used it is recommended to have one jet per plant, with a nominal flow of 30 to 70 L/h and wetting diameter of 3.5 to 5.0 m. In dripping, a minimum of four drippers per plant ought to be used per adult plant in clayey soils, and up to eight drippers per plant in sandy soils.

To choose between spray and dripping as a system of irrigation, the water availability (quantity and quality) should be considered. In dripping there is a greater savings in water and energy, because the loss of water by evaporation from the soil surface is less and the system operates at a lower pressure. On the other hand, the risk of emitter blocking is greater than with spray irrigation, thus better filtering, especially when surface water with a lot of organic matter is used. Dripping also offers the advantage of not wetting the fruits that fall onto the ground, allowing less frequent collecting where the primary product required is the nut.

3.8.2. Water requirements

In Australia, Schaper *et al.* (1996), reported that the plant could be irrigated only between flowering and harvest without decreasing yield compared to irrigating during the entire drought period. This saves much water.

The water needs of the plant vary with climate, the plant's foliar area, the growth phase of the plantation and with the irrigation method used. During periods of high evapo-transpiration, 5 L of water/day are recommended for each square meter of soil surface shaded by the plant crown or area wet by the emitters (Table 3.7). The frequency of irrigation depends on the water retention capacity of the soil and should vary between two and four days, for sandy and clayey soils, respectively.

With drip irrigation, the volumes of water recommended in Table 3.7 may be reduced by about 15%. The number of drippers per plant should increase gradually, according to the age and stature of the plant, from one drip dripper during the first year to up to four, six or eight per adult plant in clayey, medium textured and sandy soils, respectively.

Soil humidity or water tension monitoring is recommended, in order to ensure that the volumes of water applied and the frequency of irrigation best serve the needs of the plant. Tensiometers can be used to monitor soil water content. For each homogenous area, in terms of soil and cultural phase, tensiometers should be put in at three different locations where there is the greatest concentration of roots. This allows identification of sensors with readings well above or below the average and when this occurs it is necessary to determine if the problem is in the sensor or in the irrigation system (blocked emitters, leaks in the supply lines etc.).

Table 3.7. Average values of crown projection areas, percentage of soil covered by the plant and volume of water to be applied in irrigation as a function of plant age.

Year of crop	Crown projection area	Soil covering	Volume of water
	m^2	%[(1)]	L/plant/d[(2)]
1st	1	2	5
2nd	5	10	25
3rd	15	30	70
4th	25	50	120
5th +	30	60	145

[(1)]Assuming the spacing between plants to 7 x 7 m.
[(2)]If the area wetted by the nozzle is greater than the crown projection, the volume of water to be applied should be chosen as a function of the wetted area.

Source: Miranda, F.R. de., 2005; unpublished data.

For the cashew, tensiometers should be installed at two depths in each location of monitoring: the first at 20 cm and the second at 50 cm deep. The distance of the sensors in relation to the tree trunk varies from 30 cm in the first year of crop up to 1.6 m for adult plants. When drip irrigation is used, the tensiometers should be installed a lateral distance of 20 cm from the dripper. The readings from the tensiometers should be performed in the morning, preferentially. For cashews planted in sandy soil, the soil water tension between irrigations should vary between 8 and 25 centibars. For clayey soils, the ideal range is between 30 and 50 centibars. Lower readings in which the minimum values cited indicate that irrigation is excessive. Reading higher than the ideal range indicates that the soil is drier than desirable and the quantity of water ought to be increased and/or the irrigation interval reduced.

3.8.3. Fertigation

The application of fertilizers through the irrigation water (fertigation) has the advantages of increasing the efficiency of the fertilizers and reducing the costs of labour and machinery for its application. Fertigation allows the application of nutrients with greater frequency, without increasing the cost of the application, minimizing losses by volatilization and leaching and optimizing nutrient absorption by the roots. The nutrients most frequently applied in fertigation are those with greater mobility in the soil, like N and K (Oliveira *et al.,* 2002).

To apply nutrients by fertigation, tanks of the solution, where the fertilizers are pre-diluted in water, and an injecting device are necessary. The types of injectors most utilized in fertigation are: injector pumps, venturi and differential pressure tanks.

There are many advantages to fertigation: a) uniform application of nutrients; b) application of nutrients according to the needs of the plant and the rate of uptake; c) greater efficiency of nutrient use due to its mobility in the wetted zone of the soil where the root system is concentrated; d) savings on labour and agricultural equipment; e) reduction in soil compaction from the use of heavy equipment; f) ability to apply nutrients more frequently thus reducing nutrient losses (Santos *et al.,* 1997). Fertigation needs to be carefully managed to avoid soil acidification and salination in the root zone. To avoid blocking the emitters the fertilizers used should be fully soluble in water and should not form precipitates, especially calcium and iron phosphates.

3.9. References

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4. Citrus

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4.1. Introduction

Citrus make up a large group of plants of the genus *Citrus* and other affiliated genii (*Fortunella* and *Poncirus*) or hybrids of the family Rutaceae, representing most of the oranges, tangerines, lemons, limes (acidic and sweet), grapefruits and citrons. This family of plants originate principally in subtropical and tropical regions of Japan, South-East Asia, including areas west of India, Bangladesh, Philippines, and Indonesia, Australia and Africa (Webber, 1967).

These perennial plants have mesophytic characteristics (almost bare shoots, large thin leaves with superficial stomata, absence of hairs and a thin cuticle) and perennial leaves that develop in spurts of vegetative growth in spring and summer. They are cultivated in many regions of the world, adapting to different soil and climatic conditions, as long as there is adequate water and nutrition (Spiegel-Roy and Goldschmidt, 1996).

The production potential of citrus fruits in commercial orchards is determined principally by the genetic value of the scion and rootstock (Pompeu Jr., 1991). The use of grafting is fundamental to break the juvenility of the plants, for maintenance of the resistance/tolerance of the citrus to biotic (e.g. citrus tristeza virus) and abiotic stress (e.g. efficiency of water and nutrient use), and to increase fruit yield and quality. However, total production is related to the density of the plantation, vegetative growth, photosynthetic efficiency, florescence intensity and growth of the fruits, as well as management of those factors that interfere with growth in the orchard (Davies and Albrigo, 1994).

Studies on the nutritional needs of citrus in Brazil started in the 1940s (Briefer and Moreira, 1941; Vasconcellos, 1949; Rodriguez and Moreira, 1968; Rodriguez *et al.,* 1977).

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During the 1980s, the Agricultural Institute (IAC) started an extensive network of field experiments to calibrate analytical data. In 1988, the Paulista Group for Fertilization and Liming for Citrus, a group of producers, technical and extension support technicians and researchers, organized the first recommendations for managing the nutrition of citrus in Brazilian conditions. These have been periodically updated as new experimental data has become available (Grupo Paulista, 1994).

Orange is the world's main *Citrus* crop, with a total world production of 63 million mt in 2004, followed by mandarin, lemon and lime, and grapefruit (23, 12 and 5 million mt, respectively). At this time, world orange production was led by Brazil (29%), followed by the United States (19%), Mexico (6%), Spain (5%) and Italy (4%). (FAO, 2006).

4.2. Crop physiology

Citrus, due to its mesophytic and perennial characteristics, develops well at temperatures ranging from 22 to 33ºC. Above 40ºC and below 13ºC, the rate of photosynthesis diminishes, resulting in loss of productivity (Syvertsen and Lloyd, 1994). Productivity is also affected by differences in vapour pressure between the leaf and the atmosphere. If elevated, the opening of the stomata is inhibited and this reduces diffusion of atmospheric CO_2 to the carbon fixation sites on the chloroplasts. Consequently, the rate of photosynthesis is decreased (Medina *et al.*, 1999).

For citrus, the period between florescence and fruit maturation can vary from six to sixteen months, depending on the species or variety and soil and climatic conditions (Reuther, 1977). It is this interval that defines the varieties called premature (Hamlin and Westin), mid-season (Pera) and late (Valencia, Christmas and Folha Murcha).

Erickson (1968) identified four stages between florescence and maturation of the fruits.

(i) *Vegetation* – occurs during periods characterized by low temperatures or water deficiency (end of autumn or beginning of winter), when growth spurts stop and there is an accumulation of carbohydrates in the plants.

(ii) *Induction of floral differentiation* – with intensification of cold and water stress, the vegetative cells transform into reproductive cells.

(iii) *Flowering* – later, between the end of winter and the start of spring (when the temperature as well as availability of soil water increase) the flowers open. In this phase the high temperatures over a prolonged period may cause serious damage to flower retention and young fruits.

(iv) *Fruit production* – the final yield of fruits is the result of retention of just 1 to 3% of the flowers produced by the citrus. Soon after picking the fruits there is a cellular division and expansion, events that define the growth potential of the fruits at the end of maturation.

4.3. Soils

Citrus adapts well to soil conditions, maintaining elevated levels of productivity, provided soil management is adequate and the varieties grown have a high genetic potential. In less fertile soils (shallow, very clayey or very sandy in texture, alkaline or acidic in reaction or saline) citrus plantations should be planned to optimise the productive capacity of the soil. For example, appropriate strategies include the construction of terraces, planting on a level, construction of drainage canals, planting in ridges, etc. and these should be integrated with irrigation systems and the management of soil fertility (liming and fertilization) to optimise citrus production.

4.4. Mineral nutrition

Citrus growth and fruit production is the result of assimilation of CO_2, which depends on light, temperature, water, nutrients, leaf area, etc., and the partition of the fixed carbon between the various organs of the plant. The absence or deficiency of mineral nutrients, which represent only about 5% of the dry matter of the plant biomass and are absorbed principally through the roots, results in injury, abnormal development or death of the plant. For this reason, the adequate development and, consequently, the high productivity of citrus depend on the correct diagnosis of the availability of nutrients in the soil. When deficient, these nutrients should be supplemented in sufficient quantities in periods of greatest demand.

4.4.1. Soil analysis

The methods employed for the chemical analysis of the soil in the state of Sao Paulo are those given in the System IAC of Soil Analysis (Raij *et al.*, 2001). In the System IAC, phosphorus (P) is determined using an anion exchange resin and the results are adjusted for Brazilian soils to better evaluate the availability of P in the orchards.

Soil samples are taken from turf or homogenous areas (up to 10 ha) with regard to soil color and texture, position relative to the management of the orchard, age of the trees, combination of the scion and rootstock and productivity. Soil samples should be taken from where the fertilizers are to be applied and from the 0-20 cm depth of soil when the purpose is to make fertilizer recommendations. Samples are taken from below 20 cm when the intention is to diagnose chemical barriers to the development of the roots, i.e. calcium (Ca) deficiency or excess of aluminium (Al). Each sample should consist of not less than 20 sub-samples that are bulked to represent the area for which information is required. The most appropriate time for sampling is February to April (summer in the southern hemisphere, being sure to leave a minimum interval of 60 days after the last fertilization. To guarantee a more efficient and representative sample, the collection of the sub-samples should be done with a Dutch or similar auger.

The classification of soil fertility based on soil analysis for macro-nutrients is in Table 4.1 and for micro-nutrients and sulphur is in Table 4.2 (Quaggio *et al.*, 1992a, b, 1997, 1998, 2003).

Table 4.1. Soil fertility status standards for interpreting soil analysis data for citrus.

Soil fertility class	P-resin	K	Mg	Base saturation
	mg/dm^3	---------- $cmol_c/dm^3$ ----------		%
Very low	<6	<0.8	-	<26
Low	6-12	0.8-1.5	<4	26-50
Average	13-30	1.6-3.0	4-8	51-70
High	>30	>3.0	>8	>70

Source: Quaggio *et al.*, 2003.

Table 4.2. Interpretation of analysis results for sulphur and micro-nutrients.

Soil fertility class	$S\text{-}SO_4^{-2}$	B	Cu	Mn	Zn
	------------------------------ mg/dm^3 ------------------------------				
Low	<10	<0.6	<2	<3.0	<2.0
Medium	10-20	0.6-1.0	2-5	3.0-6.0	2.0-5.0
High	>20	>1.0	>5	>6.0	>5.0

Adapted from: Quaggio *et al.*, 2003 and field observations.

4.4.2. Leaf analysis

The levels of nitrogen, phosphorus and potassium diminish with the age of the leaf. The levels of calcium increase in more mature leaves (Smith, 1996). In spite of many studies reporting the influence of scions on leaf nutrient concentrations for citrus (Hiroce and Figueiredo, 1981; Wutscher, 1989), precise information is needed for each scion/rootstock combination in order to better interpret leaf analysis results.

Leaves collected for analysis should be of the same age and come from plants cultivated in similar conditions. The sample should consist of the 3rd or 4th leaf from the fruit, generated in spring and approximately six months old, on branches with fruits of 2 to 4 cm in diameter (Trani *et al.*, 1983). It is recommended to sample at least 25 trees in an area not larger than 10 ha and collect 4 undamaged leaves per tree, one from each quadrant at medium height. Sampling should be delayed until at least 30 days after the last nutritional foliar spray.

Interpretation of the results of leaf analysis was initially established based largely on studies in the USA (Chapman, 1960; Smith, 1966; Embleton *et al.*, 1973a) and later adapted to the Brazilian conditions based on field experiments there (Grupo Paulista, 1994; Quaggio *et al.*, 1997). The interpretation of leaf analysis data is in Table 4.3. The fertilization program of the orchard should be adjusted so that the nutrient composition of the leaves is in the adequate range.

Table 4.3. Ranges of macro- and micro-nutrients of citrus leaves, considered to be low, adequate and excessive, in six-month old leaves taken from fruiting branches in spring.

Nutrient	Low	Adequate	Excessive
Macro-nutrient		------------------------------ g/kg ------------------------------	
N(1)	<23	23-27	>30
P	<1.2	1.2-1.6	>2
K	<10	10-15	>20
Ca	<35	35-45	>50
Mg	<3.0	3.0-4.0	>5
S	<2.0	2.0-3.0	>5
Micro-nutrient		--------------------------- mg/kg -----------------------------	
B	<50	50-100	>150
Cu(2)	<4.0	4.1-10.0	>15
Fe	<49	50-120	>200
Mn	<34	35-50	>100
Zn	<34	35-50	>100
Mo	<0.09	0.1-1.0	>2

(1)For lemons and Tahiti limes, the ranges of interpretations of leaf N composition (mg/kg) are: <15 (= low), 15-18 (= adequate) and >25 (= excessive).

(2)For the Westin variety orange, the adequate compositions of Cu suggested are 10-20 mg/kg.

Source: Quaggio *et al.*, 1997; Grupo Paulista, 1994.

4.4.3. Liming

For perennial crops like citrus, it is important to correct soil acidity before planting the orchard, incorporating lime as deeply as possible. The amount of lime added should aim to raise the base saturation to 70% in the 0-20 cm soil layer (Quaggio *et al.*, 1992a). This value corresponds to pH 5.5 as determined in 0.01 M $CaCl_2$. Liming is also recommended to raise and maintain the level of magnesium (Mg) in the soil to at least 4 or, ideally, 8 $cmol_c/L$ (Quaggio *et al.*, 1992b).

At the time of planting it is recommended to apply additional lime at 250 g/pit into the planting hole where the seedlings will be planted, together with P, to stimulate the growth of the root system.

4.4.4. Fertilization

Recommendations for N, P and K fertilizers for citrus are distinguished by: (i) plantation, (ii) age of the trees <5 years old and (iii) production on levels of mature trees. For the latter, the amounts of fertilizer depend on the varieties of oranges, limes and lemons, tangerines and tangors (Grupo Paulista, 1994; Quaggio *et al.*, 1997). For oranges, fertilizer recommendations also take into account the quality and the destination of the fruit (industry or fresh consumption).

When planting the trees it is recommended to apply P in the pits, the amounts varying from 20 to 80 g P_2O_5/m linear, together with lime (Table 4.4). This is the ideal time for deep incorporation of P, especially in tropical soils deficient in this nutrient. Micro-nutrients may also be applied based on the results of soil analysis to ensure a good distribution and avoid loss due to the concentration of fertilizer in the region of initial root growth.

After planting, the recommended amounts of N, P_2O_5 and K_2O take into account the age of the trees and the results of soil analysis for P and K with the aim of meeting the needs of tree growth and the beginning of fruit production (Table 4.5).

When the fruits are forming, the response of sweet orange to fertilization with P is greater when grafted on Cleopatra tangerine [*Citrus reshni* (Hayata) hort. ex Tanaka] compared to Rangpur lime (C. limonia Osb.) and the citrumelo Swingle [Poncirus trifoliate (L.) Raf. x C. x *paradisi* Macf.] (Mattos Jr., 2000). The best relationship between soil P and the requirement for P fertilizers is the fruit production phase. The critical level of soluble P for young trees is more than the 20 mg/dm^3 reported for adult trees. This is because the root system of young trees is limited to a small volume of soil and to the fact that P moves to the root principally by diffusion. Similar research with K shows that in the early phase of growth the response of the scion in citrumelo Swingle to addition of K is greater than that of other grafts. Therefore, adjustments of the recommended amounts may be made taking into account both rootstock and scion chosen.

Table 4.4. Amounts of phosphorus and zinc for citrus plants according to soil analysis.[1]

Nutrient	Level in soil (mg/dm^3)[2]	Nutrient application g/m linear of pit
	P-resin	
	0-5	80
P	6-12	60
	13-30	40
	>30	20
	DTPA	
Zn	<1	1
	>1	0

[1]Apply the fertilizers in deep pits, according to soil analysis.

[2]Preferentially use simple superphosphate.

Source: Quaggio *et al.*, 1997; Grupo Paulista, 1994.

Table 4.5. Amount of N, P and K recommended for young citrus trees.

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	100	0	0	0	0	40	20	0	0
1-2	220	160	100	50	0	120	90	50	0
2-3	300	200	140	70	0	200	150	100	60
3-4	400	300	210	100	0	400	300	200	100
4-5	500	400	280	140	0	500	400	300	150

Note: For tangerine Ceopatra increase doses of P_2O_5 by 20%; for citrumelo Swingle increase doses of K_2O by 10%.

Source: Quaggio *et al.*, 1997; Grupo Paulista, 1994.

Citrus fruit production is largely influenced by the supply of N (Alva and Paramasivam, 1998). Nitrogen regulates the rate of photosynthesis and synthesis of carbohydrates (Kato, 1996), the specific weight of the leaves (Syvertsen and Smith, 1984), total biomass production and allocation of carbon to different plant organs (Lea-Cox *et al.*, 2001).

Soil analysis cannot be used to estimate the amount of N required because adequate methods of evaluating the availability of soil N are still not available. Additionally, the process of conserving samples for routine analysis is difficult (Mattos Jr., *et al*., 1995a).

However, percentage N in the leaf can be a good indicator for adjusting the amount of N required according to the impending production of fruit (Fig. 4.1). For oranges (Quaggio *et al*., 1998), tangerines and Murcott tangors (Mattos Jr. *et al*., 2004), there is practically no response to N when leaf N exceeds 28 g N/kg. For lemons and limes, there is adequate N when the leaves contain about 22 gN/kg.

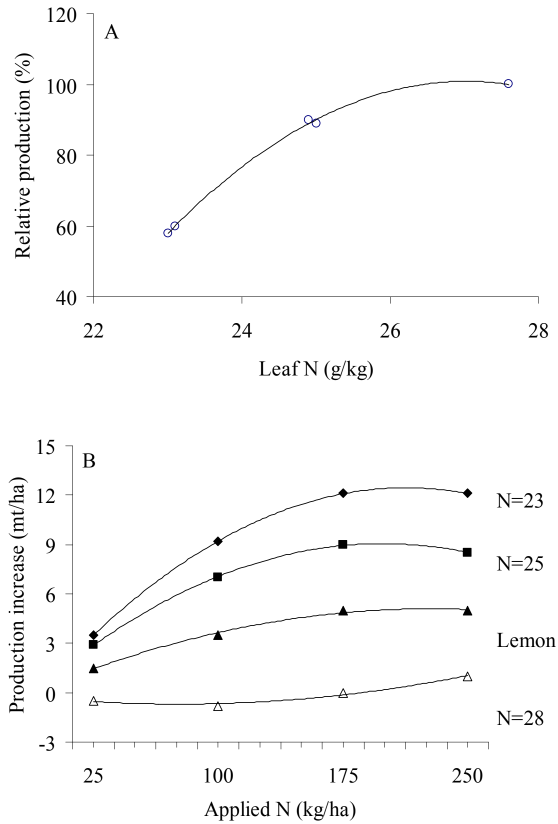

Fig. 4.1. Relative production of citrus fruits according to leaf percent N (A) and expected response to nitrogen fertilizer according to leaf %N (B), (Quaggio *et al*., 2002; Mattos. *et al*., 2003a).

Citrus stores a large quantity of N in its biomass, which may be redistributed, principally to the developing organs like leaves and fruits (Mattos Jr. *et al.*, 2003b). For this reason, decreasing the amount of N fertilizer applied may not immediately affect the production of fruits. However, when the amount of N is less than that recommended, the trees could suffer a serious decrease in crown leaf density and production, which results in losses in fruit production in later years.

Adjusting the amount of N fertilizer based on leaf analysis is important, because the lack or excess of N interferes with the size and quality of the fruit (Embleton *et al.*, 1973b). For example, large amounts of N tend to increase the number of fruits at the expense of their size and this could be a disadvantage for marketing whole fresh fruits. Fertilization with K also affects the size of the fruit. However, applying excess K could result in losses in yield owing to nutrient imbalance, seen as an accentuated decrease in leaf Ca and Mg (Mattos Jr. *et al.*, 2004). Applying large amounts of K increases fruit size and peal thickness, which are desirable qualities for the fresh fruit market. However, plants well supplied with K tend to produce fruits with greater acidity and a lower content of soluble solids, which lessens their value for the juice industry. Large concentrations of plant-available K in soil are common in orchards where traditional citrus-culture formulations have been used without taking into consideration the results of soil analysis (Quaggio, 1996).

Adequate management of N fertilizers is important to guarantee the efficient use of N. In orchards where the undergrowth is controlled by using herbicides or mowing rather than ploughing, fertilizers are applied on the soil surface, sometimes on top of plant residues. In these conditions, urea, the most common source of N, is subject to loss by ammonia (NH_3) volatilization if it is not incorporated into the soil either mechanically or with irrigation water or rain. Measurements in commercial orchards have shown N losses by volatilization of NH_3 varying from 15 to 45% of the N applied to the soil surface as urea (Cantarella *et al.*, 2003; Mattos Jr. *et al.*, 2003c). The unit price of N as urea is about 20 to 30% less than that of N as ammonium nitrate and this may compensate for the probable losses of N by volatilization of NH_3 in the field. Also, because the rate of loss increases with the amount of urea applied, dividing the application into many smaller amounts applied throughout the year may be an alternative to increase N use efficiency for citrus.

Research in Brazil allows, for the first time, the calibration of soil analysis data for P and K for citrus, based on using an ion exchange resin (Fig. 4.2 and 4.3; Quaggio *et al.*, 1996a, 1998). When the analytical data for K are divided into classes, i.e. very low, low, medium, etc. the ranges used are similar to those used in annual crops. For P, however, the critical level for perennial crops is lower (20 mg/dm^3). Experimental data have shown that the analysis of soil is important for predicting the response of citrus to fertilization with P and K. There is a very strong correlation between the levels of P in the soil and the relative production of fruits by adult trees. The response to K fertilization is also quite significant. The increase in yield per unit of K applied is greater when soil K values are very low and low.

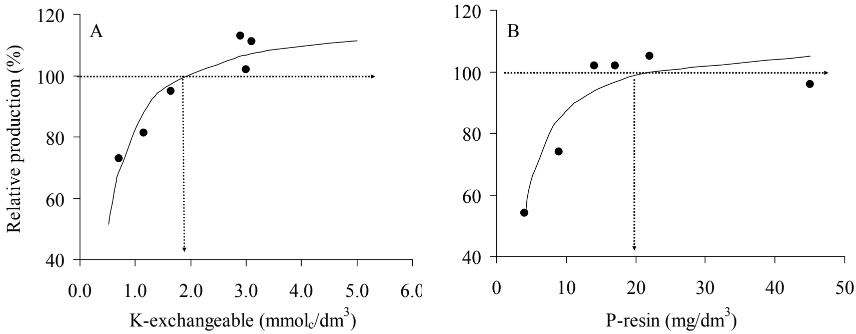

Fig. 4.2. Calibration curves for relative production of citrus according to soil exchangeable potassium (A) and P-resin (B), (Quaggio *et al.*, 1996a, 1998).

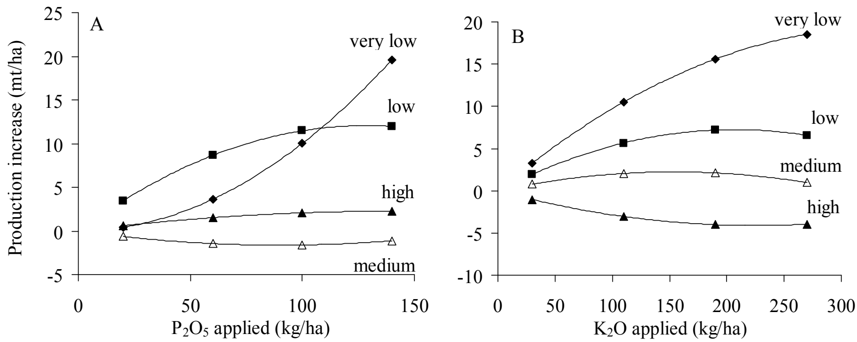

Fig. 4.3. Response to P and K fertilization at few levels of P-resin (A) and exchangeable K (B), (Quaggio *et al.*, 1996a, 1998).

For orchards in production, expected yields are also used as a criterion for adjusting the amounts of fertilizer to apply because plants that are more productive need larger quantities of nutrients for fruit production and leaf, branch and root growth. On average per mt of fruit, the amounts in kg of nutrients removed are; N and K, 1.2 to 1.9; P, 0.18; Ca, 0.52; Mg, 0.10; S, 0.10;

B, 1.9 x 10^{-3}; Cu, 0.6 x 10^{-3}; Fe, 3.4 x 10^{-3}; Mn, 1.9 x 10^{-3} and Zn 1.7 x 10^{-3} (Bataglia *et al*., 1977; Paramasivam *et al*., 2000; Mattos Jr. *et al*., 2003d). Considering the nutrient content of the whole plant, Ca is present in large quantities in mature tissues like old leaves, branches and roots, while N is present in the young leaves and rootlets. Quantities of macro- and micro-nutrients in the various parts of the plant are shown in Table 4.6.

Fertilization with P for citrus had been neglected in Brazil because data obtained in other countries suggested that this crop responded only a little to P. This information came from temperate countries where soils growing citrus were developed from sediments rich in P (Jackson *et al*., 1995). The soils of Brazil are, however, generally deficient of this nutrient (Quaggio, 1996).

For surface application, water-soluble P sources should be used. Other than this, owing to the low mobility of P in soil, it is recommended to incorporate P fertilizer together with lime, once a year, especially in soil in which P deficiency could be limiting.

Table 4.6. Total nutrient content in various parts of six years old Hamlin orange x citrumelo Swingle, on a Neosol at a density of 286 trees/ha.

Nutrient	Parts of the plant					
	Leaves	Branches	Trunk	Fruits	Roots	Total
Macro-nutrient			kg/ha			
N	17.2	11.8	2.0	18.0	17.5	66.5
K	8.7	6.9	1.4	23.2	11.8	52.0
P	1.4	2.1	0.3	2.8	1.7	8.3
Ca	27.9	25.9	2.4	8.7	13.5	78.4
Mg	1.8	2.1	0.2	1.7	2.9	8.7
S	1.8	1.2	0.2	1.3	2.3	6.8
Micro-nutrient			g/ha			
B	49	30	5	41	40	165
Cu	11	12	3	11	91	128
Fe	65	66	32	61	456	680
Mn	13	5	1	7	184	210
Zn	13	25	13	13	333	397

Source: Mattos Jr. *et al*., 2003d.

Based on this information, recommendations have been established for N, P and K fertilization for orchards in production. The amounts are calculated for maximum economic production, for different groups of varieties of orange, considering the quality and destination of the fruit (for processing see Table 4.7, or the fresh fruit market see Table 4.8). Fertilizers are applied during the rainy

Table 4.7. Fertilizer recommendations for oranges for processing based on leaf and soil analysis, and anticipated yield. The amounts were calculated to achieve maximum economic production and are kg/ha of N, P_2O_5, K_2O.

Yield	N in leaves (g/kg)			P-resin (mg/dm^3)				K-exchangeable (cmol$_c$/dm^3)			
	<23	23-27	>27	<6	6-12	13-30	>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) -----------------			
<15	100	70	60	60	40	20	0	60	40	20	0
16-20	120	80	70	80	60	40	0	80	60	40	0
21-30	140	120	90	100	80	60	0	120	100	60	0
31-40	200	160	130	120	100	80	0	140	120	80	0
41-50	220	200	160	140	120	100	0	180	140	100	0
>50	240	220	180	160	140	120	0	200	160	120	0

Adapted from: Quaggio *et al.*, 1997; Grupo Paulista, 1994.

Table 4.8. Fertilizer recommendations for oranges for fresh fruit based on leaf and soil analysis, and anticipated yield. The amounts were calculated to achieve maximum economic production and are kg/ha N, P_2O_5, K_2O.

Yield	N in leaves (g/kg)			P-resin (mg/dm^3)				K-exchangeable (cmol$_c$/dm^3)			
	<23	23-27	>27	<6	6-12	13-30	>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) -----------------			
<15	80	60	40	60	40	20	0	100	80	60	0
16-20	100	80	60	80	60	40	0	140	120	100	60
21-30	120	100	80	120	100	60	0	160	140	120	80
31-40	160	140	100	140	120	80	0	200	180	160	100
>40	180	160	120	160	140	120	0	220	220	180	120

Adapted from: Quaggio *et al.*, 1997; Grupo Paulista, 1994.

season at the beginning of spring when the demand for nutrients by citrus is greatest due to the greatest vegetation flux (Bustan and Goldschmidt, 1998). Dividing the total amounts of nitrogen and potassium into three or four applications during the year has a number of advantages. It increases the efficiency of their use and avoids loss of nutrients from the soil with water and drainage, which occurs especially in sandy soils. It also meets the demand for nutrients during the different periods of development i.e. florescence and fruit maturation. It is usual to apply 30 to 40% of the N and K in the period of flowering and the rest at the end of summer and start of autumn. When percentage N and K in the leaf is above the level considered excessive, then it is recommended to reduce or forgo with the last application for that year. P may be applied in a single dose at the beginning of the rainy season.

Boron (B), manganese (Mn) and zinc (Zn) are the most important micro-nutrients for citrus and the visual symptoms of deficiency are seen most frequent (Quaggio and Pizza Jr., 2001; Plate 4.4 for Zn deficiency). In countries where citrus is grown on soils developed on chalk and limestone, as in Spain, Italy and Morocco, iron (Fe) deficiency can limit production. See also Plates 4.1, 4.2 and 4.3 for P, K and Mg deficiency symptoms.

Zinc deficiency occurs frequently in Brazilian orchards, especially in the Pera variety because the tristeza virus, to which it is sensitive, inhibits the transport of Zn within the plant (Moreira, 1960). Citrus plants with Zn deficiency have fewer buds, leaves that are old and without vigour, and reduced crown growth and production. Tangerines, like the varieties Cleopatra and Sunki, have a greater demand for Zn than do lemons, and therefore, they need supplementary applications of Zn. Manganese deficiency is also common in citrus orchards, but only when it is severe does it reduce productivity. The symptoms are most frequent for *cv.* Pera, especially when grown on recently limed soil or when there has been a prolonged period with high temperatures.

Boron deficiency has been occurring more frequently in citrus orchards because of its low availability in the soil and the effect of climatic conditions, like periods of prolonged drought or excessive rains, when its absorption by the roots is decreased. In cooler regions, plant transpiration is lower and directly reduces the absorption of B (Brown and Shelp, 1997). According to the literature, the symptoms of B deficiency most commonly found is the presence of sap drops on the albedo and core of the fruits, fruits that harden and fall prematurely, and at times, have poorly formed seeds (Chapman, 1968). However, these symptoms occur in severely deficient conditions, provoking great loss of yield, like that reported for Ponkan tangerine (Quaggio *et al.*, 1996b). Less obvious deficiency occurs more frequently and, because the symptoms are often not recognized, there have been serious yield losses in many Brazilian citrus orchards. The symptoms are characterized by poorly developed plants, with few buds, shrivelled leaves on short branches and loss of apical dominance. The crown tends to develop on one side, without growing new branches on the other. The symptoms are the result of poorly functioning root and vascular systems, notably the phloem and, generally, are not corrected by foliar application of boron. However, the application of B to the soil reactivates the flow of sap to the roots, and this causes rapid root growth, excessive budding above ground, and the production of long branches, larger leaves than before and with apical dominance. With B there is a very narrow range of concentrations between deficiency and toxicity. In citrus, toxicity is more commonly observed in young trees, owing to the localized application of B around the plants. The visual symptoms are chlorosis at the leaf edges and tip necrosis which progress towards the centre of the leaf lamina, with gradual coalescence of chlorotic regions, and premature fall of affected leaves.

Foliar application of metallic micro-nutrients has been the most common method of applying them in citrus orchards. This is because the quantity needed is small, but also it avoids their absorption on soil colloids, which reduces their availability (Camargo, 1991). However, micro-nutrients have low mobility or are immobile in the phloem, as is the case for Mn, Zn and B (Labanauskas *et al.,* 1964; Embleton *et al*., 1965; Boaretto *et al.,* 2002, 2004). Foliar applications should be during periods of maximum growth in spring and summer, when the leaves are still young and have a poorly developed cuticle, which facilitates the absorption of micro-nutrients.

The recommended sources of metallic micro-nutrients are chloride, sulphate and nitrate salts, which have practically the same efficiency. For B it is recommended to use boric acid due to its acidic reaction. The general recommendation of foliar application of micro-nutrients for citrus is (in mg/L): Zn (500 to 1,000), Mn (300 to 700), B (200 to 300) and Cu (600 to 1,000). The required salts can be mixed with boric acid and urea, as a coagent, at 5 g/L.

Smaller concentrations are recommended for maintenance, while larger concentrations should be used when there are visible symptoms of deficiency. More concentrated solutions should be applied during the cooler hours of the day to avoid burns on the fruits and flowers. Copper is an important micro-nutrient but sufficient is usually applied in copper-based fungicides during flowering, and this supplies sufficient Cu for the tree.

When B is required it should preferably be applied to the soil. The addition of B in N-P-K blends generally causes problems of segregation, owing to the difficulty of getting a good granular source of boron. The addition of B in complex fertilizers, with all nutrients in the same granule, is advantageous from an agricultural point of view, although it has a much higher cost. One option is the application of boric acid dissolved in a contact herbicide solution, like glyphosate, which is the most practical and efficient form of applying boron.

Generally, application of these herbicides is done two or three times a year with a solution volume of 200 L/ha of area treated. In this volume of solution it is possible to dissolve 1 kg B/ha, which corresponds to 6 kg/ha of boric acid.

Quaggio *et al*. (2003) showed a positive correlation between soil applied B (as boric acid) and the yield of oranges (Fig. 4.4). In this study, maximum fruit production occurred with 4 kg B/ha applied on the soil in a band that achieved a concentration of 1.0 mg/dm^3 in the 0-20 cm soil layer. This value is higher than that used in the interpretation of soil analysis for annual crops (Raij *et al*., 1997). The amount of P that gave maximum yield resulted in a leaf concentration of B that varied between 280 to 320 mg/kg, which is sufficient to cause toxicity in citric seedlings (Mattos Jr. *et al*., 1995b).

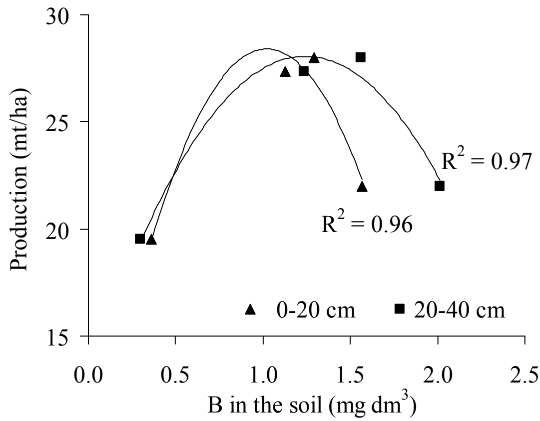

Fig. 4.4. Pera orange production according to soil boron content (B extracted with hot water).

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5. Coconut – Green Dwarf Variety

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5.1. Introduction

World coconut production in 2004 reached 54.7 million mt with 84% produced in Asia, by Indonesia, the Philippines and India with, respectively, 30%, 26% and 17% of this production. Brazilian coconut production in the same year was 2.9 mt, which corresponds to 5.3% of world production. The average annual growth in production between 1961 and 2004 was 2% and a world production of 60 mt is projected for 2010. In Asian countries, a large part of the coconut grown is destined for copra production for extraction of oil. However, in Brazil, coconut is used principally for the industrialized food production of coconut milk and flower (Cuenca, 1998). The production referred to above is for giant and hybrid varieties of coconut. However, in recent years, the planting of the dwarf coconut for producing coconut water has expanded significantly in Brazil, and includes the use of irrigation where the level of technology is much superior to that observed in non-irrigated plantations of the giant and hybrid varieties. This chapter aims to collate information about the nutrition and fertilization of the dwarf coconut, facilitating its use by those involved in the production of the dwarf coconut.

5.2. Climate, soil and morphology

5.2.1. Climate

The coconut requires annual temperatures around 27ºC, without great variation. Temperatures less than 15ºC may cause flower abortion, with negative effects

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on yield. Temperature, as a function of latitude, influences the altitude tolerance of the coconut. Close to the equator, the plant may be cultivated up to 750 m, but with increasing distance from the equator, the plant is grown at lower altitudes. The air relative humidity may influence plant development when it is lower than 60%. On the other hand, very high humidity may favor the development of diseases, as well as diminish the absorption of nutrients because of decreased transpiration. Not only the amount of rain, but more so its distribution has a strong influence on the growth of the plant. Total annual rainfall of around 1,500 mm, with a minimum of 125 mm rain each month, is satisfactory. Lack of rain may be compensated either by water within the soil but the depth of water table should not exceed 3 m, or by irrigation. The plant does not develop in low light intensities. Annual irradiation of 2,000 hours, with a monthly minimum of 120 hours is considered adequate (Fremond *et al.,* 1966). Weak to moderate winds may positively influence growth because of its effects on transpiration and nutrient absorption (Passos, 1998), but winds during drought periods may aggravate water deficit.

5.2.2. Soil

Coconut grows best in soils in soils with the certain characteristics. It does not tolerate excessively clayey soils and those that have compacted and impermeable layers, which impede root penetration or create poor aeration conditions (Fremond *et al.,* 1966). The root system develops best in sandy soils where it can exploit a greater volume of soil. The dwarf coconut has been grown on Spodosols, with sandy A and B horizons and an accumulation of organic-metallic complexes. However, some variations of the Spodosols that have a hardpan, fragipan and duripan should be avoided, because the dense soil layer limits root growth. The Fluvial Neosols (Alluvial) and Quartz Neosols (Sandy Quartz) are less naturally fertile but are also suitable for coconut. The addition of organic matter improves the chemical and physical conditions of these soils. The Latosols and Yellow Argisols in the flatlands have good potential for irrigated plantations but the occurrence of a fragipan and duripan at depths of less than 1 m could limit root growth (Embrapa, 1999).

Opening larger pits for planting may not resolve the problem of root growth in soils with compacted or hardened soil horizons, because root growth is restricted when the roots grow out of the soil in the planting pit.

5.2.3. Morphology

The coconut (*Coco nucifera* L.) is a monocotyledon of the Palm family. It possesses a fascicular root system made up of thick roots (primaries) whose principal function is to anchor the plant in the soil. These primary roots have little capacity for absorption, but from them come secondary roots and from these come tertiary roots from which come rootlets that are responsible for the absorption of water and nutrients (Fremond *et al.,* 1966). Cintra *et al.* (1992) showed that between 70% and 90% of dwarf coconut roots are within a 1.8 m radius of the centre of the stem and at a depth of 0.60 m. The trunk is a stem and at its apex is the only point of plant growth. The leaf is a fan type that has an elongated stalk (axis) to which the leaflets are attached. The inflorescence is a panicle, formed by the peduncle and head on which are the male flowers in the superior two thirds and the female flowers on the base. Bracts, which join to form the husk, protect the inflorescence. Both nutritional state and water stress may influence the number of female flowers, from which originate the fruits after fertilization. The fruit is a drupe, formed by an outer shell, a fibrous flesh, where large quantities of potassium (K) and chloride (Cl) accumulate, and an endocarp (shell), the hard layer around the seed. Initially, the interior of the shell is occupied by coconut water, which starts to form approximately two months after the opening of the inflorescence and reaches a maximum volume after six to seven months. The water decreases with the formation of solid albumen, at first jelly-like, which progressively solidifies (Passos, 1998).

5.3. Soil and crop management

Dwarf coconut seedlings are grown from seeds collected between eleven and twelve months after fertilization of the flowers. Two systems may be used for seedling production. In the conventional system, the seeds are put in a germinator where they remain for four months. During this period the seeds that germinate are transplanted to a nursery where they remain for six to eight months (Fremond *et al.,* 1966). In the alternative system, the seeds are put in the germinator, reducing the number of seeds per square meter from 30 to 20, and then the seedlings are transplanted directly to the field, at five to six months old, without going to a nursery. This system reduces production cost and time, without compromising the final quality of the seedling (Fontes *et al.,* 1998). When preparing a plantation, the ground is marked in equilateral triangles, with the main planting row in a north-south direction, to allow a greater period of direct radiation for the plants. The recommended spacing is 7.5 m, giving 204 plants/ha. To decrease any adverse effects of transplanting the seedling and provide an adequate volume of soil for the initial development of the plant in the field, planting pits are used. The pits should be opened and pre-filled with organic matter, lime and a phosphorus (P) source according to the results of soil analysis. Weed competition interferes directly with plant growth, period to maturity and productivity (Fontes *et al.,* 1998). Chemical weed control is preferred in the area covered by the crown of the plant. Post-emergence products are recommended and should be applied before the weeds flower. Glyphosate is recommended for the control, principally, of grass. Between the rows, mechanical mowing may be used. In regions with an established dry season, the occurrence of stoloniferous grasses may make ploughing necessary. This should be done sparingly and shallowly (20 cm), to avoid damage to the root system and soil structure. The latter because of the risk of soil erosion and leaching of nutrients when the rainy season comes. Planting legumes between the rows minimises weed growth and can also enrich the soil with nitrogen (N) through symbiotic fixation. Fallen leaves and clusters, from where the fruits were collected, should be spread out over the soil and mulched through mechanical mowing. These materials, especially in sandy soils, serve to improve water and nutrient retention. In situations where the coconut shell is returned to the field, it may also contribute to improve the moisture retention of the soil.

Of the coconut varieties, the dwarf coconut is the most sensitive to water deficit. In regions where there is a defined dry season, irrigation where water is available is required to produce large yields. Amongst the methods of irrigation, jet and surface dripping are the most appropriate (Nogueira *et al.,* 1998). Jets are placed in the region of greatest root growth, which occurs in a radius of up to 1.80 m from the plant (Cintra *et al.,* 1992). For dripping, a hose is connected to a lateral line around the trunk, with the drip also placed in the region of greatest root growth. The amount of water required is estimated to be between 100 and 150 L/tree. However, the actual amount depends on climatic factors so that local adjustments should be made.

For the identification of diseases and their control consult Ferreira *et al.* (1998).

Where the fruits are produced for coconut water they are collected between six and seven months old. In this stage of maturity the fruit weighs about 2.4 kg with approximately 600 ml of water, with a pH around 5.0 and Brix value at 20º about 5.8. Variations in fruit weight and water volume may be associated with nutritional problems and water deficiency which, when severe, may cause a change in the fruit's shape, which becomes oblong.

5.4. Mineral nutrition

5.4.1. Uptake and export of nutrients

The amount of nutrients in dwarf coconut fruits were estimated using data from Ouvrier (1984) and recalculated according to Sobral (1998). For a yield of 200 fruits/plant/yr, the offtake of N, P, K, Ca, Mg, S and Cl, are approximately: 87.71; 12.44; 169.77; 6.02; 9.48; 7.85 and 92.0 kg/ha/yr, respectively. The largest offtakes are of N, K and Cl. Uexkull (1972) demonstrated the importance of Cl in coconut nutrition. By virtue of the quantity of Cl removed, the authors propose that this nutrient be considered a macro-nutrient for coconut. The demand for P, Ca Mg and S is less than that for N, K and Cl.

5.4.2. Functions and importance of nutrients

Nitrogen (N): Lack of N causes gradual yellowing of the leaves (Plate 5.1) and a reduction of the number of female flowers. With acute deficiency, there is a decrease in the number and size of the leaves and a narrowing of the stalk, causing what is called a "pencil tip". Sobral and Leal (1999) observed that N influenced the number of fruits of the giant coconut and considered that 17.18 g/kg as the critical N level in leaf 14. Sobral (2004) observed an increase in the number of green dwarf coconut fruits when the plant was fertigated with N as urea.

Phosphorus (P): Phosphorus deficiency causes reduced growth and darker green leaves caused by a greater relative concentration of chlorophyll. The removal of P in the harvested fruits is small (Table 5.1), but in soils with very low levels of plant-available P the nutrient becomes limiting.

Potassium (K): The symptoms of K deficiency are characterized by the appearance of rust colored stains on both sides of the leaves that become more intense at the extremities, and eventually developing into necrosis (Plate 5.2). For the plant as a whole, yellowing of the leaves in the middle of the crown may indicate K deficiency, followed later by the drying of the oldest leaves. The younger leaves remain green (Manciot *et al*., 1980). Potassium is exported in large quantities in the fruits. Occasionally an apparent anomaly may be seen with K. Analysis may show large amounts of K in the leaves but this does not signify good K nutrition. Potassium can accumulate in the leaves when other factors cause poor fruit yields and hence transfer of K to the fruits is limited.

Chlorine (Cl): Uexkull (1972) demonstrated the importance of the nutrient Cl for coconut when the application of KCl increased the weight of albumen, from 117 to 216g, and the composition of Cl, from 0.40 to 2.33 g/kg in leaf number 14. The composition of K in the same leaf varied only from 10.9 to 11.7 g/kg, *i.e.* K was not increased by the addition of more K. The symptoms of K deficiency appear first in the oldest leaves, which yellow and have orange spots. The leaflets dry along the edges and extremities, and the fruits are smaller.

Calcium (Ca): The first symptoms of Ca deficiency appear on leaf numbers 1, 2 and 3 and they become yellow and rounded, turning brown at the centre. The spots are isolated in the early stages, joining and drying later on. In young leaves, the spots are uniformly distributed, however starting from leaf number 4 the spots are concentrated at the base of the leaf. Plants with such symptoms contained only 0.85 g/kg Ca in leaf number 4 (Dufour *et al.,* 1984).

Table 5.1. Critical levels of macro- and micro-nutrients in leaves 9 and 14 of the green dwarf coconut.

Nutrient	Leaf n° 9	Leaf n° 14
Macro-nutrient	--------------------------------g/kg	---------------------------------
N	21.0	22.0
P	1.50	1.40
K	16.0	15.0
Ca	3.0	3.5
Mg	3.0	3.30
S	1.3	1.5
Micro-nutrient	-------------------------------mg/kg	---------------------------------
Cl	8.0	7.5
Na	1.5	1.3
B	17.0	20.0
Cu	5.0	5.0
Mn	60.0	65.0
Zn	14.0	15.0
Fe	35.0	40.0

Sources: Holanda, J.S de, 2004; Raij, B. van., 2004; Sobral, L.F., 2004; unpublished data.

Magnesium (Mg): The symptoms of Mg deficiency appear first in the old leaves. At the extremities of the leaflets and the parts exposed to the sun, the yellowing is more intense, while the leaves close to the trunk remain green (Plate 5.3). When the deficiency becomes severe, there is a necrosis on the extremities of the leaflets, which become dark yellow. At this stage translucent spots become visible.

Sulphur (S): When S is deficient it is not translocated from the older to the newer leaves (Mengel and Kirkby, 1978). In young coconuts, when there is a deficiency of S the new leaves become yellowish (Plate 5.4) and orangey, with necrosis on the extremities of the leaflets. In the adult coconut there is a reduction of the number of living leaves, which become yellow. In the oldest leaves the stalk becomes weak and it bends around the stem. The number of fruits is small and approaches zero when the deficiency is serious. The albumen, after drying (copra), becomes thin and elastic and contains little oil (Southern, 1969).

Boron (B): B deficiency is manifest in the leaflets, which are joined at the extremities. In severe cases the leaflets at the base of the stem are smaller, crest, and may even disappear. When B deficiency is very severe the point of growth completely deforms, preventing the development of the plant (Plate 5.4). In young coconuts, deficiency may be corrected by applying 30 g of borax at the axial of leaf number 4. In adult coconuts, B can be added as borax mixed with other fertilizers and added to the soil. Because the limits of deficiency and toxicity are very close, elevated doses of B may cause toxicity in the plant (Plate 5.5).

Copper (Cu): Deficiency of Cu in coconuts was described by Ochs *et al.* (1993) when the plants were grown in peat soils in Indonesia. Firstly, the stems of the new leaves become flaccid and later bend. Almost simultaneously, the extremities of the leaflets start to dry, going from green to yellow, and finally, to brown – appearing burnt. When the deficiency is serious new leaves are small and chlorotic and the plant may dry completely. In Brazil, Cu deficiency was found in coconuts planted in Quartz Neosols (Sandy Quartz).

Iron (Fe): The symptoms of Fe deficiency were described by Pomier (1969) when found on the Pacific Coralline Islands where the high levels of calcium carbonate render the iron unavailable. It is important to remember that in tropical soils, the presence of iron oxides is substantial.

Manganese (Mn): Mn deficiency is characterized by generalized chlorosis. For coconuts grown in north-eastern Brazil, analysis of leaf number 14 showed great variability in the Mn composition. Sobral (1989), studying the nutritional state of coconuts in Sergipe, showed no direct relationship between Mn in leaves and the burned leaf symptom. It was observed, however, that there is a significant relationship between the composition of Mn in the soil and the leaf.

5.5. Liming and fertilizing

5.5.1. Determining the need for fertilizers

Determining the need of fertilizers is done best by soil and leaf analysis.

Soil analysis: Soil samples should be collected from within the projection of the crown, where fertilizers will be applied, taking about 20 samples to make one sample for not exceeding 10 ha. The sample should be taken at least sixty days after the last application of fertilizer, from depths of 0 to 20 cm and of 20 to 40 cm, because a large part of the plant roots are concentrated at these depths (Cintra *et al.,* 1992). When the plants are fertigated, the samples can be taken at any time and the soils should be collected from the area wetted by the emitter. For liming, the samples should be taken between the rows, at a depth of 0 to 20 cm.

Leaf analysis: Leaf analysis for coconut has been adapted from methods developed for the African oil palm (Rognon, 1984), and the first critical nutrient levels for the east African giant coconut were obtained in 1955 (Frémond *et al.,* 1966).

For the green dwarf coconut, the authors of this chapter have found, as a first approximation, critical levels of N, P, K, Ca, Mg, S, Cl and Na, expressed in g/kg, and of Mn, Zn, Cu, B and Fe, expressed in mg/kg, in leaves 4, 9 and 14. These data are shown in Table 5.1.

The principal requirement is that the leaf samples are taken from the middle of the crown and not from very young or very old leaves. This is because there is significant translocation of nutrients between leaves of different ages and this affects the results. Nutrient composition is also affected by leaf position. With leaf age, percent N increases and then later decreases, the levels of P, K and B decrease while those of Ca, Mg and Mn increase. In the adult coconut, the nutrient composition of leaf number 14 best expresses the nutritional state of the plant (Frémond *et al.,* 1966). In young plants, leaves number 4 and 9 may be used. Leaves 4 and 9 can be found as follows: the leaf that has not yet opened, known as the arrow, is leaf zero. The leaf immediately after this is number 1, and so forth until numbers 4 and 9 are reached. Leaf 14 can be found as follows: find the leaf where the most recent open inflorescence is developing in the axial (space between the trunk and the leaf stalk); this is leaf number 10. On the opposite side is leaf number 9, below which is leaf number 14.

To collect leaves, the plantation should be divided into homogenous areas, taking into account the plant's ages, nutritional status and plant health, as well as soil variability. In each homogeneous area, which should not exceed 10 ha, leaflets should be collected from a minimum of 20 plants. In plantations without irrigation, the samples should be collected at the start of the dry season and between the hours of 7 and 11 am. If there has been a rain of more than 20 mm, it is necessary to wait 36 hours, to avoid variations caused by nutrient leaching. Once the sample leaf has been identified, three leaflets are taken from each side at the central part of the leaf, avoiding damaged leaflets. From each leaflet, only the central 10 cm are taken and placed in a paper bag whose identification should contain the location of the sample, the date, tree number and the position of the leaf. If it is not possible to send the samples to the laboratory on the same day, they should be placed in a refrigerator, avoiding freezing.

In the laboratory, the 10 cm central segments are cleaned with cotton soaked in distilled water, and both the central vein and the laminar edges, about 2 mm, are discarded. The samples are dried in a forced air circulation oven at 70 to 80ºC for 48 hours. Temperatures exceeding 105ºC should be avoided to prevent N losses.

5.5.2. Liming

For the coconut, a base saturation of the soil of 60 to 70% is recommended. At this level exchangeable Al becomes insoluble and exchangeable Ca and Mg should exceed 20 $mmol_c/dm^3$. In some situations it has been observed that although these values have been reached, the levels of Ca and Mg in the leaves remain below the critical level. In this case, calcium sulphate and magnesium oxide may be used to correct the deficiency.

Liming can be over the entire area of the plantation or only within the projection of the crown. The following criteria may be used to determine how to lime. For soils with a sandy A horizon where kaolinite predominates in the clay fraction, if Al is above 5 $mmol_c/cm^3$ the whole area should be limed to reduce toxicity. The quantity should not exceed 2 mt/ha because these soils have a low retention capacity for cations. In other situations, the Al saturation should be used as a parameter, because the Al-saturation tolerance of the coconut is not yet known.

Where the Al, Ca and Mg levels are low, Ca and Mg should be applied to correct the deficiency. In this case, lime should be applied in a circular area, with the trunk at the centre and the edges at the crown projection as the outer limit (Sobral, 1998). The quantity of lime to be applied per plant is obtained by the proportion between the quantity per hectare and the calculated area of the crown projection. In all cases, incorporation is important, to correct acidity and place Ca and Mg near the roots. Where fertigation is not practised, the interval between liming and fertilization should be at least 60 days. When this advice is ignored, the rapid increase in soil pH after liming can result in N losses by volatilization, soluble P becoming less soluble and K being lost by leaching if Ca and Mg replace K on cation exchange sites.

5.5.3. Fertilization

Suggestions for fertilizing dwarf coconut at various stages of growth are in Tables 5.2, 5.3 and 5.4. In the first year, 160 g P_2O_5, as single superphosphate, should be added to soil in the planting pit. It is also recommended to apply 450 g of N/plant, but the actual amount will depend on whether the plants are to be irrigated or not and on soil texture. It is important to remember that in the first year the root system is not well developed and nutrients may be leached, especially in sandy soils. From the second year, fertilizer recommendations are based on soil analysis by the resin method. In regions where the Mehlich 1 method is used, the results may be converted to the resin method using the following equations: P (resin) = 0.6901 (Mehlich 1) + 6.3942 and K (resin) = 1.1481 K (Mehlich 1) – 1.8387. It is important to stress that these equations were obtained using non-fertilized soils, where sand is predominant in the A horizon and kaolinite is predominant in the clay fraction in this horizon.

Fertilizer recommendations for N, P and K that take into account expected productivity are shown in Table 5.3.

Table 5.2. Fertilizer recommendations for N, P and K for the green dwarf coconut according to plant age, based on leaf analysis for N and soil analysis for P and K.

Age	Leaf N			P-resin (mg/dm^3)			K-exchangeable ($mmol_c/dm^3$)		
	<16	16-20	>20	0-12	13-30	>30	<1.6	1.6-3.0	>3.0
yr	-------- N (g/plant) -------			------ P_2O_5 (g/plant) ------			------ K_2O (g/plant) ------		
0-1[1]	450	450	450	0	0	0	600	400	200
1-2	600	450	300	200	150	100	900	700	500
2-3	900	750	600	300	200	100	1,200	900	600

[1]Blanket application of 450 N gr/plant.

Sources: Holanda, J.S de, 2004; Raij, B. van., 2004; Sobral, L.F., 2004; unpublished data.

Table 5.3. Fertilizer suggestions for N, P and K for the green dwarf coconut according to expected yield and based on leaf analysis for N and soil analysis for P and K.

1,000 fruits/ha	Leaf N (Leaf 14) (g/kg)			P-resin (mg/dm^3)			K-exchangeable ($mmol_c/dm^3$)		
	<16	16-20	>20	0-12	13-30	>30	<1.6	1.6-3.0	>3.0
	-------- N (kg/ha) --------			------- P_2O_5 (kg/ha) ------			------ K_2O (kg/ha) ------		
<20	180	120	80	80	60	20	200	150	100
30-30	220	180	100	100	70	30	250	200	120
30-40	260	200	120	120	90	40	300	240	150
40-50	300	220	140	140	100	50	400	300	180
>50	360	250	160	160	120	60	500	350	200

Sources: Holanda, J.S de, 2004; Raij, B. van., 2004; Sobral, L.F., 2004; unpublished data.

Table 5.4 shows recommended additions of B, Cu, Mn, and Zn based on soil and leaf analysis. The levels of Cu, Mn and Zn may be converted to the Mehlich 1 method using the following equations: Mn (DTPA) = 0.5036 Mn (Mehlich 1) + 0.5435; Zn (DTPA) = 0.6379 Zn (Mehlich 1) + 0.0122; Cu (DTPA) = 1.153 Cu (Mehlich 1) – 0.1954. As for the P and K conversions given above, these equations were derived using non-fertilized soils with a predominantly sandy A horizon and kaolinite as the principle clay mineral.

Table 5.4. Fertilizer recommendations for B, Cu, Mn and Zn based on soil and leaf analysis.

Nutrient/Analysis method	Soil	Leaf number and nutrient content 9	14	Fertilizer
	mg/dm^3	----- mg/kg -----		g/plant
Boron (hot water)	0-0.6	<17	<20	Borax 50
	>0.6	≥17	≥20	-
Copper (DTPA)	0-0.8	<5	<5	Copper sulphate 100
	>0.8	≥5	≥5	-
Manganese (DTPA)	0-5.0	<60	<65	Manganese sulphate 100
	>5.0	≥60	≥65	-
Zinc (DTPA)	0-1.2	<14	<15	Zinc sulphate 120
	>1.2	≥14	≥15	-

Sources: Holanda, J.S de, 2004; Raij, B. van., 2004; Sobral, L.F., 2004; unpublished data.

The application of fertilizers through the irrigation system (fertigation) has become a common practice in irrigated agriculture. The primary advantage of fertigation is an improved efficiency of nutrient utilization and minimal losses by leaching. A major disadvantage is the risk of chemical reactions between the fertilizers used if these are not chosen with care (Papadopoulos, 1999). For a fertilizer to be used in fertigation it needs to be water-soluble and there should be minimum risk of it causing salinity within the soil (Villas Bôas *et al*., 1999). The salinity index of a fertilizer is related to that of $NaNO_3$ to which is attributed a value of 100. Table 5.5 shows the solubility and salinity index values of some fertilizers used in fertigation. Nutrient applications for fertigation are based on the same concepts as those for conventional fertilizers and can be determined using soil and leaf analysis. For dwarf coconut, the total annual nutrient requirement is divided by the number of fertigation cycles to be made during the year to determine the quantity of nutrient to be added with each fertigation. The quantity of fertilizers to be dissolved for injection into the system is calculated taking into consideration the discharge rate of the emitters and the duration of irrigation. However, it must be remembered that the solubility of the fertilizer determines the maximum quantity that may be dissolved in a given volume of water. To achieve uniform application, fertigation should only be started after the irrigation system has been pressurized. Nutrient additions may be monitored by collecting solution samples at the nozzle.

Table 5.5. Solubility and salinity index values of some fertilizers used in fertigation.

Fertilizer	Solubility 20°C	Salinity index
	g/100 ml	
Urea	78	75.4
Ammonium sulphate	71	69.0
Ammonium nitrate	118	104.7
Calcium nitrate	102	52.5
Sodium nitrate	73	100.0
Monoammonium phosphate	23	29.9
Phosphoric acid	45.7	no value
Potassium nitrate	32	73.6
Potassium chloride	34	116.3
Potassium sulphate	11	46.1

Source: Villas Bôas, *et al.*, 1999

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6. Guava

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6.1. Introduction

Globally, India, Pakistan and Brazil are the principle producers of commercial guava cultivars. India has the greatest number of trees, but in dispersed and poorly productive plantations, the fruit is used for the production of white guava juice. Pakistan is the principal exporter of the fresh fruit. In Brazil, guava is consumed more as a fresh fruit, especially the red pulp variety (Plate 6.1), and the fresh fruit is exported principally to France, Canada, Germany and Portugal (Guedes and Vilela, 1999, cited by Almeida, 1999).

Guava is one of the most widely accepted tropical fruits worldwide and in Brazil. It is enjoyed both as fresh fruit and processed as sweets, jelly, jam and juice. The fruit is rich in sugars, vitamin C and mineral salts. The increase in consumption both as a table fruit and natural juices is a worldwide trend, accompanying a growing popular preoccupation over health and aesthetics.

In Brazil, the guava is grown in all states, being grown commercially on approximately 17 million ha (IBGE, 2002 cited by Goiabrás, 2004). Total annual production of approximately 350,000 mt is small compared to the potential productivity of the plants (Natale, 1993). Although the guava has long been considered a rugged plant in its tolerance of acidity and adaptation to small soil nutrient reserves, the rational application of fertilizers promotes substantial increases in fruit production (Natale, 1993). Further, genetic selection and vegetative multiplication of guava has given rise to plants with a large yield potential, like the cultivars Rica and Paluma (Pereira *et al.,* 1982), but these cultivars have large nutrient demands and thus export more nutrients from the

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soil. Thus, better knowledge of nutrient and fertilizer requirements is fundamental to guarantee greater yields.

6.2. Climate, soil and morphology

The guava originates from Tropical America, possibly between Peru and Mexico, where it can still be found in the wild form. The plants capacity for dispersion and rapid adaptation to different environments made possible the presence of this *Mirtaceae* in many tropical and subtropical areas of the world, and it is even considered a weed species in some regions (Menzel, 1985). Avilan (1988) studied the plants development cycle in a tropical region (Venezuela) and identified four phases: (a) growth, between ten months and two years of age; (b) full production, from three to five years; (c) production, from five to eight years; and (d) senility, starting at nine years of age. In each of these stages of development fruit production was about 30, 35, 50 and 22 kg/plant/yr, respectively. Thus Avilan (1988) considered the guava to be a short-cycle fruit tree starting production between 10 and 12 months after planting, and with maximum productivity when three or four years old. However, with the vegetative propagation of herbaceous cuttings, the plants can become fully productive earlier. In spite of being a plant native to tropical regions, the guava develops and produces well in regions from sea level up to 1700 m altitude, and for this reason is found in many regions worldwide, including Brazil.

The ideal temperature for growth and production is between 25 and 30ºC. Temperature not only limits, but also determines the season of fruit production. A long photoperiod is necessary for optimal fruit production. The plants can be severely damaged by frost and strong winds.

The ideal range for rainfall is 1,000 to 1,600 mm/yr, well distributed throughout the year, and should not be less than 600 mm/yr. In regions with prolonged dry seasons, irrigation is necessary.

Air relative humidity should be between 50 and 80%, because this can influence both the physiology of the plant and fruit production.

Although guava adapts well to growing on most soil types, soils with high clay content, low drainage capacity and excessive salts should be avoided. Ideally, orchards should be planted on flat or slightly sloping land to facilitate mechanical operations.

6.3. Soil and cultivation

Prior to planting, initial soil preparation should aim to destroy compacted layers in the subsurface soil and correct acidity by incorporation of lime when necessary. Prado and Natale (2004) tested different methods for incorporating lime during soil preparation. Shallow ploughing incorporated lime only in the superficial layer of the soil. First disking the soil then ploughing it shallowly proved satisfactory but was less satisfactory than deep ploughing. The superior performance of deep ploughing was not only the depth of incorporation but also the greater degree of mixing of the lime with the soil throughout the entire 0 to 30 cm soil layer. With discing, only half of the lime reached the deeper soil, with the rest being incorporated superficially with the shallow ploughing. The advantage of deep ploughing, other than optimizing the incorporation of lime, is less demand for time and total energy. However, this method demands the use of a powerful tractor. The deep incorporation of lime is important where perennial crops are to be grown because soil acidity at depth can compromise the productivity of an orchard for a long time (Raij *et al.,* 1996). Also surface applications only very slowly improve soil acidity at depth. Corrêa (2004) showed that it took 12 and 24 months after the surface application of calcined lime and common lime, respectively, for acidity to be neutralized in the 0-20 cm soil layer. Ploughing to incorporate lime is not recommended in existing orchards because of possible damage to the root system, which causes an increase in the occurrence of phyto-sanitary problems in the plants.

In orchards established on acidic soils with high levels of aluminium (Al), liming precipitates the toxic Al in the surface soil. This allows greater development of the root system and, therefore, greater plant growth owing to the more efficient use of water and nutrients.

When establishing guava orchards, a soil base saturation close to 60% is adequate (Prado, 2003). However, the concentration of magnesium (Mg) in the soil should not be less than 9 $mmol_c/dm^3$. For plants up to three years old, leaf calcium (Ca) and Mg of around 9.0 and 2.5 g/kg, respectively, are considered adequate (Prado, 2003a).

When producing guava seedlings, soil acidity can be corrected with alternative materials like eucalyptus biomass ashes and steel mill slag. These residues may also be a source of nutrients, increasing production and preserving the environment by recycling such materials. Prado *et al.* (2003b) tested the application of five amounts of biomass ash to two soils with base saturation of 50 and 80% on which guava seedlings were produced. Starting with a soil of base saturation of 50%, the amounts of ash tested aimed to produce a range of soils with base saturation up to a maximum of 70%, there was also a nil treatment as control. After 135 days, the growth of the seedlings was evaluated; they responded positively to the application of ash independent of the soil's reaction. The largest response was associated with applications of 1.0 to 1.2 and 1.2 to 1.6 g ash/container in soil with base saturation 50% and 80%, respectively.

To establish an orchard, the seedlings should be planted in a line of pits 0.40 m deep by 0.30 m wide. The soil below the crown of the seedling should be kept free of weeds by periodical manual weeding, or application of herbicides. In between the rows and in the areas between the plants, weeds can be controlled mechanically with a mower.

Guava responds positively to irrigation. To satisfy the plant's demand for water 1,000 to 1,800 mm/yr are required (Maranca, 1981). Pereira *et al.* (2000) observed that a deficiency of 73 to 119 mm water for 5 consecutive months, was sufficient to reduce the fruit production of different cultivars by as much as 51% of the fresh weight. Bassoi *et al.* (2001a) estimated the K*c* in a guava orchard growing cv. Paluma at 6 x 5 m, on Red-Yellow Argisol (120 g/kg of clay), in the north-east region (Petrolina, PE). The plants were irrigated by jets that wetted 42% of the soil surface. During the first year of growth the average water consumption was 36.7 L/plant, and this increased to 46.3 and 45.6 L/plant in the second and third years, respectively. The value of K*c* in the first year was less than that in the second and third years. For the same physiological phases, the K*c* values in the first, second and third years were, respectively, for (i) vegetative growth: 0.50; 0.55 and 0.65; (ii) florescence: 0.60; 0.65 and 0.75; (iii) fruit growth: 0.60; 0.65 and 0.75; and (iv) maturation and harvest: 0.60; 0.80 and 0.70. The K_c values referred to previously were estimated by the class A evaporation pan. The efficiency of the application is estimated by the percentage of total water supplied by irrigation that is considered useful to the plants (Bernardo, 1995).

Application efficiency is a result of a greater uniformity in distribution of water in the whole horizontal and vertical soil volume occupied by the root system, such that superficial losses by evaporation, and losses by leaching are minimized.

Fertilization of guava depends on whether irrigation is used. If the plants are irrigated, nutrients can be supplied with the irrigation water (fertigation). In a non-irrigated system, fertilizers have to be applied to the soil. In special situations, foliar application of nutrients is possible, and this is often recommended for supplying micro-nutrients.

6.4. Mineral nutrition

6.4.1. Export of nutrients

Table 6.1 shows the nutrients exported by the fruits (pulp and core with the seeds) (Natale, 1993). For cv. Rica, the amounts of macro-nutrients in decreasing order are: K>N>P>S>Mg = Ca: and those of micro-nutrients are: Mn>Fe>Zn>Cu>B. For cv. Paluma the order for both the macro- and micro-nutrients is slightly different to that for cv. Rica. For the macro-nutrients the order is: K>N>P>S = Mg>Ca, and for micro-nutrients: Zn>Mn = Fe>Cu>B. There is greatest variation in percent nitrogen (N) and potassium (K), the principal macro-nutrients in the fruits. Cv. Rica had 15.7 g/kg K and 9.8 g/kg N in dry matter, and cv. Paluma had lower values, 12.4 g/kg K and 8.6 g/kg N in the fruit dry matter.

Table 6.1. The uptake of macro- and micro-nutrients by the guava cultivars Rica and Paluma, in experiments in the municipalities of Jaboticabal and Sao Carlos, Sao Paulo state.

Nutrient	cv. Rica			cv. Paluma		
	Dry matter	Fresh matter		Dry matter	Fresh matter	
Macro-nutrient	g/kg	g/mt	kg/ha	g/kg	g/mt	kg/ha
N	9.80	1,353	66.8	8.6	1,146	84.3
P	1.20	166	8.3	0.9	121	8.9
K	1.57	2,167	107.1	12.4	1,662	122.8
Ca	0.80	110	5.4	0.7	94	6.9
Mg	0.80	110	5.4	0.9	114	8.4
S	1.10	152	7.5	0.9	114	8.4
Micro-nutrient	mg/kg	g/mt	g/ha	mg/kg	g/mt	g/ha
B	6	0.83	41	5	0.67	50
Cu	8	1.11	54	11	1.48	109
Fe	15	2.07	98	14	1.88	139
Mn	28	3.87	188	14	1.88	139
Zn	13	1.73	84	15	1.95	144

Adapted from: Natale, 1993 ; Natale *et al.*, 2002. The calculation is based on the dry matter of the fruits being, on average, 13.8 and 13.4% of the fresh matter for the cv. Rica and Paluma respectively. Average fruit production was 49.4 and 73.6 mt/ha for cv. Rica and Paluma, respectively, in the third year of production.

Knowledge of the chemical mineral composition of the fruits provides information to optimise the fertilization program to maximise efficient production and maintain soil fertility. The quantities of nutrients exported are for the whole fruit. About 95% of the total production of an orchard is useable leaving a 5% residue of fresh material (27% moisture). Fernandes *et al.* (2002) studied the application of such a residue on soil fertility. The chemical analysis of the residue (in g/kg) was: N, 17.2; P, 2.1; K, 2.9; Ca, 1.1 and Mg, 0.9. The application of such a seed residue at up to 120 mt/ha of fresh material, increased soil organic matter (SOM) ($y = 11.23 + 0,\ 1680x$, $R^2 = 0.98^{**}$) and exchangeable K ($y = 1.15 + 0.0217x$, $R^2 = 0.99^{**}$) in the soil, with benefits on the sum of the base cations and CTC. Extrapolating the data for one application of 60 mt/ha of this fresh seed residue (44 mt dry weight) can make about 127 kg K and 64 kg P available to the crop in the first year after application. Also there was an increase in available N from the mineralization of the extra SOM.

The removal of nutrients from guava orchards occurs because of the harvested fruit, as was stated earlier, and also by pruning the trees. In adult guava orchards, drastic pruning is common, which may greatly reduce the aboveground biomass to 40 to 60%. The material removed consists of about 24.5 kg of green material per plant (7.8 kg of leaves; 2 kg of boughs and 14.7 kg of branches, twigs and small fruits) (Natale, 1997). Assuming that this material contains 85% moisture and that there are 285 plants/ha, pruning the plants could remove, in kg/ha, about: N, 7.4; P, 0.6; K, 5.9; Ca, 6.5; Mg, 1.8; S, 1.4 and g/ha, B, 22; Cu, 122; Fe, 207; Mn, 282 and Zn, 21.

6.4.2. Functions and importance of nutrients

From a studying of growing six-month-old guava plants in a Hoagland and Arnon nutrient solution with one nutrient omitted from each solution, Accorsi *et al.* (1960) described the symptom of the deficiencies of N, P, K, Ca, Mg and S in guava, as follows:

Nitrogen (N): Accorsi *et al.* (1960) showed that guava leaves deficient in N had the normal shape but the lamina was uniformly pale yellow. The veins were lightly yellowed and without spots. The lower surface of the leaves was a less intense green than the upper surface.

In experiments in guava orchards growing on in a Red-Yellow Argisol, Natale *et al.* (1994) studied the effects of N fertilizers, using one-year-old plants of the cv. Rica, during three consecutive years. The plants responded to N applied at 52, 75 and 120 kg/ha in the first, second and third years, respectively. Over the three years, 90% of the maximum production was associated with 23 to 25 g N/kg in leaves sampled in the period of full florescence.

Natale *et al.* (1996b) extended their field investigation for a further three years, using one-year-old plants of the cv. Paluma, planted in a Red-Yellow Latosol in the region of São Carlos, SP. The N treatments in the first year were 0, 9, 17, 34, 51, 68 and 85 kg N/ha and in the second and third years these amounts were doubled and then tripled, respectively. Leaf samples were taken in the florescence stage, and the fruits were counted and weighed at harvest. Yields were increased only in the third year when yields increased linearly with N applied, and 90% of the maximum yield was given by 178 kg N/ha and 22.2 g N/kg in the leaf. There was a significant effect of N on fruit quality. Excessive amounts of N tended to decrease the size of the fruit, inversely to the number of fruits produced by the plant, and seriously compromised the commercial value for the fresh fruit market (Fig. 6.1).

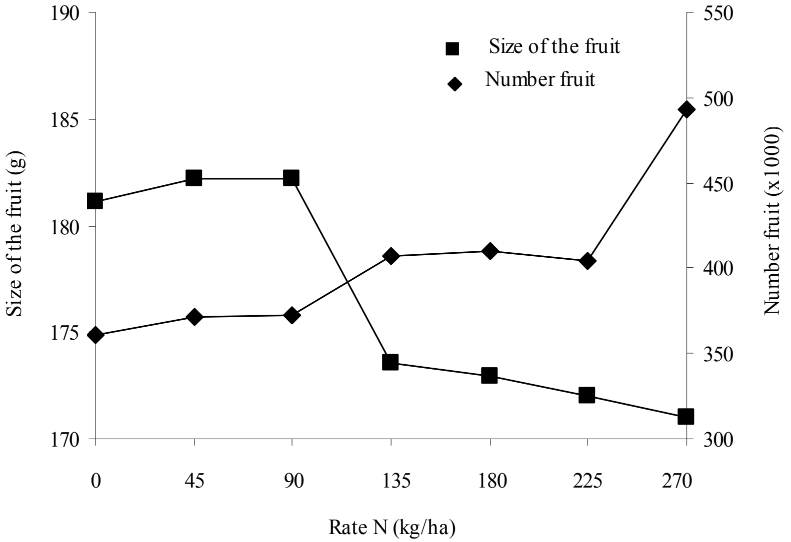

Fig. 6.1. Effects of N fertilizers on the production and quality of guava fruits (*Adapted from*: Natale *et al.*, 1995).

Phosphorus (P): The nutrient solution experiment (Accorsi *et al.,* 1960) showed that when P was deficient, the upper surface of the leaf is a scarlet color, which progresses from the base to the apex and edges until only the vicinity of the main vein remains green. When the deficiency is more severe, the whole upper surface turns purple. When the leaves are viewed against a light background, the secondary veins are transparent and the extremities of the veins become light purple. When seen against light, the under surface of the leaf has a dark background because of the scarlet coloring of the upper surface. The shape of the leaf is normal.

Studies on the response of guava to P fertilizers are rare. Corrêa *et al.* (2003) tested the response of guava seedlings to both amounts and methods of applying P fertilizer. Seedlings were transplanted into plastic bags (18 x 28 cm) divided in such a way that the root system could be divided equally between the two halves of the bag. Each half of the bag contained 2.8 dm^3 of Argisol subsoil containing 1 mg/dm^3 P-resin. Phosphorus, as triple superphosphate, was tested at 70, 140 and 280 mg P/dm^3 soil. Methods of applying P were tested as follows: either it was applied only to one half of the bag or it was divided equally between both halves; in addition the P was mixed throughout the entire soil volume or it was mixed only into the top 1/3 of the soil in the half-bag. The guava seedlings responded positively to P and about 100 mg P/dm^3 of soil was sufficient for good growth, in excess of this amount growth was decreased. Applying the P only in the topsoil or throughout all the soil did not effect the supply of P to the seedlings. However, applying P uniformly throughout the soil resulted in a larger root system and less aboveground growth compared to applying P only in the surface soil.

Natale *et al.* (2000) tested the effects of increasing amounts of both lime and P fertilizer on the growth of seedlings in a factorial 4 x 4 test, and measured effects on the soil, the production of dry matter and seedling development. In the soil, lime increased the amount of exchangeable Ca and Mg, base saturation of the CEC and soil pH. In plant dry matter, both percent Mg and P were increased while Mn and Zn were decreased. In general, 1.2 g lime and 200 mg P/dm^3 soil were sufficient to give optimum dry matter weights. In a field experiment lasting three years, Natale *et al.* (2001) studied the effects of P fertilizers on one-year-old plants of the guava cv. Paluma, grown on a Red-Yellow Latosol near Sao Carlos, SP. Seven amounts of P_2O_5, 0, 9, 17, 34, 51, 68 and 85 kg/ha were tested in the first year and these amounts were doubled in the second and the third years. Although soil P was increased there was no effect on the P concentration in the leaf or on the production of fruit. Natale (1999) observed similar results with the cv. Rica.

In view of the small response to soil applied P by adult plants, Natale *et al.* (1999) studied the application of P to the leaf, together with phytosanitary treatments. This was done by spraying a liquid solution of monoammonium phosphate (MAP) at 2% with a specific activity of ^{32}P equal to 0.15 μCi mL^{-1} on every third pair of guava seedlings. The maximum amount of P absorbed corresponding to 12% of the total applied at 20 days after the application. Approximately 20% of P absorbed by the leaves was redistributed in the plant, especially to the newer growth. Natale *et al.* (2002b) also tested a foliar application of P in a field experiment for three consecutive years on adult cv. Paluma guavas. The amounts were 0, 0.5, 1.0 and 2% P_2O_5 as MAP and these were compared with 200 g P_2O_5/plant applied to the soil. Although the concentration of P in the soil and the plant were increased, yields were not affected.

Potassium (K): According to Accorsi *et al.* (1960), guavas grown under K deficiency in solution culture exhibit numerous brown, small and grouped spots of different shapes on the leaves. These spots are distributed throughout the leaf lamina, starting from the edges and moving towards the main vein, but are concentrated in the upper middle lamina resulting in a mottled appearance. There are smaller spots on the main vein and on many of the secondary veins. As the deficiency progresses, the spots fuse, especially around the leaf edge, forming larger and darker spots that lead to necrosis of the lamina tissue. Small areas of the lamina remain green. The under side of the leaf has a yellowish-brown color corresponding to the position of the spots on the upper side. The leaves appear a reddish color.

In field experiments, 0, 9, 17, 34, 51, 68 and 85 kg K_2O/ha, was tested in the first year and double and triple these amounts in the second and third years, respectively, on cv. Paluma. Yield was increased by applying K in the third year and 90% of the maximum production was associated with 16.2 g K/kg in the leaves and 0.75 $mmol_c/dm^3$ of exchangeable K in the soil. These values were obtained with an application of 82 kg K_2O/ha (Natale *et al.,* 1996c).

In similar experiments with cv. Rica, 90% of the maximum production in the third year was associated with 18.9 g K/kg in the leaves and an application of 150 kg K_2O/ha (Natale *et al.,* 1996b).

Calcium (Ca): The effect of Ca on the function of the middle lamella may influence the texture, firmness and maturation of the fruits by reducing the rate of degradation of vitamin C, the production of ethylene and CO_2 and the incidence of post-harvest disease. An increase in Ca in the fruit promotes firmness and reduces water loss, producing better quality fruit and a longer post-harvest storage period (Fig. 6.2).

Magnesium (Mg): When grown in Mg deficient conditions, guava leaves have two rows of yellow spots, parallel to the main vein, one on each side, on the upper side. Each spot is situated between two secondary veins. The rows start at the base of the leaf and end a short distance from the apex. Other than these spots, there are numerous other brown spots of different sizes, shapes and contours, which at times fuse together. On the under side of the leaf there are the same symptoms but the spots are less visible. The main vein is light green (Accorsi *et al.,* 1960). Prado (2003) observed a positive response in the initial phase of production to an application of Mg, like calcareous dolomite. There is a significant relationship between the leaf compositions of Mg (g/kg) and the production of guava fruit (mt/ha), as follows:

$$\text{Production} = -132.4 + 136.9\ Mg_{leaf} - 26.4\ Mg_{leaf}^2;\ R^2 = 0.80^{**}.$$

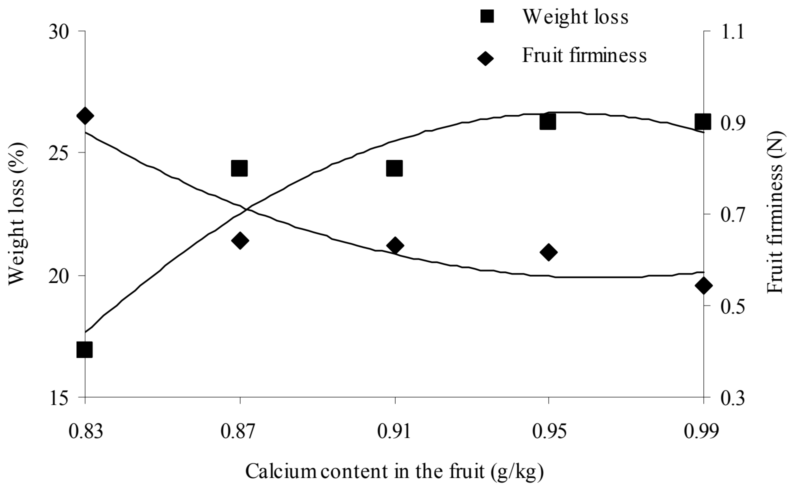

Fig. 6.2. Relationship between calcium concentration in the fruit pulp and the loss of weight and firmness of guava, after eight days in storage at room temperature (Prado *et al.*, unpublished data).

Sulphur (S): According to Accorsi *et al.* (1960), S deficiency of in guava is characterized by the occurrence of necrotic spots that vary in shape, size, number and contour, localized principally in the middle underside of the leaf. These spots are more clearly seen when the leaf is examined against the light. The color is purplish along almost the full extension of the main vein (except on the extremities, in this phase of the symptoms) and the secondary veins (except in the basal and apical region of the leaf). The interveinal areas have a uniform citrine-green color. The under surface of the leaf, other than being a little lighter than the upper side, has chlorotic spots, although these are no easy to see. Only the secondary veins have a lighter purple on the upper surface. The main vein has normal coloring.

Micro-nutrients: There is a lack of information on the response of guava to micro-nutrients. However, some studies have evaluated their effect on guava seedlings. Natale *et al.* (2002c) tested applying zinc (Zn) on the growth and nutrient composition of guava seedlings grown in pots containing 2.8 dm^3 of a Red-Yellow Argisol. The amounts of Zn, as zinc sulphate, tested were: 0, 2, 4, 6 and 8 mg of Zn/dm^3 soil, and the experiment was in a mesh net nursery. After 135 days the height, leaf area and aboveground and root dry matter of the plants were measured together with the concentrations of the macro-nutrients and Zn. There was a positive response to Zn up to 2 mg of Zn/dm^3. Amounts equal to or larger than 4 mg/dm^3 decreased seedling yield and macro-nutrient content significantly. Micro-nutrients are important especially in tropical soils. Steel mill slag, which is a residue of cast iron and stainless steel production, is a suitable source of micro-nutrients. Prado *et al.* (2002) tested slag as a source of micro-nutrients for guava seedlings. The amounts used aimed to increase the base saturation of the soil by 0.5, 1, 1.5, 2 and 2.5 times, with the largest amount increasing the base saturation to 70%. The amounts of slag applied were 1.68, 3.36, 5.04, 6.72 and 8.40 g per 2.8 dm^{-3} soil, as well as a control with no application. The soil, a Red-Yellow Argisol, and slag were incubated for 90 days before the guava seedlings (cv. Paluma) were planted and then grown for 110 days in a mesh net nursery. The slag made the soil less acid and increased the availability of Zn, Cu, Mn and B in the soil. There were exponential effects on the concentrations of Zn, Cu and Mn in the soil with the larger amounts of slag at 5.8; 6.3 and 7.5 g/pot, respectively, while, for B, the effect was linear. A soil base saturation between 51 and 55% increased the availability of Zn, Cu and Mn, but for B the value was 65%. In the same way as occurred in the soil, the application of slag had exponential effects on the concentrations of Zn, Cu and Mn in the aboveground and root dry matter, but the effect for B was linear. It was concluded that the slag both helped correct acidity and was also a source of micro-nutrients for guava seedlings.

6.4.3. Leaf analysis

Leaf analysis is an important diagnostic tool, which together with soil analysis makes it possible to devise a fertilizer management programme of an orchard. Leaves should be sampled during flowering because any deficiencies can be corrected at that time. Samples should be taken from groups of trees with similar cultivar characteristics, age and productivity where the soil is homogeneous and orchard management the same. The leaves sampled are the third pair from the extremity of the branch. In Sao Paulo state, sampling is done during full flowering, usually in September and October. However, the time may vary according to several factors, specifically the start of the rainy season or the period of pruning. The sample should consist of four leaves per plant from at least 25 trees per sample area (Natale, 1993; Natale *et al.,* 1996a; Natale *et al.,* 2002a).

Nutrient concentrations considered adequate for the cvs. Rica and Paluma, the latter is the one most planted in Brazil, are shown in Table 6.2. These values differ slightly from those recommended by Quaggio *et al.* (1996); their adequate ranges, in g/kg were: N, 13 to 16; P, 1.4 to 1.6; K, 13 to 16; Ca, 9 to 15; Mg, 2.4 to 4.0) but these do not discriminate between varieties.

Table 6.2. Composition of macro- and micro-nutrients in leaves collected during the period of full flowering and considered adequate for guava from the third year of age.

Nutrient	cv. Rica	cv. Paluma
Macro-nutrient	---------------------------- g/kg	--------------------------
N	22-26	20-23
P	1.5-1.9	1.4-1.8
K	17-20	14-17
Ca	11-15	7-11
Mg	2.5-3.5	3.4-4.0
S	3.0-3.5	2.5-3.5
Micro-nutrient	--------------------------- mg/kg	-------------------------
B	20-25	20-25
Cu	10-40	20-40
Fe	50-150	60-90
Mn	180-250	40-80
Zn	25-35	25-35

Source: Natale *et al.*, 1996; Natale *et al.*, 2002.

The concentration and accumulation of nutrients in the tree varies, among other factors, with the phenological stage of the plant. Thus, for each phenophase there is an adequate level of macro- and micro-nutrients and studies on the rate of nutrient absorption must aim to correlate the nutrients in the sampled organ with the phenological stage. Through these studies it is possible to predict the time (or times) of greater plant nutrient demand. Unfortunately, in spite of this importance, there are no studies of rate of nutrient absorption by guava plants grown in the field where the plant has an extensive root system. This makes studies done in pots of little relevance.

6.5. Fertilization

6.5.1. Fertilization before planting the orchard

The amount of P fertilizers to apply depends on the P status of the soil. Because P is not very mobile in soil it should be added to the planting pit together with 20 to 30 L of organic compost consisting of cured corral manure (or a third part chicken manure) according to the recommendations in Table 6.3 (Natale *et al.*, 1996a). It is also recommended to apply micro-nutrients, especially B (1 g/pit) and Zn (2 g/pit) to the planting pit. The organic compost, P fertilizer and micro-nutrients should be mixed with the soil before filling the pit about 30 days before planting of the seedlings.

Table 6.3. Phosphorus application required at planting a guava orchard, according to the phosphorus composition of the soil.

P-resin (mg/dm^3)	Amount of P_2O_5 (g/pit)
<6	180
6-12	140
13-30	100
>30	60

Source: Natale *et al.*, 1996a.

6.5.2. Fertilization for initial growth

From planting the seedlings until they are three years old the recommended fertilization is based on soil analysis, on the cultivar and its age (Table 6.4).

Table 6.4. Fertilizer recommendations for the growth of guava plants according to age, cultivar and soil analysis.

Age	N	P-resin (mg/dm^3)				K-exchangeable (mmol$_c$/dm^3)			
		<6	6-12	13-30	>30	<0.8	0.8-1.5	1.6-3.0	>3.0
yr	g/plant	------------ P_2O_5 (g/plant) ---------				----------- K_2O (g/plant) ------------			
cv. Rica									
0-1	120	0	0	0	0	120	90	60	30
1-2	240	120	80	40	0	240	180	120	60
2-3	480	240	160	80	0	480	360	180	90
cv. Paluma									
0-1	100	0	0	0	0	100	80	50	30
1-2	200	100	50	30	0	200	150	100	50
2-3	400	200	100	60	0	400	300	150	80

Source: Natale *et al.*, 1996a.

The quantities of fertilizer to be applied, using commercially available sources, should be according to local need (see Tables 6.4, 6.5 and 6.6). These recommendations were determined for on non-irrigated guava production systems but they can be also used for fertigated orchards up to two years old. Bassoi *et al.* (2001b), studying the distribution of the guava root system during the initial stages of growth in an Argisol (clay content was 120 g/kg), found that more than 70% of the root system was related to the age of the plant, increasing up to 34 months. At the same time, the effective distance of the roots was increasing, at 6, 12, 24 and 34 months it extended up to 20, 40, 60, and 100 cm, respectively. The authors also found that the effective rooting depth was 80 cm

18 months after planting. This information may be useful for managing the location of emitter and tensiometer installations where irrigation is used, as well as for placing fertilizer throughout the growth of the crop. However, it should be noted that this pattern of root distribution may vary with the variety and the soil and climatic conditions where the orchard is planted.

Table 6.5. Micro-nutrient solution for boron and zinc for foliar application.

Nutrient source	Concentration	Quantity per 100 L of water	Time of application 1st	2nd
	%	g		
Boric acid	0.06	60	September	November
Zinc sulphate	0.5	500		

Adapted from: Natale *et al.*, 1996.

Table 6.6. Fertilizer recommendations for fruit production by cultivar and expected productivity and according to soil and leaf analysis data.

Production	N(1)	P-resin (mg/dm^3)				K-exchangeable ($mmol_c/dm^3$)(2)			
		<6	6-12	13-30	>30	<0.8	0.8-1.5	1.6-3.0	>3.0
mt/ha	kg/ha	------------- P_2O_5 (kg/ha) -----------				------------- K_2O (kg/ha) ------------			
cv. Rica									
<40	210	60	45	15	0	210	140	70	35
40-60	230	60	45	15	0	270	200	100	60
60-80	290	70	60	30	0	330	240	145	85
>80	340	90	70	45	0	390	290	190	115
cv. Paluma									
<60	230	45	30	15	0	230	145	85	45
60-80	290	45	30	15	0	315	230	115	70
80-100	340	60	45	30	0	370	270	170	100
>100	400	70	60	45	0	430	330	230	115

(1)When the leaf composition of N is above 26 g/kg (cv. Rica) or 23 g/kg (cv. Paluma), reduce the N applied by withholding the final application.

(2)When leaf K is above 19 g/kg (cv. Rica) or 17 g/kg (cv. Paluma), reduce the K applied by withholding the last final application.

Source: Natale *et al.*, 1996a.

In orchards more than two years old with fertigation, fertilizers can be applied more frequently according to the needs of the plants. Silva *et al.* (2000) studied the dynamics of K with fertigation and observed that there was a larger concentration of K ions in the soil solution with increased frequency of irrigation (every three days) when the recommended amount of K or less was applied. However, when the amount of K applied was larger than that recommended, applying irrigation every three days resulted in a lower concentration of K in the soil solution. They concluded, therefore, that with fertigation the rational management of both irrigation and fertilization is as important as the quantities of fertilizer applied. If frequent fertigation results in an increase in the amount of fertilizer applied, there is an increased risk of loss of nutrients by leaching. In regions like south-eastern Brazil, which is characterized by a concentration of rains in one short period of the year, this loss of nutrients may be even more pronounced.

Other than N, P and K fertilizers, micro-nutrients should also be considered, especially B and Zn, because of their general deficiency in tropical soils and removal in the harvested fruits. Micro-nutrients can be applied when required as foliar sprays often in two applications (Table 6.5). It may be possible to apply them together with insecticides and fungicides. Leaf analysis is an adequate monitor of the nutritional and micronutrient needs of the plant.

It is important to suspend irrigation at least 30 days before pruning during fruit development to cause the plant to undergo water stress.

6.5.3. Fertilization for production

Differences between conventional fertilization and fertigation should be considered, especially in the period of fruit production. In this phase, the trees have increased physiological activity and, consequently, greater nutritional needs. Studies to determine the nutritional needs of the plant and fertilizer recommendations were mainly in the absence of irrigation. With the use of fertigation, there are changes in the plant-soil system that requires adjustments to fertilizer recommendations.

Factors that may lead to an increase in fertilizer recommendations are directly related to the plant and the Brazilian climate, especially in Sao Paulo state. Regarding the plant, irrigation must increase the yield potential, which increases the demand for nutrients. With irrigation, especially when the water is applied to a limited volume of soil, the plant root system is confined to the wetted soil, inhibiting root expansion. Consequently, it is necessary to increase the concentration of nutrients in the wetted soil. The second factor is climate. In the Sao Paulo region, there is increased rainfall for a short period with the risk of greater nutrient losses by leaching, especially of nutrients that are readily mobile within the soil solution. Zanini (1991) followed the concentration of K in the soil when it was applied by drip fertigation. In the wetted area, where soil samples were taken 24 hours after fertigation and again after six successive irrigations only with water, the concentration of K had decreased by between 58 and 66% in the 0 to 40 cm depth of soil.

With irrigation that applies water to a limited volume of soil the distribution of roots may be affected, indicating that fertigation is the most appropriate method for nutrient application. This allows the roots, especially the fine and very fine ones that take up nutrients, to exploit the whole soil volume to which nutrients are applied. When nutrients are applied to the soil surface only part of the root system has access to nutrients, necessitating larger inputs to ensure adequate quantities are available (Coelho *et al.,* 2001). When water and nutrients are applied together, the nutritional demands of the plant can be met in any phase of the production cycle.

There are no long-term data specifically for guava that allow definite recommendations for fertigation. Until experiments provide conclusive results, fertilizer recommendations for fertigation should consider the features of the plant-soil system for the region of production. However, research results of the nutrient requirements of the plant under drought conditions can be adjusted taking into consideration phyto-technical information for the crop, and even data for other fertigated fruit trees, to make a first approximation for recommendations for the guava grown with fertigation.

Fertilizing for fruit production should start in the fourth year after planting the orchard, when the plants enter the full production phase. At this time, fertilizer applications should take into account the nutritional needs of the crop, as much for maintenance as to compensate for the offtake of nutrients in the fruits and ensure adequate fruit quality. The amount of fertilizer to be applied should be based on annual soil and leaf analysis data and related to the age of the plants, management of the orchard and expected productivity. The aim is to obtain maximum productivity with minimum cost. To achieve this other inputs, like pruning and irrigation, must be appropriate to ensure three harvests every two years.

Table 6.6 gives amounts of N, P_2O_5 and K_2O to be used in the orchard, based on soil and leaf analysis and expected production, according to the experimental results of Natale (1993) and Natale *et al.* (1994, 1995, 1996a,b,c). Differences in the fertilizer recommendations for the two varieties are related to their production potential. Of the two cultivars, Rica and Paluma, the latter is the one most planted in Brazil.

The first application of fertilizers by fertigation in the production phase should start one month before pruning, aiming to produce the appropriate amount of vegetation and meet the nutrient demand for future fruit production. Although the period from pruning to harvest is about 6 months depending on soil and climatic conditions, fertilizers should be applied every 30 days for 7 months.

6.6. References

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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 (25ºC day and 15ºC night) and a drought period before flowering. At temperatures around 30ºC during the fruit forming phase if water is available, by irrigation or rain, mango also produces well (Chacko, 1986). At temperatures below 15ºC and/or above 30ºC 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 35ºC. 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 27º N and 27º 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/dm^3)				K-exchangeable ($mmol_c/dm^3$)			
	<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/dm^3)				K-soil ($mmol_c/dm^3$)			
	<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).

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8. Papaya

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8.1. Introduction

In 2004 the world papaya fruit production was about 6.8 million mt of which most (1.6 million mt) were produced in Brazil (Table 8.1). Average yield in Brazil was 46.81 mt/ha, the largest amongst producing countries.

International exports currently account for 300,000 mt papaya with an annual growth rate exceeding 5%.

Mexico is the largest papaya fruit exporter (97,000 mt in 2004), followed by Malaysia (58,000 mt) and Brazil (36,000 mt) (Table 8.2).

The United States are the largest papaya fruit importer (130,000 mt in 2004), followed by China (55,000 mt) and Singapore (19,000 mt).

8.2. Climate, soil and plant

8.2.1. Climate

The papaya is a typical tropical plant, growing in regions with temperatures varying from 22 to 26ºC. In temperatures above 30ºC the rate of water assimilation is reduced significantly, reaching 50% of its potential maximum. Elevated temperatures, according to Dantas and Castro Neto (2000), influence the rate of fruit development.

The papaya develops well in regions with an average annual rainfall of 1,800 to 2,000 mm, well distributed throughout the growing season. When water is deficient, the plant is less tall and the oldest leaves become chlorotic and eventually fall off. On the other hand, excessive water also affects the plant's development, two days of flooding can cause death, and survivors recover only slowly. As a consequence of prolonged periods of heavy rains and flooding, even if only temporary, the lower leaves may fall prematurely, the youngest

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leaves become yellow and the trunks long and thin. Yields are decreased and there can be a greater incidence of stem rot, caused by the *Phytophthora* fungi (Oliveira *et al.,* 1994).

Table 8.1. Production and area harvested in the primary producing countries.

Countries	Production (1,000 mt of fruit)									
	Years									
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Brazil	1,041	933	1301	1,378	1,402	1,440	1,490	1,598	1,715	1,612
Nigeria	648	662	675	751	748	748	748	755	755	755
India	478	540	620	582	660	700	700	700	700	700
Mexico	483	497	594	576	569	672	873	876	956	956
Indonesia	586	382	361	490	450	429	501	605	627	733
Ethiopia	n.d.	n.d.	n.d.	180	180	197	223	226	230	230
Congo	225	224	226	227	220	213	206	210	211	211
Peru	140	136	147	165	171	171	159	173	191	195
China	146	146	154	131	175	154	159	163	165	154
Philippines	57	60	65	63	72	76	77	128	131	132
Other	763	778	859	878	997	1014	1,104	1,082	1,094	1,079
Total	4,567	4,358	5,002	5,421	5,644	5,814	6,240	6,516	6,775	6,757
	Area harvested (1,000 ha)									
Brazil	33	33	39	40	39	40	35	36	36	34
Nigeria	80	80	82	90	90	90	90	91	91	91
India	42	46	70	60	60	70	70	80	80	80
Mexico	14	17	20	20	17	17	22	20	26	26
Indonesia	11	10	10	10	10	9	10	10	32	29
Ethiopia	n.d.	n.d.	n.d.	9	9	10	11	11	11	11
Congo	13	13	13	14	13	13	13	12	12	12
Peru	11	12	13	14	14	13	12	12	13	13
China	4	4	4	5	5	5	5	5	6	6
Philippines	5	5	5	6	6	6	6	9	9	9
Other	57	59	65	63	70	72	78	78	80	79
Total	270	279	321	331	333	345	352	364	396	390

Source: FAO, 2004.

Table 8.2. World exports of papaya.

Countries	Exports									
	Years, value, quantity (in '000)									
	2000		2001		2002		2003		2004	
	mt	US$	mt	US$	mt	US$	mt	US$	mt	US$
Mexico	60	24	74	30	69	30	75	44	97	73
Malaysia	44	18	54	25	61	26	71	27	58	22
Brazil	22	18	23	19	29	22	39	29	36	27
Belize	6	9	6	5	11	8	17	11	29	17
United States	6	14	8	17	7	14	7	14	10	16
Netherlands	3	7	4	7	3	7	11	17	10	17
Equador	4	0	4	0	2	0	4	1	7	2
China	0	0	0	0	1	0	6	1	4	1
India	12	4	2	1	3	1	4	1	3	1
Philippines	3	3	4	5	4	5	1	2	3	4
Other	18	15	18	15	22	18	18	15	20	23
Total	177	112	198	124	213	131	253	163	277	203

Source: FAO, 2004.

Papaya grows best at altitudes up to 200 m above sea level, although some varieties produce satisfactory yields at higher altitudes. Strong winds may cause the leaves to split and fall, reducing leaf area and, consequently, photosynthetic capacity. This also exposes the fruits to solar radiation, resulting in surface burns. Winds may also cause the flowers and fruits to fall as well as mature plants with a weak root system. In regions with strong winds the plantation should be protected with wind-breaks consisting of appropriate plant species (Oliveira *et al.,* 1994).

Papaya develops best when the relative air humidity is between 60 and 85%. Stomatal opening is controlled by a mechanism responding to air vapour pressure. Water soil deficit associated with air vapour pressure deficit, decreases stomatal opening and photosynthetic rate (Dantas and Castro Neto, 2000).

Solar radiation affects CO_2 assimilation as for the majority of C_3 plants and the point of light saturation is relatively high, around 1000 mmol/m/s. In the tropics, on sunny days with photon flow densities higher than 2000 mmol/m^2/s, the papaya experiences photoinhibition. In the shade, plant size, foliar area, density of stomata, length of the mesophilic cells and the specific weight and breadth of the leaf are all decreased, while the quantity of leaf chlorophyll is increased (Dantas and Castro Neto, 2000).

8.2.2. Soil

In Brazil, 85% of papaya is produced in Bahia and Espírito Santo states. The soils are mostly Latosols and Yellow Podzolic soils, which have small amounts of nutrients. It is also grown on Acrisols, with a sandy textured surface soil and very dense, compacted subsurface horizons that impede water infiltration and prevent the development of a deep root system. Plantations are generally on flat or gently undulating topography (Ribeiro, 1996). Preferably the soil should be rich in organic matter, have a pH between 5.5 and 6.7 and be medium or sandy-clay in texture. Clayey soils are more prone to have compacted layers, which aggravate flooding and aeration problems. The ideal soil for papaya to develop a good root system is one with good depth, aeration and drainage. In shallow soils with compacted layers on or near the surface or in the subsurface, root development is impeded and the problems of excess water or its deficit are aggravated. Clay soils and/or those with compacted layers should be subsoiled to a depth of 0.5 m or more.

8.2.3. Plant

The species *Carica papaya* L. has male, female and hermaphrodite plants that quickly grow to 3 to 8 m. The stem, which has a diameter of between 0.10 and 0.30 m, is erect, undivided, herbaceous and fistulous and ends in a concentration of leaves in the apical region that tends to be spiral in shape. The leaves are alternatively attached to the trunk. They have large foliar stems, with oval or round laminas, palmate lobes and 7 to 11 main veins. The pedicels are fistulous, cylindrical, about 0.50 to 0.70 m long, but can be 1.0 m. The root system is pivotal, with root ramifications and a main napiform root (Dantas and Castro Neto, 2000; Costa and Pacova, 2003).

8.3. Soil and cultivation management

Adequate soil moisture is required for appropriate soil preparation by agricultural machinery and equipment. An initial light cultivation is followed 20 to 30 days later by ploughing once or twice. In soils with compacted horizons, deep cultivation to a depth of 50 cm is recommended (Oliveira, 1999b).

Papaya grows well in soils with a pH ranging from 5.5-6.7. In more acidic soils (pH <5.5) with exchangeable aluminium (Al) greater than 4 $mmol_c/dm^3$ and $Ca^{2+} + Mg^{2+}$ less than 20 $mmol_c/dm^3$, liming to correct acidity is necessary. When liming is recommended, it should be done two or three months before planting and if the concentration of Mg is less than 9 $mmol_c/dm^3$, calcareous dolomite should be used. The recommended the minimum concentration for Ca is 20 $mmol_c/dm^3$.

Papaya seed can be germed in polyethylene bags, styrofoam trays or tubes, and the seedlings grown in plastic containers. The most commonly used container is a polyethylene bag either 7 x 18.5 cm x 0.06 cm or 15 x 25 x 0.06 cm (width, height and thickness, respectively). Approximately 15% more seeds are sown than the number of seedlings required for planting to allow for germination failures and losses in the nursery and when planting in the orchard.

Planting can be at any time of the year but in dryland conditions it should start at the beginning of the rainy season and on cloudy or rainy days. Papaya has a relatively short cycle and fruit harvest starts about 10 months after planting. If possible, a grower should plant a new orchard so that harvesting starts when market prices for fruit are likely to be high.

The pits for planting should be 30 x 30 x 30 cm. However, when planting large orchards, the preference is to open furrows to a depth of 30 to 40 cm because this is more efficient and minimizes costs. When planting cultivars belonging to the "Solo" group, three seedlings should be planted per pit, and then at the time of flowering thinning them to leave just one hermaphrodite plant. This will produce fruits adequate for the consumer market. For the "Formosa" variety, the market is not very demanding with respect to the shape of the fruit, so only one seedling should be planted per pit.

8.4. Mineral nutrition

8.4.1. Uptake and removal of nutrients

Papaya takes up relatively large quantities of nutrients and the demand continues until the plants are about 12 months old (Fig. 8.1 and 8.2). Because harvests are intermittent from the start of production, the plant needs frequent applications of water and nutrients to ensure the continuous production of fruit and flowers.

Papaya has three distinct development phases: 1) initial growth; 2) flowering and fruit formation; 3) production. Table 8.3 gives the percentage distribution of the macro-nutrients in each stage of the phenological cycle and this shows that the demand in each phase of development is distinct and increases with the larger percentages in the production phase.

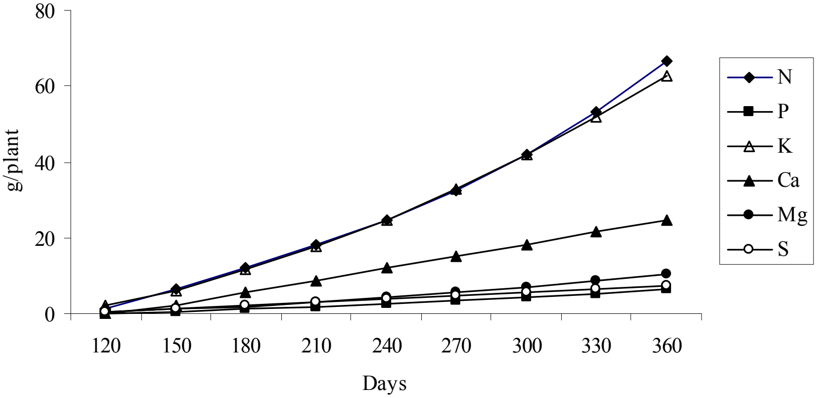

Fig. 8.1. Rate of macro-nutrient absorption by the papaya.
Adapted from: Cunha, 1979.

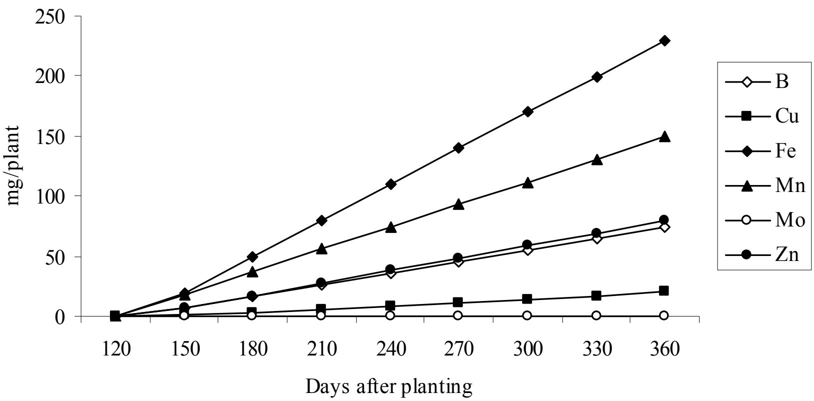

Fig. 8.2. Rate of micro-nutrient absorption by the papaya.
Adapted from: Cunha, 1979.

Table 8.3. Percentage distribution, during the development of papaya, of the total nitrogen (N), phosphorus (P) and potassium (K) in the crop at the end of the first year of growth, based on the rate of nutrient absorption determined by Cunha (1979).

Period		N	P	K
		%		
Formation	1st to 4th month	1.7	2.6	3.1
Flowering and fructification	5th to 6th month	16.2	15.3	15.1
	7th and 8th month	19.2	21.3	21.2
Production (harvest)	9th and 10th months	25.8	27.3	27.3
	11th and 12th months	37.1	33.5	33.3

Source: Oliveira, 2002a.

The quantity of each nutrient in the aboveground part of the plant, including flowers and fruits, for plants 360 days old and at 1650 plants/ha are as follows. In kg/ha, the amount of each macro-nutrient is: N, 104; P, 10; K, 108; Ca, 37; Mg, 16 and S, 12. In g/ha, the amount of each micro-nutrient is: B, 102; Cu, 30; Fe, 338; Mn, 211; Mo, 0.25; and Zn, 106 (Cunha, 1979). In the first year of growth the export of nutrients in the fruits will be less than in subsequent years because there will only be three to four months of harvest.

Of the macro-nutrients, those that accumulate in relatively small quantities in the fruits are Mg and Ca with only 12.5% and 13.5%, respectively, of the total taken up. Of the small quantity of P taken up in the first year, 30% is in the fruits and flowers. Nitrogen, K and S in the flowers and fruits range from 24 to 25% of the total taken up.

Of the micro-nutrients, some 36% of the total Mo taken up is in the flowers and fruits that contain about 20% of the total B, Cu and Zn taken up by the plant. On the other hand, Mn and Fe, despite being taken up in larger amounts, have the smallest relative proportions (14 and 16%) in the flowers and fruits in the first year of cultivation.

In the second year of cultivation, the papaya enters into a process of continuous fruit production. Cunha (1979), taking an average annual yield of 49 mt/ha, showed that the offtake, in kg/ha, of macro-nutrients during 12 months of harvest, was about N, 87; P, 10; K, 103; Ca, 17; Mg, 10 and S, 10. For micro-nutrients, the annual amounts, in g/ha, were about: B, 48; Cu, 16; Fe, 164; Mn, 90; Mo, 0.38 and Zn, 68. Although the amount of B removed in the fruit ranks only fourth in the list of micro-nutrients, its deficiency is widespread in orchards where B is not applied.

8.4.2. Functions and importance of nutrients

Nitrogen (N): Required for vegetative growth, N should not be limiting in the first 5 to 6 months after planting. Symptoms of N deficiency appear first in the mature leaves, which have yellowish areas between the veins. Later, these leaves become yellow, age and stand out from the trunk, and may even become necrotic with the centre turning brown and the edges purple (Plate 8.1). When N deficiency is severe, all of the leaves turn yellow, new leaves have slimmer stems and leaf laminas are not well developed (Costa and Costa, 2003; Cunha, 1979; Cibez and Gaztambide, 1978). Excess N results in excessive growth, with a greater distance between fruits on the trunk and inconsistent quality of the pulp.

Marinho *et al.* (2001) analysed fruit of the "Sunrise Solo" variety grown with variable amounts and different forms of N. They observed that increasing the amount of N did not affect the pH of the fruits. However, increasing amounts of ammonium sulphate, but not ammonium nitrate, linearly reduced the total percentage of soluble solids. On the other hand, Luna and Caldas (1984), Viégas *et al.* (1999) and Oliveira *et al.* (2002b) observed that fertilization with different amounts of urea, as a source of N, did not alter the total composition of soluble solids. Marinho *et al.* (2001) suggest that the accompanying anion influences the total concentration of soluble solids in the fruits.

Phosphorus (P): Although it is the macro-nutrient required in the least amount, its accumulation in the plant increases uniformly, and is most important during initial root development. Thus it is necessary to give the young plants a source of readily plant-available P. It is also suggested that P has an effect on setting the fruit.

Cibez and Gaztambide (1978), growing plants in a nutritive solution, observed that P deficiency symptoms initially appear in the oldest leaves, which have a mottled yellow color along the edges. As deficiency progresses, the yellow areas become necrotic and the leaves have pointed lobes while the edges curl upwards. Later, the leaves turn completely yellow and fall from the trunk. New leaves are smaller and have a dark green coloring. Costa and Costa (2003) describe P deficiency symptoms first appearing as purple spots on the mature leaf laminas, followed by the centre of each spot becoming necrotic with time, with a brownish color.

Potassium (K): Required in large amounts, papaya takes up K continuously throughout the entire plant cycle. It is especially important after the fertilization of the flowers to produce larger, better quality fruit, with elevated levels of sugars and total soluble solids.

A ratio of $N:K_2O$ of 1:1 seems to be the most favorable to obtain good yields, which suggests that the fertilizers used should have $N:K_2O$ ratios close to 1:1 (Gaillard, 1972; Coelho *et al.*, 2001; Oliveira and Caldas, 2004).

Potassium deficiency if first evident in the oldest leaves with a decrease in their number and with the stem positioned obliquely to the trunk. The oldest leaves are yellow between the veins and along the edges with a slight marginal necrosis on the extremities of the lobes. The leaves tend to dry from the tip to the centre. The developing leaves show chlorotic edges with small necrotic spots. When K deficiency is severe the growing point is affected (Costa and Costa, 2003; Cunha, 1979; Cibes and Gaztambide, 1978).

Calcium (Ca): It is the third most required nutrient and it also accumulates uniformly like K. Awada and Suehisa (1984) noted that Ca deficiency causes an initial chlorosis of recently mature leaves, with small necrotic spots spread over the leaf lamina. This chlorosis extends back to the youngest leaves and the affected leaves have twisted and folded stems. However, Costa and Costa (2003) consider that the initial symptoms of Ca deficiency are seen in the youngest, expanding leaves, which have curled edges, harming leaf development. Calcium deficiency is also responsible for the softening of the fruit pulp, which results in problems in transport and a short commercial shelf life.

Magnesium (Mg): Deficiency of Mg results in the mature leaves having an intense yellow color, while the regions in the proximity of the veins remain green (Plate 8.2). When Mg is very deficient, the new leaves also have similar symptoms.

Sulphur (S): Sulphur occurs in papain, a proteolytic enzyme, and, in general, performs functions in the plant that affect yield and quality of the fruit. The sulphate ion favors the activity of anabolic enzymes that play a part in the formation and accumulation of starch and proteins. When S is deficient, new, expanding leaves are light green in color before becoming uniformly yellow. With increasing deficiency, the completely expanded leaves also become yellow. Before the appearance of visual symptoms in the leaves, the growth of the papaya plant is affected. Sulphur uptake may be affected by the presence of chloride ions added to soil in fertilizer.

Boron (B): It is the most important micro-nutrient for papaya because it affects both the yield and quality of the fruit. Liming the soil, excessive soil acidity, water deficiency, high light intensities, low levels of soil organic matter and of B in the soil are cited as causes of B deficiency (Oliveira, 1999a).

When B deficiency is severe, the growing points of both stems and roots are affected, the fruits are poorly formed and have a gaunt appearance and latex drains from the skin at from 1 to 5 distinct points (Wang and Ko, 1975). Additional symptoms of B deficiency are that flowers abort in periods of drought, fruits alternate on the trunk, leaves are yellow with short stems and the vascular system may or may not appear darker (Plate 8.3).

Zinc (Zn): Zinc deficiency is seen in the expanding leaves as interveinal chlorosis that later become purple spots. With increasing deficiency, the youngest leaves remain small, possibly showing necrosis along the edges and on the lamina between the principal veins. The internodal space is also shortened (Costa and Costa, 2003).

Foliar diagnosis of the nutritional state of the plant: For this purpose, chemical analysis of the leaves is important but the time of sampling and the position of the leaves sampled is also critical. Currently, there is disagreement as to which tissue best represents the nutritional status for the majority of nutrients, although various authors have established indices based on the leaf lamina (Table 8.4).

Table 8.4. Standard compositions of macro-nutrients and micro-nutrients in the leaf lamina of papaya, by different authors.

Nutrient	Cunha, 1979	Nautiyal *et al.*, 1986 Agarwala *et al.*, 1986[(1)]	Cibes and Gartambide, 1978	Prezotti, 1992
Macro-nutrient		g/kg		
N	42.4	-	22.5	45-50
P	5.2	-	8.2	5-7
K	38.1	-	15.8	25-30
Ca	12.9	-	36.1	20-22
Mg	6.5	-	12.1	10
S	3.1	-	12.1	4-6
Micro-nutrient		mg/kg		
B	136	17.3	109	15
Fe	-	140.0	252	291
Mn	-	62.7	88	-
Zn	-	22.4	-	43
Cu	-	11.8	-	11
Mo	-	1.85	-	-

[(1)]Values obtained for plants, grown in solution, containing all the nutrients.

There also are nutritional indices based on analysis of the leaf stems (Awada, 1969, 1976, 1977; Awada and Long, 1969, 1971 a, b and 1978; Awada and Suehisa, 1984; Awada *et al.,* 1975). These authors suggest values, mg/kg, are satisfactory: N, 12.5 to 14.5; P, 1.6 to 2.5; K, 36.1; Ca, 7.3 to 9.3. On the other hand, in studies in Brazil, in the papaya-producing region in northern Espírito Santo, standards of reference were established for the development of a Diagnosis and Recommendation Integrated System for the papaya (DRIS) (Table 8.5). In these studies, Costa (1995) found that nutrient concentrations in the leaf stem correlated best with the nutritional state of the plant. Nutritional indices based on analysis of leaves taken in the dry season were best because the availability of water also influenced the nutrient composition of the leaves.

Table 8.5. Standard compositions of macro-nutrients and micro-nutrients in the leaf stems of papaya in the dry and rainy seasons.

Nutrient	Season	
	Dry	Rainy
Macro-nutrient	-------------- g/kg	--------------
N	11.0	26.4
P	1.7	1.6
K	28.1	24.9
Ca	18.4	16.5
Mg	5.3	5.7
S	2.6	3.2
Micro-nutrient	------------- mg/kg	--------------
B	25.2	23.1
Fe	51.0	43.3
Mn	41.7	42.9
Zn	15.3	10.5
Cu	2.4	2.9

Source: Costa, 1995.

Leaves for chemical analysis should be sampled from the same cultivar, from plants of the same chronological and physiological age and be representative of the average plants in the orchard. Only leaves that have a ready to open or recently opened flower should be sampled, with a minimum of twelve leaves per sample. Lamina and stem should be separated and analysed separately.

8.5. Fertilization

Papaya grows, flowers and bears fruit continuously and, in consequence, there is a constant demand for nutrients. Gaillard (1972), in an exploratory test with "Solo" group papayas, observed that fertilization with K benefited growth and yield but the amount applied per plant should not exceed 300 g. It was also observed that the largest yield of fruit was obtained with 250 g N and 250 g K_2O per plant, *i.e.* a ratio of N:K_2O of 1:1. Larger amounts of N and K in the same ratio (500 g N and 500 g K_2O per plant) decreased yield.

In Brazil, Luna and Caldas (1984) measured the response of "Solo" papaya to three levels of each N (0, 200, 400 kg N/ha), P (0, 80 160 kg P_2O_5/ha) and K (0, 60, 120 kg K_2O/ha). There was a significant positive response to N and P in the average weight of the fruit and total yield, but no response to K. 200 kg N and 160 kg P_2O_5/ha gave the largest yield. Oliveira and Caldas (2004), obtained a yield of 93.41 mt/ha of fruit in the first harvest year from an application of 347 and 360 kg/ha/yr of N and K_2O, respectively. Besides the quantity of fertilizer, the success of its application depends on both the time at which it is applied and where it is placed.

Fertilizer recommendations are related to the availability of nutrients in the soil as determined by chemical analysis. Table 8.6 shows recommendations based on soil analysis and expected productivity. In the second year after planting the soil should be sampled and analysed again to adjust the recommendations shown in Table 8.6.

Papaya should be fertilized frequently, preferably with water soluble fertilizers and at least one should contain S. The root system of plants growing in the Brazilian Coastal Flatlands is concentrated within a radius of less than 60 cm around the trunk and at a depth of up to 1.0 m. In this situation, Costa *et al.* (2003) suggest that the fertilizer should be broadcast uniformly between the middle of the crown projection and the trunk of the plant.

Micro-nutrients may be applied to the soil in the planting pit, in soil cover or as a foliar application. The requirement for B is determined by soil analysis and the amount required should be applied in two equal portions per year. When using fritted trace elements (F.T.E.), 50 to 100g F.T.E. Br-8 or F.T.E. Br-9 should be applied in the pit, the actual amount used should supply 1 to 2 g B/pit).

Papaya responds well to the incorporation of organic compost, which improves the physical, chemical and biological conditions of the soil, and as often as possible use mixed composts containing, for example, castor beans or cocoa, bovine or chicken manure. However, papaya residues should not be used in organic composts because this material could inhibit the plant's growth.

Table 8.6. Fertilizer recommendations, based on chemical soil analysis, for an orchard in its second year.

Development phase	N	P-resin (mg/dm^3)			K-exchangeable (mmol$_c$/dm^3)			B hot water (mg/dm^3)		
		0-12	13-30	>30	0-1.5	1.6-3.0	>3	0-0.2	0.2-0.6	>0.6
	kg/ha	----------- P_2O_5 (kg/ha) ----------			----------- K_2O (kg/ha) -----------			----------- B (kg/ha) -----------		
At planting	60[1]	60	40	20	-	-	-	-	-	-
Days after planting										
30	10	-	-	-	20	15	10	1	0.5	0
60	10	20	15	10	20	15	10	-	-	-
90	20	-	-	-	20	15	10	-	-	-
120	20	20	15	10	20	15	10	-	-	-
Start of flowering to 360 days after planting										
Expected yield (mt/ha)										
30-50	180	60	40	20	220	140	60	1	0.5	0
50-70	230	70	50	30	270	180	80	1	0.5	0
>70	280	80	60	40	320	210	100	1	0.5	0
Second year										
30-50	200	130	80	40	240	160	80	2	1	0
50-70	240	150	100	50	280	190	95	2	1	0
>70	280	170	120	60	320	220	110	2	1	0

[1]Organic source.

Source: Oliveira *et al.*, 2004.

8.6. Irrigation

When the plant is irrigated, it produces bigger and better fruit and the larger leaves give increased cover of the fruit and this results in a reduction in fruit burns by the sun.

8.6.1. Irrigation methods

The irrigation methods usually recommended are pressurized, conventional, localized and spray irrigation and for the latter the self-propelled and centre pivot systems are the most used.

In localized irrigation systems, both dripping and jets have been much used. Jets work under low pressure (100 to 300 kPa) and with a discharge rate of between 20 and 175 L/h. There is normally one emitter for every two or four plants, assuming a uniform water distribution greater than 85%. In dripping systems, which work in the pressure range of 50 to 250 kPa, and discharge rates between 2 and 4 L/h, it is recommended to put two drip emitters for every plant and have a discharge rate of approximately 4 L/h. The dripper should be installed 0.25 m from the base of the plant in sandy soils and 0.50 m in clay soils. The drip system may be above or below ground. When below ground at 0.20 to 0.30 m depth, the use of flux turbulence drippers, with a discharge rate of about 2 L/h is recommended. This provides a more uniform water distribution, which facilitates root development and maintains an adequate air/water ratio for the root system. Planting is recommended in the rainy season in order to establish before the drought period, a root system that is able to use the water in the wetted volume of soil created by the drip emitter.

Irrigation by jets wets a larger area of soil, and nominally better conditions for root development, but compared to an above ground dripping system along the row of plants, the increase in yield is less than 10%. The use of above ground dripping for papaya of the "Solo" group growing in the Coastal Lowlands, produced on average, 15% less fruits than given by a subsurface irrigation system.

8.6.2. Water requirements

Research has shown that water use by papaya varies greatly with evapo-transpiration. Low temperature, a small number of daylight hours, high relative humidity and little wind favor low evapo-transpiration and water consumption is about 2 to 4 mm/day. Consumption of water increases up to 7 to 8 mm/day in periods of high evapo-transpiration, i.e. high temperature and light intensity and low relative humidity. When evapo-transpiration is large, an adult plant when producing fruit from the 9th to 12th month, requires a maximum daily application of up to 45 L of water.

Papaya is an herbaceous plant with a large hydraulic conductivity, which contributes to an increased energy exchange with the atmosphere, and this is also favored by increased exposure of the leaves to solar radiation. These characteristics mean that the plant transpires significantly per unit area of leaf when compared to those species that have large leaf densities.

Transpiration values for plants with different leaf surface areas can be compared for days with variable evapo-transpiration. For the papaya, Coelho Filho *et al.* (2003a) produced the following equation:

$$Tr = 0.56 \text{ x } ET$$

where Tr is the transpiration per unit leaf area (L/m^2 of leaf/d) and ET_o is the reference evapo-transpiration (mm/day).

Table 8.7 shows water loss based on leaf area and the reference evapo-transpiration but ignoring loss by evaporation and the inefficiency of the irrigation system. These values may serve as a reference for irrigated orchards in which soil water conservation management is practised through, for example, the use of highly efficient irrigation systems, like subsurface dripping.

Table 8.7. Estimated values (L/day/plant) of the water transpired by papaya based on foliar area and reference evapo-transpiration (ETo).

Foliar area	ET_o (mm/day)				
	2	3	4	5	6
m^2	------------------------------ L/day/plant ------------------------------				
1	1.12	1.68	2.24	2.80	3.36
2	2.24	3.36	4.48	5.60	6.72
3	3.36	5.04	6.72	8.40	10.08
4	4.48	6.72	8.96	11.20	13.44
5	5.60	8.40	11.20	14.00	16.80
6	6.72	10.08	13.44	16.80	20.16
7	7.84	11.76	15.68	19.60	23.52
8	4.48	8.96	13.44	17.92	26.8
9	5.04	10.08	15.12	20.16	30.24
10	5.60	11.20	16.80	22.40	33.60

Source: Coelho Filho *et al.*, 2003b.

8.6.3. Fertigation

Frequently solid fertilizers are applied close to the plant and on the soil surface. For the nutrients to reach the roots the fertilizers have to dissolve in the soil solution in which the nutrients move to the roots. The volume of soil solution depends on the amount of rainfall or irrigation. On many occasions solid fertilizers are deposited in locations remote from the greatest concentration of roots.

When applied in irrigation water, the time for nutrients to reach the roots is significantly reduced, and the nutrients are uniformly distributed throughout the wetted soil. This greatly increases the opportunity for the roots to take up nutrients at a rate appropriate to the needs of the plant. The following advantages of fertigation may be cited:

1. The quantities and concentration of nutrients may be adapted to the needs of the plant at different growth stages.
2. Saving in manual labour.
3. Minimal risk of soil compaction from people and machinery.

On the other hand, the following disadvantages are possible:

1. Possibility of the soil solution being brought back to the soil surface as water is transpired.
2. Possibility of emitter clogging.
3. Possibility of contaminating a surface or subsurface water supply.

In Brazil, the average yield in the first year of harvest of the "Sunrise Solo" and "Formosa" papayas is 40 and 60 mt/ha, respectively, well below the potential yield of these varieties. Adequate management of important aspects of production, like water and nutrients, may increase yield. Producers in the far southern part of Bahia and northern Espírito Santo have reported that in irrigated plantations average annual yields can reach 60 and 80 mt/ha of "Sunrise Solo" and "Formosa" varieties, respectively.

Coelho *et al.* (2002a) and Coelho *et al.* (2002b) obtained yields close to 50 mt/ha in the first harvest year of cv. "Sunrise Solo" with irrigation. In an experiment testing five levels each of N and K at 35, 210, 350, 490 and 665 kg/ha N and K_2O, maximum yield was given by 490 kg/ha N and 490 kg/ha K_2O (Coelho *et al.*, 2001). In a similar experiment with cv. Tainung Nº 1, the same five levels of N and K, together with five levels of irrigation were tested. The largest yield was given by 490 kg N/ha and 665 kg K_2O/ha (Silva *et al.*, 2003). These authors also found that N and K had a larger effect on yield than did irrigation.

Research by Coelho and Santos (2003) showed no significant effect from frequent fertigation. When N is applied in an amide or ammonium form, the frequency of fertigation may be 7 to 15 days to allow for the uptake of N as both ammonium and nitrate. When nitrate N is applied, the frequency can be greater, every three days. In the first year after planting, it is recommended to apply nutrients as follows: 15% of the N in the planting pit, as organic N, together with 33% of the P as single superphosphate and all the S. In general, when applying N and K in the irrigation water it should be given weekly or biweekly according to the crop's need and the current economics of producing the crop. Phosphorus should be applied monthly or bimonthly.

In the second year, the total quantities of N and K recommended according to soil analysis, should be divided equally into forty-eight or twenty-four amounts and applied weekly or biweekly, respectively. The quantity of P required in the second year should also be divided equally between bimonthly applications.

Fertigation, *i.e.* adding nutrients in the irrigation water, aims to increase the efficiency of fertilizer use by meeting the nutritional demands of the crop appropriate to the stage of growth with fewer losses by leaching, fixation and volatilization.

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9. Passion-Fruit

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9.1. Introduction

The passion-fruit is extremely important in Brazil. Its fruits are rich in mineral salts and vitamins, especially A and C, and its juice has a wonderful aroma and flavor. It is widely accepted in different markets and there is a large potential for exports, not to mention its pharmacological properties.

In Brazil, the passion-fruit vine is cultivated predominantly in small orchards, on average 1.0 to 4.0 ha, and is an important source of income for small to medium producers.

Brazil is the world's foremost producer of passion-fruit, with about 90% of the production, followed by Peru, Venezuela, South Africa, Sri Lanka and Australia. Brazilian production is around 478,000 mt with a yield of about 13.8 mt/ha. The northern and north-eastern regions of the country are responsible for more than 80% of the national production.

In Brazil, the passion-fruit is used primarily for fresh consumption and the production of juice, which is also exported. For Brazilian exporters, the principal market is Europe, which imports more than 90% of the juice. However, there are very good prospects in the American, Canadian and Japanese markets.

9.2. Climate, soil and plant

9.2.1. Climate

Brazil, as a centre of passion-fruit production, provides excellent conditions for its cultivation. It develops well in tropical and subtropical regions, where the climate is hot and humid. Temperature, relative humidity, light intensity and precipitation have an important influence on the longevity and the yield of the plants, but also favor the incidence of pests and diseases.

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Biological processes, such as flowering, fertilization, fruit formation, maturation and fruit quality depend on elevated temperatures. The temperature range between 21 and 25ºC is considered as the most favorable for the growth of the plant, being best between 23 and 25ºC, but passion-fruit is being successfully cultivated in temperatures between 18ºC and 35ºC (São José, 1993). Lower temperatures slow the growth of the plant and reduce the uptake of nutrients and fruit production, while very high or very low temperatures affect fruit bearing (Manica, 1981). At intermediate temperatures of 23ºC to 28ºC, the fruit growth period for is 60.3 days, when the temperatures where lower (23ºC) and higher (33ºC) the period was 75 days (Utsunomiya, 1992). The germination period of the seeds is shorter in summer time than in the coldest months, when the period is longer (São José *et al*., 1991).

Growing passion-fruit at altitudes between 100 m and 1,000 m is recommended. Plantations at lower altitudes last for a shorter period of time than those with higher altitudes. In South Africa, at altitudes between 1,200 and 1,400 m, plantations may be productive for eight years, owing to the longer cycles, implicating a greater longevity (Teixeira, 1995).

Relative humidity has a great influence on vegetative development and the phytosanitary state of the passion-fruit. Air relative humidity of around 60% is the most favorable for the passion-fruit cultivar. Elevated temperature, associated with constant wind and low relative humidity, causes a drying out of the tissues by excessive transpiration and impedes the development of the passion-fruit. Relative humidity of greater than 60%, when associated with rains, favors the appearance of disease, like citrus scab, anthracnose (black spot) and bacteriose, in the aboveground parts of the vine (Lima and Borges, 2002).

The susceptibility of passion-fruit to strong winds is also an important factor for this crop. Besides direct damage to the plant, it has to adapt its conduction systems. Strong winds cause plants to fall and cold winds cause flowers and new fruits to fall, as well as delaying plant growth. In regions prone to high winds the use of windbreaks, like bamboo, grevillea, pine, hibiscus, eucalyptus and grass species is indispensable (Ruggiero *et al.,* 1996).

Light is also an important factor affecting growth due to its effects on photosynthesis. An increase in the hours of daylight results in greater photosynthetic activity, with an increase in the plants vigour and the size and quality of the fruit.

Inadequate light affects the formation of the flowers and fruit. Regions in which the day length is greater than 11 hours have the best conditions for flowering. In the winter months, the plants do not flower because the days are shorter. In the semi-arid regions of Brazil, with more than 11 hours of day light associated with high temperatures throughout the year, the passion flowers continuously and produces fruit throughout the year, as long as there is an adequate supply of water.

Light intensity greatly influences the phenological phenomenon of flower opening in the yellow passion-fruit (Gamarra Rojas and Medina, 1995). The flowers normally open at 12.00 hrs, immediately following the maximum incidence of photosynthetically active radiation (PAR), and close at 15.00 hrs; however when light intensity is lower, they close at 14.30 hrs.

Passion-fruit develops continuously and so needs a constant supply of water. The demand for water varies from 800 to 1,750 mm and must be well distributed throughout the year, preferably with 60 to 120 mm of water each month, by rain complemented when necessary with irrigation (São José, 1993).

Although the plant withstands droughts relatively well, prolonged drought damages its vegetative development, causing, in sever cases, leaf fall and the formation of smaller and lighter fruits. On the other hand, intense rains in the flowering period also damage production, because they inhibit pollination by diminishing the activity of pollinating insects and causing pollen grains to burst.

In regions where the rains occur in specific periods, resulting in shortage for a few months, for example north of Minas Gerais and in the semi-arid regions of the north-east, the use of irrigation is indispensable to guarantee good production and fruit quality (Lima and Borges, 2002).

9.2.2. Soil

The passion-fruit has a superficial root system (60% of the roots located within 30 cm of the surface). So it is important that there is no impedance to root growth in the top 60 cm. Passion-fruit can be grown on a range of soils, sands to clay loams. In general, it is recommended that the soil should be deep, relatively fertile and well drained. Poorly permeable soils with high clay content, subject to flooding, are not recommended. The best soils are sandy clay (Ramos, 1986, cited by Teixeira, 1995). For good growth, it is recommended that the soil have neither impermeable, rocky or hardened layers, nor a water table at less than 2 m to avoid the appearance of dry rot (Lima and Borges, 2002).

The availability of an adequate supply of oxygen is of fundamental importance for good root development of the plant. Oxygen deficiency results in roots losing their structure, and they may quickly rot. Poor soil aeration may be induced by soil compaction or flooding. Soils subject to flooding favor the occurrence of root diseases (Lima and Borges, 2002). Flat and smoothly undulated lands (gradients less than 8%) are most suitable because crop management, mechanization, harvest and soil cultivation and conservation are facilitated. On steeper slopes (in the range of 8 to 30%), besides erosion control measures (including levelling to create terraces, etc.), irrigation and/or fertigation are more difficult. In very steep areas, passion-fruit should be grown individually and the soil constantly replenished to maintain a natural soil covering (Lima and Borges, 2002).

9.2.3. Plant

The passion-fruit plant is a woody vine (climber) with very fast, vigorous, continuous and exuberant growth (Kliemann *et al.,* 1986). The growth rate is reduced at fruiting and at low temperatures. In the north and north-east of Brazil flowering is continuous due to very little variation in the photoperiod and high temperatures; in such way, the absorption of nutrients should be constant. In the south-east and east-central regions development and nutrient absorption are reduced in the winter because of a shorter photoperiod and/or lower temperatures.

In the south-east region, stem and leaf growth increases at around 250 days (8^{th} month), and decreases after about 340 days (11^{th} month). Branch growth is linear from 160 days (5^{th} month), reaching more than 8 m at 370 days (12^{th} month). Fruit formation starts at 280 days (9^{th} month), starting from the axillary flowers developed on new branches, with a fast accumulation of dry material within the first 60 days and then establishing itself during maturation (370 days, 12^{th} month). With the root system, there are three phases of growth: up to 220 days (7^{th} month) the growth is slow, with reduced production of dry matter; from 220 (7^{th} month) up to 310 days (10^{th} month) there is expansion; later growth stabilizes (Haag *et al.*, 1973).

There is little absorption of nutrients until 220 to 250 days (7^{th} to 8^{th} months), because of the small production of dry matter. After the appearance of the fruits (8^{th} and 9^{th} months), growth becomes exponential, increasing the uptake of N, K and Ca and also that of the micro-nutrients, especially Mn and Fe (Haag *et al.*, 1973).

9.3. Soil and crop management

Soil preparation aims to improve the soil conditions for root development, by way of increasing aeration and water infiltration and reducing soil resistance to root growth. Manual soil preparation starts with clearing existing vegetation and using it as mulch or burning it. Soil preparation is limited to the manual opening of the pits for planting the vines. Mechanical preparation is done by machine, taking care to not remove the superficial layer of soil, which is rich in organic material. This is followed by ploughing and then pit digging or creating of furrows for planting. Surface scarifying may substitute for ploughing for minimum soil preparation.

Weed control can be done manually in the rows and mechanically between the rows. During harvest weed control needs to be especially well done in the rows parallel to the planting lines because the fruits are usually collected from the ground. Mechanical weeding (close to the plant less than 1 meter) is not recommended in order to prevent damages to the roots, which are largely concentrated within 15 to 45 cm from the stem (Lima and Borges, 2002). Chemical weeding, using selective herbicides eliminates not only the weeds, but reduces operational costs and simplifies the work.

The best pre-emergence herbicides are “diuron” and “bromacil” (Durigan, 1987). Paraquat or glyphosate have been used in some plantations in the Triângulo Mineiro and in Sao Paulo at 1.5 to 2.0 L/ha, and applied between the rows, leaving the dead weeds as a form of mulch covering the soil surface (Silva and Rabelo, 1991). Lima *et al.* (1999), studying the selectivity of pre-emergence herbicides “diuron” (1.2, 2.4 and 4.8 kg/ha), “oxyfluorfen” (0.48, 0.96 and 1.92 kg/ha), “alachlor” (2.8, 5.6 and 11.2 kg/ha) and “atrazine” + “metolachlor” (3.0, 6.0 and 12.0 kg/ha), in yellow passion-fruit seedlings, observed that only “atrazine” + “metolachlor”, in doses of 6.0 and 12.0 kg/ha, caused serious injury to the seedlings, while the others proved promisingly useful. Due to the fact that herbicide activity, in general, is limited to a specific plant or group of plants, it is recommended to use mixtures and planned combinations of herbicides pre-emergence and post-emergence, aiming to increase the period and active spectrum of the chemical control.

9.4. Mineral nutrition

9.4.1. Uptake and export of nutrients

For growth and production, passion-fruit requires an adequate nutritional state at all stages of growth and this requires a fertilization plan to permit the maintenance of an adequate nutritional state of the crop. From the start of fruit formation there is a great demand for energy by the plant and a strong translocation of nutrients from the leaves to the developing fruits and this reduces the vegetative growth of the plant.

The total quantities of nutrients taken up and exported by the entire plant, including the fruits, at 370 days, with 1,500 plants/ha, are shown in Table 9.1. The macro-nutrients N, K and Ca are taken up in the greatest quantities, followed by S, P and Mg. Of the micro-nutrients, Mn and Fe are absorbed in the greatest quantities, followed by Zn, B and Cu (Haag *et al.,* 1973).

Of the nutrients removed in the harvested fruits by far the largest quantity is K followed by N. Although only small quantities of Mg, S, Ca and P are removed, the amounts of P and Mg represent 40% and 29% of the total taken up, respectively (Table 9.1) (Haag *et al.,* 1973). Of the micro-nutrients, Mn is taken up most, but by percent Zn, followed by Cu, are the most exported. In spite of the large amount of Mn found in the fruits, it represents only 6.4% of the total taken up; however 34% of Zn, 32% of Cu, 13% of B and 11% of Fe are accumulated in the fruit and, thereby, removed at harvest (Table 9.2) (Haag *et al.,* 1973).

In this way for a crop yielding about 25 mt/ha, the export of macro-nutrients in the fresh fruits, in kg/mt, is 1.82 of N, 0.28 of P, 3.01 of K, 0.28 of Ca, 0.17 of Mg and 0.17 of S; while that for micro-nutrients, in g/t, is 1.54 of B, 2.61 of Cu, 3.59 of Fe, 7.35 of Mn and 4.41 of Zn.

Table 9.1. Quantities of nutrients absorbed by the whole plant (AB) and removed in the fruits (EX) of the yellow passion-fruit, at 370 days of age, with 1,500 plants/ha at yield level of 13 mt/ha.

Nutrient	Quantity	
	AB	EX
Macro-nutrient	------------- kg/ha	--------------
N	205	44.6
P	17	6.9
K	184	73.8
Ca	152	6.8
Mg	14	4.0
S	25	4.0
Micro-nutrient	-------------- g/ha	--------------
B	296	37.8
Fe	779	88.0
Mn	2,810	180.2
Zn	317	108.2
Cu	199	64.0

Source: Haag *et al.*, 1973.

9.4.2. Functions and importance of nutrients

Nitrogen (N): It is fundamental for the growth of all plant parts (Baumgartner, 1987; Kliemann *et al.*, 1986). It stimulates the development of floral and fruit buds, as well as increasing the amount of protein (Malavolta *et al.*, 1989). In its absence, growth is slow and the plant's size is reduced, with thinner and fewer branches (Marteleto, 1991). Data from the north-east region shows that there is a greater quantity of total soluble solids and lower acidity in yellow passion-fruit juice, as well as higher productivity, with the application of larger amounts of N to the soil (Marteleto, 1991).

Phosphorus (P): In its absence passion-fruit growth is reduced, affecting the quantity of dry matter, root growth and fruit production (Manica, 1981; Baumgartner, 1987).

Potassium (K): Its deficiency reduces the weight of the plant and the production of fruits, which fall prematurely or shrivel (Manica, 1981). In the north-east region increases in length and diameter of the fruit were observed with the application of larger amounts of K (Borges *et al.*, 1998).

Calcium (Ca): Its deficiency results in deformed leaves due to the breakdown of leaf tissue structure (Cereda *et al.*, 1991), because Ca affects cell elongation and the process of cell division (Ruggiero *et al.*, 1996).

Magnesium (Mg): In nutrient culture experiments, the absence of Mg affected the nutrient state of the plant, resulting in a greater absorption of P, K and Ca, relative to plants grown using a complete solution (Fernandes *et al.*, 1991).

Boron (B): Boron deficiency results in an increase in N, P and S in the tendrils and Mn in the stem and leaves of passion-fruit (Kliemann *et al.*, 1986).

Visual diagnosis: Based on the fact that each nutrient has a specific role in the physiological functions of plants, then excesses or deficiencies, i.e. imbalances, often result in characteristic symptoms, which permit the identification of the cause of the disorder. To establish the cause of visual symptoms requires knowledge of the symptom and its cause determined in both controlled experiments, which simulate the nutritional disorders systematically, and from soil and plant analysis. In Table 9.2 symptoms of nutritional deficiencies are described.

However, it is not sufficient to just rely on visual symptoms, to confirm that an anomaly is due to a disorder provoked by a specific nutrient. Because many factors may act simultaneously, to rely on one diagnostic based only on visual symptoms is not prudent. Visual symptoms should be confirmed by leaf and soil analysis of samples taken from crops grown in the field. Once it has been confirmed that deficiency or excess of a specific nutrient is the cause of the problem appropriate corrections can be made.

Leaf diagnosis: This consists of the determination, via chemical analysis, of the nutrient composition of the leaf which is the organ that best reflects the nutritional state of the plant. To be successful appropriate leaves in relation to stage of growth and position on the plant must be taken for analysis.

Table 9.2. Visual symptoms of nutrient deficiency in passion-fruit leaves.

Nutrient	Leaf age	Leaf symptoms
N	Oldest	Light green and smaller area. Yellowing and premature falling. *Cause*: low composition of organic matter, acidity (lower mineralization), leaching, prolonged drought.
P	Old	Dark green, later yellowing from the edges to the centre. *Cause*: low composition of P in the soil, low pH (lower availability).
K	Old	Progressive chlorosis from the edges to the centre, necrosis and tissue "burn". *Cause*: low composition of K in the soil, leaching and excessive liming.
Mg	Old	Yellowish spots between the veins, wizened lamina curling down. *Cause:* soils low in Mg, acidity and excessive potassium in fertilization.
Ca	Young	Death of apical sprout, interveinal chlorosis and necrosis. *Cause*: low Ca composition in the soil, excessive potassium in fertilization.
S	Young	Chlorotic, yellowish veins on the bottom side of the leaves. *Cause*: low soil S composition, low organic matter content.
Cu	Old	Large and wide leaves, dark green in color and partially shrivelled, thickening of the veins on the upper side, curved downwards. *Cause*: low soil Cu composition, excessive liming and high levels of organic matter.
Mo	Old	Interveinal chlorosis. *Cause*: acidity, excessive sulphate.
B	Young	Plants atrophied, necrosis of the terminal sprout. Smaller and shrivelled leaves with waves along the edges. *Cause*: low soil B composition, low organic matter content, excessive acidity, leaching.
Fe	Young	Interveinal chlorosis. *Cause*: Excessive liming, elevated organic matter content, low soil Fe composition and elevated moisture.
Mn	Young	Chlorotic spots between the veins. *Cause*: excessive liming, elevated organic matter content, low soil Mn composition.
Zn	Young	Small leaves, gaunt and pointed lobes, milky white spots with yellow edges *Cause*: low soil Zn composition, excessive liming and phosphatized fertilization.

Source: Borges and Lima, 1998.

For passion-fruit it is recommended to sample the 4th leaf from non-shaded and non-pruned branch apices, taking four leaves per plant, from both sides, including the leaf stem. In the first year, samples should be taken between the 8th and 9th months and, in the following years, during the flowering period. Adequate ranges of macro- and micro-nutrient compositions are given in Table 9.3.

Table 9.3. Adequate ranges of macro- and micro-nutrients in passion-fruit leaves.

Nutrient	Concentration
Macro-nutrient	---------- g/kg ----------
N	47.5-52.5
P	2.5-3.5
K	20.0-25.0
Ca	5.0-15.0
Mg	2.5-3.5
S	2.0-4.0
Micro-nutrient	---------- mg/kg --------
B	2.0-4.0
Cu	5.20
Fe	100-200
Mn	50-200
Zn	45-80

Source: IFA, 1992.

9.5. Fertilization

9.5.1. Inorganic fertilizer

Fertilization consists of supplying nutrients in quantities sufficient for the plant to be able to reach its production potential. Fertilization aims to increase both productivity and quality, without compromising the fertility of the soil, especially in irrigated areas, keeping in mind that fertilization can degrade soil. Any fertilization programme should take into account the fertilizer to be used, the quantity, the time of year and the location of application relative to the plant. Thus, there is no single formula that would be the best for all conditions. It is important that, for each plant, one takes into account soil fertility, evaluated by soil analysis, and the expected productivity (Table 9.4). Amounts of fertilizer used during early growth of the plant are, to a certain extent, comparable amongst the different regions of Brazil.

Fertilizer recommendations are related to soil analytical data and the potential productivity of the site and the phenological phase of the plant.

9.5.2. Organic manures

Using organic manures helps to maintain the soil's productivity, because it has beneficial effects on the physical, chemical and biological properties of the soil. The materials to be applied in the planting holes, especially in sandy soils and those of low fertility, depend on their availability. The quantities vary according to the nutrient composition of the materials available and may be corral manure (20 to 30 L), chicken manure (5 to 10 L), castor bean debris (2 to 4 L) and compost, amongst others. However, it is recommended to give preference to bovine manure, due to the greater amount that is available (Borges *et al.*, 2002).

9.5.3. Fertilization with micro-nutrients

In the absence of soil analytical data apply 50 g of F.T.E. BR-12 in the planting hole. Zinc and B are the micro-nutrients taken up in largest amounts by the plant, followed by Mn and Fe. With Zn deficiency, apply 20 g of zinc sulphate ($ZnSO_4.H_2O$) per plant, and of B, apply 6.5 g of boric acid (H_3BO_3) per plant. Boron and zinc recommendations for the yellow passion-fruit are given in Table 9.5.

9.5.4. Splitting fertilization applications

Deciding whether to split fertilizer application depends on the texture and the CEC of the soil, as well as the pattern of rainfall. In sandy soils and those with a low CEC, fertilizers should be applied weekly or biweekly. In more clayey soils, fertilizers can be applied monthly or bimonthly, especially when applied to the soil. With fertigation nutrients can be applied weekly or biweekly, depending on soil texture (Borges *et al.*, 2002).

9.5.5. Fertilization position

Passion-fruit has a shallow superficial root system, i.e. about 60% of the roots are found in the upper 30 cm of soil, and 87% between 0 and 45 cm from the base of the stem. In young orchards, fertilizers should be distributed in a 20 cm wide area around and 10 cm from the trunk, gradually increasing this distance with the age of the plants (Fig. 9.1 A and 9.1 B). In mature vines it is recommended to apply fertilizer in a band 2 m long and 1 m wide, on both sides of the plants and 20 to 30 cm from the trunk (Borges *et al.*, 2002).

Table 9.4. Fertilization recommendation in the plantation, formation and production phases of the irrigated yellow passion-fruit.

	N	P-resin (mg/dm^3)			K-soil ($cmol_c/dm^3$)				
		0-15	16-40	>40	0-0.07	0.08-0.15	0.16-0.30	0.31-0.50	>0.50
	kg/ha	--------------------- P_2O_5 (kg/ha) ---------------------			---------------------- K_2O (kg/ha) -----------------------				
At planting	150[1]	120	80	0	0	0	0	0	0
During growth									
Days after planting									
30	10	0	0	0	20	10	0	0	0
60	20	0	0	0	30	20	10	0	0
90	30	0	0	0	40	30	20	10	0
120-180	40	0	0	0	60	40	30	20	0
During fruit production									
Expected yield (mt/ha)									
<15	50	50	30	20	100	90	70	50	0
15-25	70	90	60	40	160	120	90	70	0
25-35	90	120	80	50	200	160	120	80	0
>35	120	150	100	60	250	200	150	100	0

[1] In the form of bovine manure.

Source: Borges *et al.*, 2002.

Table 9.5. Boron (B) and zinc (Zn) recommendation for the irrigated yellow passion-fruit.

Nutrient	Soil composition (mg/dm^3)	Classes of fertility	Nutrient dose (kg/ha)
	Hot water		
B	<0.2	Low	2
	0.21-0.6	Medium	1.0
	>0.6	High	0
	DTPA		
Zn	<0.5	Low	6
	0.6-1.2	Medium	3
	>1.2	High	0

Source: Borges *et al*., 2002.

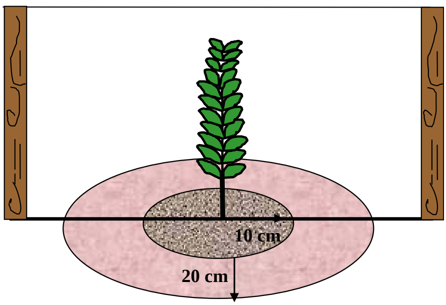

Fig. 9.1 A. Localization of fertilizers in young passion-fruit plants.

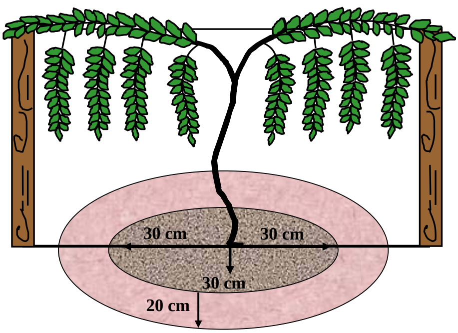

Fig. 9.1 B. Localization of fertilizers in adult passion-fruit plants.

Source: Borges, A.L., unpublished.

9.6. Irrigation

The soil water level influences passion-fruit flowering (Vasconcelos, 1994). A lack of moisture results in loss of leaves and fruits, especially at the start of their development, and this affects the production and quality of the fruits (Manica, 1981; Ruggiero *et al.,* 1996).

9.6.1. Irrigation method

The method most frequently used is localized irrigation, using drip and spray systems. Spraying promotes a greater wetted area of soil compared to dripping, thus permitting greater volume of root system expansion. The drip irrigation system has been more widely adopted by farmers because it provides moisture and aeration conditions that favor the development and productivity of the plants. Drip irrigation has the advantage of not contributing to the formation of a humid transitory microclimate within the culture orchard, thus helps to decreases the risk of diseases (Oliveira *et al.*, 2002).

9.6.2. Water requirements

Rainfall in the range of 800 to 1,750 mm, regularly distributed throughout the year, is ideal for passion-fruit. Productivity of around 40 mt/ha, has been obtained with a total water supply (rain + irrigation) of 1,300 to 1,470 mm, where 826 mm came from rain (Martins *et al.*, 1998, cited by Oliveira *et al.*, 2002). In areas where the rains are insufficient or poorly distributed, irrigation is essential, not only to increase productivity, but also to improve the quality of the fruit, via continuous and uniform production (Oliveira *et al.*, 2002).

9.6.3. Fertigation

The application of fertilizers via irrigation water results a more rational use of fertilizers in irrigated agriculture, because there is an increase in its efficiency, and a reduction in labour and energy costs. In addition, it allows flexibility in the time of nutrient application, which may be divided according to the needs of the crop in its various stages of development. Drip irrigation is the most appropriate for fertigation, because nutrients are applied directly to the zone of greatest concentration of active roots.

Nitrogen is the nutrient usually applied via irrigation, because it has a high mobility in the soil, especially in the form of nitrate (NO_3^-), but care must be taken not to favor loss by leaching. In fertigation, N is applied accordingly to the demand of the plant to reduce losses, especially in sandy soils. Because it is so mobile in soil, N should be applied frequently at three to seven day intervals, except in sandy soils when the interval should be around three days. The recommended quantity should be distributed throughout the period between the first four months of growths, corresponding to the formation phase of the plant and the beginning of the production phase (first year). Solid N fertilizers are available in four forms: ammoniacal (ammonium sulphate), nitric (calcium nitrate), ammoniacal-nitric (ammonium nitrate) and amide (urea), all being soluble in water and adequate for fertigation, including drip irrigation. In general, these N sources behave similarly and can be applied with other nutrients. Their different effect on the soil pH has to be considered (Borges and Sousa, 2002).

In general, P is not often applied with irrigation due to the low solubility of most P fertilizers and their facility of precipitate, causing blockage of the lines and emitters. Phosphoric acid, apart from a risk of corrosion in metallic lines and connections, does not cause problems of emitter blockage, and is applied via irrigation water to promote cleaning of the lines and emitters in fertigation systems. Apart from this, diammonium phosphate (DAP) and monoammonium phosphate (MAP) can be used in fertigation (Borges and Sousa, 2002).

Like N, the application of K via irrigation water is viable, because K fertilizers are soluble. When using split applications, it is important to consider its potential loss by leaching in very sandy soils and its adsorption by clay minerals in heavy soils. Potassium fertilizers normally used in fertigation are potassium chloride, potassium sulphate, potassium nitrate and potassium and magnesium sulphate. The application of K with irrigation may be done every six or seven days and it is recommended to continue the distribution throughout the growth of the plant. Starting from the second year, the recommended quantity of K_2O for the production period may be divided between the 5th and the 12th month after the seedlings have been transplanted (Borges and Sousa, 2002).

Drip irrigation emitters are usually placed at two emitters per plant at a distance of 60 cm between them and each one placed 30 cm from the stem (Borges *et al.*, 2002).

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10. Pineapple

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Domingo Haroldo Reinhardt[1]

10.1. Introduction

Pineapple is one of the tropical fruits in greatest demand on the international market, with world production in 2004 of 16.1 million mt. Of this total, Asia produces 51% (8.2 million mt), with Thailand (12%) and the Philippines (11%) the two most productive countries. America and Africa contribute 32% and 16% of world production, respectively, with Brazil (9%) and Nigeria (6%) also being major producers (FAO, 2006). A major part of world production is processed as canned products and juices, and about 25% goes to the fresh fruit market (Souza *et al*., 1999). In Brazil, pineapple is grown in most states and there has been a significant increase in production in recent years.

10.2. Climate, soil and plant

10.2.1. Climate

The pineapple, a tropical plant, grows best and produces better quality fruit at temperatures ranging from 22 to 32ºC and with a daily amplitude of 8 to 14ºC. In temperatures above 32ºC the plant grows less well and if associated with high solar radiation can burn the fruit during the maturation phase. Temperatures below 20ºC also result in diminished growth and favor the occurrence of premature flowering, which increases management problems and the loss of fruits (Bartholomew *et al*., 2003). The plant is severely damaged by frost, but tolerates periods of low temperatures provided they are above 0ºC.

The plant grows best when annual exposure to the sun ranges from about 2,500 to 3,000 h, or 7 to 8 h of sunlight per day. There is a minimum demand of 1,200 to 1,500 h of sun. Shading affects the development of the plant, and this needs to be considered when choosing a site for its cultivation as a monocrop or in association with other crops (Reinhardt, 2001).

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Although cultivation at altitudes not exceeding 400 m is recommended, there are many production areas at higher altitudes. At higher altitudes, temperatures are lower and solar radiation less, and this in turn results in slower growth, a longer cycle and the production of smaller, more acidic fruit (Aubert *et al.*, 1973; Py *et al.*, 1987).

As pineapple is a short day plant (Van Overbeek, 1946; Gowing, 1961; Bartholomew *et al.*, 2003), natural flowering in the southern hemisphere occurs, for the most part, from June to August, when the days are shorter and night time temperatures are lower. Decreased sunlight due to clouds and water stress may sometimes trigger natural flower differentiation in other seasons, for example in autumn (April and May) and spring (October and November). Natural flowering occurs earlier in more developed plants and there are varietal differences, the cultivar 'Pérola' flowering earlier than 'Smooth Cayenne'.

Pineapple has a lower water requirement than the vast majority of cultivated plants. It has a series of morphological and physical characteristics typical of xerophile plants. It has the capacity to store water in the hypoderm of the leaves, to collect water efficiently, including dew, in its trough-shaped leaves, and to considerably reduce water loss (reduced transpiration) by several mechanisms.

Despite these adaptations to dry conditions, the greatest yields and the best quality fruits are obtained when the crop is well supplied with water. Well-distributed rainfall of 1,200 to 1,500 mm annually is adequate for the crop. In regions of prolonged drought, irrigation has often become indispensable. The pineapple's demand for water varies from 1.3 to 5.0 mm/day, depending on its state of development and on soil moisture. A commercial pineapple crop generally requires a quantity of water equivalent to a monthly precipitation of 60 to 150 mm (Almeida, 2001).

Relative air humidity averaging 70% or higher is optimal, but the plant can tolerate moderate variations. Periods of very low relative humidity (less than 50%) can cause fruit-splitting and cracking during the maturation phase. The low physical profile of the plant and the high planting densities used, reduce the crop's susceptibility to damage caused by strong winds. Hail can cause damage, but generally less than in other crops, because of the high fiber content and strength of the leaves.

10.2.2. Soil

Pineapple is very sensitive to saturation of the soil with water, which affects its growth and production. Consequently, good drainage and concomitant good aeration are basic requirements because they favor root development and reduce the risk of plant loss from fungal pathogens of the genus *Phytophthora*. The water table should be not less than 80 – 90 cm from the soil surface.

It is considered that an effective soil depth of between 80 and 100 cm will be adequate for growing pineapple because the roots tend to be concentrated in the top 15 to 20 cm of soil. However, within the effective soil depth, soil texture changes and/or abrupt increases in soil density inhibit root growth and prevent the roots growing deeper (Pinon, 1978; Py *et al*., 1987).

Soils of an intermediate texture (15-35% clay and more than 15% sand), without obstacles to the free drainage of excess water, are recommended most for this crop. Soils with a sandy texture (up to 15% clay and more than 70% sand), which generally have no drainage problems, are also recommended, but almost always, the incorporation of organic residues and manures is needed to increase their water-holding capacity and the retention of nutrients.

Clayey soils (more than 35% clay) that have good drainage, like many Oxisols, may also be recommended for pineapple plantations. On the other hand, silt soils (less than 35% clay and 15% sand) should be avoided. The large silt content causes undesirable soil structure characteristics, which affect aeration and drainage, and may negatively influence plant establishment and development (Pinon, 1978).

Land that is flat or has a slope not exceeding 5% is preferred because, in addition to facilitating mechanized cultural practices, the soil is less susceptible to erosion. Erosion can be a serious problem because the pineapple has a shallow root system and for a large part of the crop cycle there is little or no vegetative covering on the soil. Preventing soil erosion justifies considerable attention on the part of the grower. The utilization of more sloping land requires the adoption of conservation practices, like planting along contour lines.

Pineapple is well adapted to growing on acidic soils, a pH of 4.5 to 5.5 is recommended with slight variations depending on the variety grown (Bartholomew and Kadzimin, 1977; Pinon, 1978; Py *et al*., 1987). The plant tolerates a high exchangeable aluminum and manganese content in the soil, a condition favored on highly acidic soils. (Souza *et al*., 1986; Malézieux and Bartholomew, 2003).

An adequate ratio of exchangeable Ca/Mg should be close to 1.0 and even lower (Boyer, 1978). This means that the Mg content should be at least the same as that of Ca if not larger. This ratio is smaller than that recommended for other tropical species.

For many tropical and subtropical crops the optimal values for the ratio of exchangeable K/Mg in the soil are between 0.25 and 0.33 (Boyer, 1978). Py *et al*. (1987) stated that the ratio should not be greater than 1.0 i.e. K larger than Mg, because of the antagonism between these nutrients in root uptake. A decrease in the concentrations of Ca and Mg was observed in the 'D' leaf of cultivar ‘Pérola’ when given increasing amounts of K, indicating competition for uptake by these nutrients (Souza *et al*., 2002).

10.2.3. Plant

The pineapple (*Ananas comosus* L., Merrill) is a tropical plant, a monocotyledon and a herbaceous perennial, of the family Bromeliaceae, with about 50 genera and 2,000 known species. In addition to the fruit as a food, many species are grown for their leaf fibre from which bagging material is produced, and other species are grown as ornamentals (Collins, 1960; Cunha and Cabral, 1999).

The plant has a short, thick stem around which grow narrow, rigid trough-shaped leaves, and from which auxiliary roots develop. The root system is superficial and fibrous and generally grows no deeper than 30 cm and is rarely more than 60 cm from the soil surface. Adult plants of the commercial varieties measure 0.80 m to 1.20 m in height and 1.00 to 1.50 m in diameter (Kraus, 1948a; Coppens d’Eeckenbrugge and Leal, 2003).

The leaves are classified, according to their shape and their position on the plant, as A, B, C, D, E, F, from the oldest on the outside, to the youngest towards the centre (Fig. 10.1) (Krauss, 1948b, Py *et al*., 1987). The ‘D’ leaf, the youngest amongst the adult leaves and the most physiologically active, is used to evaluate the growth and nutritional state of the plant. It is the tallest leaf and grows at 45º to the soil surface and it presents its lower borders perpendicular to the base. The D leaf can be easily separated from the plant.

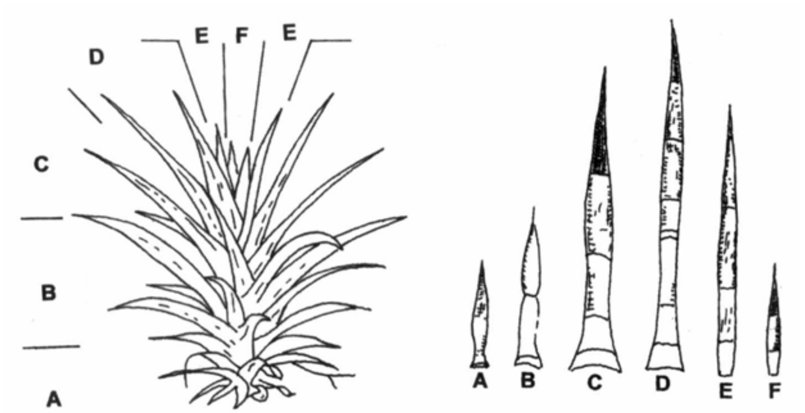

Fig. 10.1. Distribution of the pineapple plant leaves, according to age (A - oldest; F – youngest). (Py, 1969; Malavolta, 1982).

Inserted into the stem is the peduncle which supports the flowers and, later on, the sorosis type fruit (Okimoto, 1948). Plantlets develop from auxiliary buds located in the stem (suckers) and the peduncle (slips), which are most used as planting material (Reinhardt, 1998).

Pineapples can be grown once (a single cycle) or in one or more additional ratoon cycles. The cycles vary in duration, depending on the climatic conditions, the vigour of the plant material and the management of the cultivar. For example, and typical of pineapple cultivation worldwide, in the Brazilian Tropical Region, the first cycle lasts 14 to 18 months, whereas the ratoon cycles are shorter, often lasting only about 12 to 14 months (Reinhardt, 2000).

10.3. Soil and culture management

10.3.1. Soil preparation and liming

Careful preparation of the soil is important to guarantee good root development especially into the deeper soil layers. In virgin land, it is necessary to remove the vegetation by means of logging, removal of shrubs and branches, slashing and burning, followed by plowing and harrowing the soil in both directions to a minimum depth of 30 cm. In areas that have already been cultivated and there is no vegetation to remove it is only necessary to cultivate the soil as already described. Where pineapple has been grown previously it is essential to remove all crop residues, preferably by incorporating them into the soil, after partial decomposition. This helps to improve the physical and biological condition of the soil, because more than 50 mt/ha biomass will be incorporated into the soil.

Despite the recognition that pineapple is well adapted to growing on acidic soils, there are situations in which liming is necessary, principally when soil calcium and magnesium levels are low. Soil should be analysed to decide if it is necessary to apply limestone. The amount of lime applied should be such as to raise the soil to pH 4.5 to 5.5. Higher values can limit the availability of micro-nutrients (zinc, copper, iron and manganese) and favor the development of harmful microorganisms, like fungi of the genus *Phytophthora*, especially under wet conditions. If lime is required it should be applied 30 to 90 days prior to planting and incorporated by the plowing and/or harrowing used for soil preparation. It is preferable to use calcareous dolomite, because of the pineapple's requirement for magnesium.

10.3.2. Planting and weed control

The pineapple is planted into pits or shallow furrows to a depth not greater than one third the length of the plant, taking care to not let soil fall into the "eye" (leaf rosette) of the plant. Planting should be done in squares, the distance between plants depending on their type and size, to facilitate subsequent management (Cunha, 1999).

Planting densities vary according to the cultivar, product destination, level of mechanization, use of irrigation and other factors. High planting densities favor greater productivity, lower densities generally permit the production of a higher percentage of large fruits, which get higher prices in the market for fresh fruits. In Brazil the plant densities vary, in general, from 25 to 50 thousand/ha. Densities from 30 to 40 thousand/ha are more common, aiming to maintain a balance between fruit size and productivity. In other countries, where the "Smooth Cayenne" variety or its hybrids are grown, the densities can reach 86,000 plants/ha (Hepton, 2003), especially when the fruit is destined for canned fruit slices.

The plantation can be set up in a single or double row system. In Brazil the following spacings predominant: a) simple rows: 1.00 x 0.30 m (33,333 plants/ha), 0.90 x 0.30 m (37,030 plants/ha) and 0.80 x 0.30 m (41,660 plants/ha); b) double rows: 1.20 x 0.50 x 0.40 m (29,411 plants/ha), 1.00 x 0.40 x 0.40 m (35,714 plants/ha), 1.00 x 0.40 x 0.35 m (40,816 plants/ha), 1.00 x 0.40 x 0.30 (47,619 plants/ha) (Reinhardt, 2001).

For crops without irrigation, planting is usually at the end of the dry season and the beginning of the rainy season. Depending on the availability of planting material and local knowledge, planting can be done at other periods so that fruit production occurs when market conditions are more favorable. Irrigation makes it possible to plant and produce fruit during the whole year.

Because pineapple grows slowly and has a superficial root system, weed competition is very harmful especially when it occurs between planting and flower differentiation during the first five to six months after planting. In this period, the crop should be kept clean, but in the fruit formation phase the presence of weeds has practically no negative effect on production (Reinhardt and Cunha, 1984). Weed control is done in various ways, the most common ones being manual weeding and application of herbicides. Depending on climatic conditions and soil fertility, it may be necessary to weed manually up to twelve times during the crop cycle. During the initial establishment of the crop, it is possible to cut the weeds using cultivators pulled by animals. Another alternative, still little employed, is soil surface mulching. Depending on what is available on the farm or in the region, the dry straw of maize, beans and grasses, as well as pineapple plant residues and leaves, should be uniformly distributed over the soil surface, especially along the plant rows. In countries with high labor costs mechanical methods are used as is covering the soil between the rows with black polyethylene film (Reinhardt *et al.*, 1981). Weed control with herbicides is a good alternative to reduce the demand on manual labor, especially on large plantations and in rainy periods when weeds grow rapidly.

The most used herbicides belong to the uracil group (diuron, bromacil) while the triazines (ametryn, simazyn, atrazyn), are recommended for pre-emergence or early post-emergence application (Broadley *et al.*, 1993; Reinhardt, 2000).

10.3.3. Irrigation

Irrigation systems are usually drip and jets, and overhead sprinkle irrigation. Drip irrigation is used where the availability of water is limited, the cost of manual labor is high and cultivation techniques are advanced. In Hawaii, the drip irrigation system is commonly used along with polyethylene film to cover the soil along the planted rows in order to reduce evaporation. This system is generally characterized by high cost, because the density of plants requires a drip line for each double row of plants (Almeida, 2001).

Jet sprayers have the same efficiency and offers better opportunities for adaption to the crop than does drip irrigation, however it requires elevation of the emitter assembly to increase the effective area sprayed. As for drip irrigation, filtration of the water is not necessary.

Overhead spray irrigation is perhaps the best system considering the cup shape and the leaf arrangement on the plant. This facilitates the collection of water and its absorption is increased by the presence of external roots in the axil of the leaves. The systems most used are conventional spray, lateral row self-propelled, with linear (lateral boom) or radial movement (central pivot), self-propelled sprayers (with or without traction cables) and direct mounting (Almeida and Reinhardt, 1999).

In managing irrigation, especially in estimating the number and frequency of applications, it is necessary to consider the decrease in the effective rooting depth of the soil. In addition, it is important to use crop coefficients that reflect the various stages in the plant's growth. Initially growth is slow with a small ground cover and a coefficient of 0.4 to 0.6 should be used. This followed by a period of accelerated growth until about 70 to 80% of the ground surface is covered and the coefficients increase until they reach 1.0 to 1.2. With the maintenance of the ground cover and water demand until the start of the fruit's maturation phase, coefficients of 1.0 to 1.2 are used. Finally, in the final fruit maturation phase the water supply is reduced (decreasing coefficients from 1.0/1.2 to 0.4/0.6) with the aim of accumulating solutes and the quality of the fruit (Almeida and Reinhardt, 1999; Almeida, 2001).

10.3.4. Control of flowering

Flowering and harvest can be anticipated and coordinated by the application of growth regulators. Harvest should be planned to occur at the best time for selling and to avoid the concentration of on-farm operations (Cunha and Reinhardt, 1999).

Flowering can be induced by a number of compounds, the most common are calcium carbide and 2-chloroethylphosphonic acid (ethephon). Calcium carbide can be applied in granular or liquid form. As granules, 0.5 to 1.0 g/plant are put into the center of the leaf rosette during a wet or rainy period. In the presence of water, acetylene is produced from the calcium carbide and this initiates flowering. The liquid form can be used in dry season, the calcium carbide is diluted in water (4 to 5 g/L), in a tightly closed container, applying about 50 ml of solution to the center of each leaf rosette (Reinhardt *et al.*, 2001).

Ethephon is a liquid that releases the gas ethylene, the primary hormone responsible for flower differentiation in the pineapple. Ethephon can be applied in the center of the rosette or sprayed over the whole plant, using 50 ml/plant of a solution prepared with 0.5 to 2 ml/L water of the commercial product Ethrel (24% active ingredient) or a similar product. The increase in the pH of the solution, which is very low (3.0 to 3.5), due to the addition of calcium hydroxide (0.35 g/L), increases the release of ethylene. A 1 to 2% aqueous solution of urea stimulates the penetration of ethylene into the plant's tissues (Cunha, 1999).

The floral induction treatment is more effective if done at night or during cooler periods of the day (e.g. early morning or the end of the afternoon), preferably on cloudy days. This is because at these times the leaf stomata are open, increasing the absorption of the chemical.

Floral induction should only be performed on strong and well-developed plants, capable of producing fruits of appropriate size for sale and/or plantlets for use in new plantings. Fruit weight is directly related to plant vigor at the time of floral differentiation, although it also depends on the climatic conditions during its development. In the 'Pérola' variety, it is recommended to induce flowering in plants that have 'D' leaves with a minimum fresh weight of 80 g and a minimum length of 1.0 m, in order to get fruits weighing more than 1.5 kg (Reinhardt *et al.*, 1987).

10.4. Mineral nutrition

10.4.1. Uptake and export of nutrients

The pineapple has a large demand for plant nutrients and the amounts required often exceed those which the majority of cultivated soils can supply. For this reason, fertilization is almost mandatory where the fruit is destined for sale. Table 10.1 summarizes data from diverse authors concerning the quantity of macro-nutrients extracted from the soil by the pineapple plant.

The data in Table 10.1 indicate the following decreasing order of uptake. For macro-nutrients: K>N>Ca>Mg>S>P. The amounts, per hectare, are on average, 178 kg N, 21 kg P (48 kg P_2O_5) and 445 kg K (536 kg K_2O), with an average extraction ratio of 1.0:0.12:2.5, for N:P:K and 1.0:0.27:3.0, for $N:P_2O_5:K_2O$.

Table 10.1. Extraction of macro-nutrients by the pineapple crop (kg/ha, according to various authors).

Source	N	P	K	Ca	Mg	S
	------------------------- kg/ha -------------------------					
Stewart, Thomas & Horner	67	8	198			
Kraus	350	53	939	175		
Follett-Smith & Bourne	107	38	346	81	45	
Boname	83	12	363			
Cowie	123	15	256			
Choudhury	308	30	730			
Menon & Pandalai	139	20	243			
Menon & Pandalai	110	13	229			
Menon & Pandalai	74	30	325			
Hiroce *et al*.	355	32	509	236	115	40
França	106	10	243			
França	60	8	151			
Paula *et al*.	315	14	1,257	252	157	17
Paula *et al*.	300	14	444	161	33	35

Source: Teiwes and Gruneberg, 1963; França, 1976; Hiroce, 1982; Paula *et al*., 1985.

Table 10.2 summarizes some data referring to the extraction/accumulation of micro-nutrients by pineapple, which indicates the following decreasing order of uptake: Mn>Fe>Zn>B>Cu>Mo.

Nutrient off take is mainly in the fruits. Py *et al*. (1987) estimated the following quantities of nutrients are removed per tonne of fruit: 0.75 to 0.80 kg N, 0.15 kg P_2O_5, 2.00 to 2.60 kg K_2O, 0.15 to 0.20 kg CaO and 0.13 to 0.18 kg MgO. Based on these numbers, a harvest of 40 tons of fruit/ha results in the following export of nutrients per ha: 30 to 32 kg N, 6 kg P_2O_5/ha, 80 to 104 kg K_2O, 6 to 8 kg CaO and 5.2 to 7.2 MgO kg.

Table 10.2. Accumulation of micro-nutrients by the pineapple plant (g/ha, according to various authors).

Source	Zn	Cu	B	Fe	Mn	Mo	Observations
	----------------------- g/ha -----------------------						
Hiroce *et al.* (1977)	404	191	311	5,095	2,456	5	50,000 plants/ha, cv. S.Cayenne
Paula *et al*. (1985)	337	169	267	4,020	7,308		50,000 plants, cv. Pérola
Paula *et al*. (1985)	225	197	–	4,793	6,351		50,000 plants, cv. S. Cayenne

Nutrients are also exported in propagating material (crowns, slips and suckers) destined for planting in another area, and, less frequently, in plant residues removed from the field and used for other purposes like animal feeding.

10.4.2. Functions and importance of macro-nutrients

Nitrogen (N): Nitrogen, is required second after potassium by pineapple. Nitrogen mostly determines the productivity of the plant. The absence of N in either organic or mineral form, almost always results in compromised development and/or productivity of the plant, with the appearance of typical symptoms of N deficiency.

Deficiency symptoms (Plate 10.1) are characterized by greenish-yellow to yellow foliage, small and narrow leaves, a weak plant with slow growth, small and colorful fruit with a small crown and the absence of plantlets. Such symptoms are common on soils poor in organic matter, without fertilization and under hot and sunny conditions (Py *et al*., 1987).

In respect of fruit quality, studies conducted in several countries have shown reductions in juice acidity as the amount of N applied increases. Teisson *et al*. (1979), besides referring to the reduction of juice acidity with increases in N supply, also observed a decrease in juice ascorbic acid, and as a result an increase in internal darkening of the fruit. This symptom is often seen in long cycle crops.

Increasing levels of N can result either in a reduction of the Brix value or no significant changes in fruit sugar content. An excess of N also contributes to a reduction in fruit pulp firmness and an increase in translucency and, in hot periods, can also increase the risk of the appearance of a symptom known as "jaune" (ripening of the pulp, while the skin of the fruit remains green), according to Py *et al*. (1987).

The most common sources for N for the pineapple crop are urea and ammonium sulfate. Other sources of N, such as potassium nitrate and ammonium nitrate, as well as organic fertilizers (animal manure, plant cakes, compost and others) can also be used depending on their economic viability.

Phosphorus (P): Although there is a relatively small demand for P (the macronutrient accumulated in the smallest quantity) increases in productivity have been observed, in Brazil as well as in other countries (Malaysia, Guadeloupe and India, for example). This is certainly due to the low availability of P in most soils growing this crop.

According to Py *et al*. (1987), the symptoms of P deficiency include dark, bluish-green foliage, which is more pronounced in the presence of excess N, and leaves that completely dry out at the tips, starting from the older ones. The old leaves have dry, brownish-red tips and brown transverse striations and the borders of these leaves turn yellow from the tips. Plants suffering from P deficiency also have more erect, long and narrow leaves and roots with longer, more colored and less ramified hairs; the fruit is small and reddish in color. Such symptoms rarely occur, but they may appear more or less temporarily, especially in periods of drought, in poor soils or where the deeper soil horizons were exposed during soil preparation.

Malézieux and Bartholomew (2003) pointed out that P deficiency causes a reduction in the growth of all parts of the plant. They called attention to the fact that visual deficiency symptoms are often not seen and are not very specific, and hence could be mistaken for symptoms resulting from damage to the root system caused by water deficiency, nematodes or pests. Little importance has been given to P nutrition in relation to the quality characteristics of the fruit.

The main sources of P are fertilizers soluble in water, such as triple superphosphate (TSP), monoammonium phosphate (MAP), diammonium phosphate (DAP) and single superphosphate (SSP). The latter contains also sulfur (10-12% S). Magnesium thermophosphates (17% P_2O_5) have also been used as sources of P and magnesium (9% Mg).

Potassium (K): Potassium, the nutrient that accumulates in the largest amount in the plant, also influences productivity, although to a lesser extent than that of N. The large demand for K often results in the symptoms of K deficiency, especially in soils with low K availability.

Such deficiency symptoms (Plate 10.2) are mainly characterized by leaves with small yellow spots, which increase in size, multiply and coalesce around the leaf borders, which dry out. The plant has a more erect stature, a weak fruit peduncle, small fruit with low acidity and less aroma. These symptoms are common except in soils rich in K. The symptoms are favored by unbalanced fertilization, especially with N, strong solar irradiation, intensive soil lixivation and soils with high pH, rich in Ca and Mg (Py *et al*., 1987).

Potassium has a significant effect on fruit quality. Experimental studies have shown that increasing the amount of K increases the acidity of the pulp and/or sugar content, improves aroma, increases peduncle diameter (contributing to reduced fruit drop) and improves pulp firmness. Teisson *et al*. (1979) ascribed the benefit of increasing amounts of K to an increase in ascorbic acid in the fruit pulp and, in consequence contributing to a reduction of internal fruit darkening.

Potassium can be applied as KCl, potassium sulfate (K_2SO_4), potassium and magnesium bisulfate (20% K_2O) and potassium nitrate (44% KNO_3).

Calcium (Ca): Py *et al*. (1987) described the following symptoms of Ca deficiency in the pineapple plant: very small, short, narrow and breakable leaves and very short internode spacing. In a controlled environment Ca deficiency led to the death of the apex, with the development of lateral shoots, which have similar symptoms. Calcium deficiency occurs rarely, except in very poor soils.

Calcareous rocks are the most common sources of calcium. When raising soil pH is not required, agricultural gypsum (17 to 20% Ca) as well as single superphosphate (18 to 20% Ca) are good options. Calcium nitrate (17 to 20% Ca) can also be considered, when applied in liquid form (Souza, 2004).

Magnesium (Mg): Plants with Mg deficiency have yellow old leaves, except where shaded by younger leaves when they stay green (Plate 10.3); yellow spots which turn brown in a controlled environment; drying of older leaves, which have not finished growing before the deficiency appears; fruits without acidity, low in sugar content and without any flavor. Such deficiencies are very common on soils low in Mg, especially when intensely fertilized with K under conditions of high solar irradiation (Py *et al*., 1987).

Calcareous dolomites are, in principle, the source of Mg for the pineapple crop. When deficiency symptoms appear after the application of calcareous materials, or after the establishment of the crop, magnesium sulfate is an alternative for supplying Mg. This product can be applied in solid or liquid (spray) form, but its compatibility with other minerals should be verified, if mixtures are used. For foliar sprays the concentration of magnesium sulfate in the solutions can vary between 0.5% and 2.5%. Magnesium thermophosphates (around 9% Mg), used as a source of P also supply Mg.

Sulfur (S): Py *et al*. (1987) described the following symptoms associated with a deficiency of sulfur: pale yellow to gold colored foliage; pinkish leaf borders, especially on older leaves; normal plant stature; very small fruit. However, both Py *et al*. (1987), as well as Malézieux and Bartholomew (2003) considered the occurrence of such symptoms very rare in pineapples. Sulfur supply is normally done by fertilizers that are at the same time sources of some of the primary macro-nutrients, like ammonium sulfate (23 to 24% S), potassium sulfate (17 to 18% S) and single superphosphate (10 to 12% S). In selecting which fertilizer to use, it is important to be certain of the amount of S they contain. This is especially so where the crop is intensely cultivated and on soils poor in organic matter, in order to prevent possible S deficiency.

10.4.3. Functions and importance of micro-nutrients

According to Su (1975), the micro-nutrients that are most important for pineapples in many parts of the world, are iron (Fe), zinc (Zn), copper (Cu) and boron (B).

Normally, soils with little organic matter and available nutrients that have been exhausted by intensive cropping, or those with high pH (above 6.5) are likely to be also short of micro-nutrients and they require special attention in relation to micro-nutrients.

Py *et al.* (1987) described the following symptoms of micro-nutrient deficiency for pineapple.

Boron (B): A number of symptoms in different situations are attributed to boron. These include: orange and yellow discoloration, which becomes brown on only one side of the leaf; minimum leaf growth to two thirds of its normal length and with dry tips; a tendency for the leaf to curl, especially when grown hydroponically (Ivory Coast); chlorosis of the young leaves with reddening of the dead borders at the apex, especially when grown hydroponically (Malaysia); fruits with multiple crowns (Hawaii, Martinique); formation of a dead suberized tissue between fruitlets, at times accompanied by very small, spherical fruits (Australia, Martinique). These symptoms often appear on soils with a high pH, and when due to drought there is little B in the soil solution.

Copper (Cu): Light green narrow leaves with wavy borders, a pronounced U shape in cross-section and a small number of tricomes; leaf tips curved downward; old leaves with purple-red coloration at the fold; short roots with reduced hairs; stunted plant. These symptoms are relatively common, but their descriptions are often imprecise (Plate 10.4).

Iron (Fe): Development of chlorosis, starting in young leaves; the leaves are generally flaccid, wide, and yellow with a green ‘web’ of conductor veins. The old leaves are dry and when sprayed with large amounts of iron the leaves have green transverse lines. The fruit is red with a chlorotic crown. Symptoms can appear when large quantities of nitrate have been added. Iron deficiency can occur under a range of conditions, for example, on soil with high pH, soils rich in manganese (Mn/Fe = 2), compacted soils, areas of termite infestation and attack by pests both of which rapidly decrease root activity, drought, as well as other factors (Plate 10.5).

Manganese (Mn): The symptoms are not very well defined; the damaged leaves are marbled with light green areas, especially where the veins are situated, surrounding areas with a darker green color. Manganese deficiency is rare, but may occur on soils rich in Ca and with a high pH.

Molybdenum (Mo): Deficiency is likely in soils with pH <4, but there are few descriptions of the symptoms associated with Mo deficiency (Py *et al*., 1987; Malézieux and Bartholomew, 2003). An excess of nitrate in the fruit can affect the quality of canned pineapple products (Chairidchai, 2000; Chongpraditnun *et al*., 2000). As molybdenum is a component of the enzyme nitrate reductase, these authors studied the influence of applying Mo on the concentration of nitrate in the fruit. The concentration of Mo in the 'D' leaf was associated with a decrease in the nitrate in the fruit.

Zinc (Zn): In young plants, the center of the leaf rosette is closed, the young leaves are rigid, cracked and sometimes curved ("crook-neck"). In old plants, the basal leaves contain irregular veins, with the appearance of marble, and orange-yellow discoloration on the leaf borders and the tips are dry. Frequent attacks of the pest *Diaspis* result in these characteristic symptoms. Zinc deficiency tends to be rare, except in soils with high pH, due to excessive limestone applications, or where Ca and P have been poorly incorporated.

In conclusion, the following applications of micro-nutrients, in kg/ha, are recommended where deficiencies are seen. 1 to 5 kg Fe; 1 to 6 kg Zn; 1 to 10 kg Cu; 1 to 2.5 kg Mn; and 0.3 to 2 kg B. These micro-nutrients can be applied as solutions of their salts, e.g. $FeSO_4,7H_2O$ (20% Fe), $ZnSO_4.7H_2O$ (22% Zn), $CuSO_4.5H_2O$ (24% Cu), copper oxychlorate (35 to 50% Cu), $MnSO_4,4H_2O$ (25% Mn) and borax (11.3% B). These micro-nutrients can also be applied to the soil as solids, often as oxides and frits (synthesized silicates) of the respective elements. In the case of metallic micro-nutrients there is also the option of using their respective chelates, which can be applied as solids or liquids.

10.4.4. Evaluation of the nutritional status of the plant

The nutritional status of the plant can be done by analysis of the 'D' leaf (Fig. 10.1), as it is considered the one which best represents the nutritional state of the plant (see the section "The plant and its life cycle"). The "D" leaf is identified by gathering all the leaves in the hands to form a vertical "bundle" in the center of the plant. The "D" leaves are the longest ones. Leaf sampling can be done at any point in the vegetative cycle, i.e. from the fourth month after planting until the induction of flowering, at intervals of two to four months between samplings, although within ± 15 days of floral induction has been adopted as the best time for leaf sampling.

When sampling a commercial crop it is recommended to take at least 25 leaves, from each area of uniform crop, collecting one leaf per plant. The leaves should be pre-dried in the shade in a well-ventilated area before being cut into smaller pieces to send to the laboratory. For the analyses, the intermediate third of the non-chlorophyll portion (white) of the basal zone (Hawaiian technique) or the whole leaf (French technique) can be used. Table 10.3 summarizes information from different authors/institutions on the interpretation of the results of leaf analysis.

Table 10.3. Adequate concentrations of nutrients in the 'D' leaf of the pineapple plant, according to different authors/institutions.

Source	Dalldorf and Langenegger	IRFA	Pinon	Malavolta	Malavolta
Sample	--------------------- Whole "D" leaf ---------------------				Third middle part of the basal white portion of "D" leaf at 5 months
Timing	At the emergence of flowering	At the moment of flower induction	Along the cycle	At 4 months	
Nutrient					
Macro-nutrient	----------------------------------- g/kg -----------------------------------				
N	15-17	>12	13-15	15-17	20-22
P	±1.0	>0.8	1.3	2.3-2.5	2.1-2.3
K	22-30	>28	35	39-57	25-27
Ca	8 to 12	>1.0	1.4	5-7	3.5-4.0
Mg	±3.0	>1.8	1.8-2.5	1.8-2.0	4.0-4.5
Micro-nutrient	---------------------------------- mg/kg ----------------------------------				
Zn	±10			17-39	
Cu	±8			5-17	9-12
Mn	50-200			90-100	
Fe	100-200			600-1,000	
B	30				

Sources: Pinon, 1981; Malavolta, 1982; Lacoeuilhe, 1984.

10.5. Fertilization

The large nutrient demand of the pineapple means that fertilization is a common practice. Besides the nutritional requirements of the plant and the capacity of the soil to supply nutrients, specific recommendations for each area or producing region should take into account the following factors, which vary from region to region. These factors include the level of technology adopted and implemented, the destination and the value of the product and the cost of fertilizers. In spite of the variations that can occur because of these factors, in many pineapple producing countries, including Brazil, the recommendations per plant vary, in the majority of situations, from 6 to 10 g N, 1 to 4 g P_2O_5 and 4 to 15 g K_2O. However, decisions about the amount of each nutrient to apply that do not consider data from soil and/or plant analyses, could lead to gross errors that affect productivity, fruit quality and, consequently, economic returns. Souza *et al.* (2001) gave recommendations for an irrigated pineapple crop, based on results of soil analyses (Table 10.4).

Table 10.4. Fertilizer recommendations for an irrigated pineapple crop in semi-arid regions, results based on soil analysis.

	N	Soil phosphorus Mehlich (mg P/dm^3)			Soil potassium Mehlich (mg K/dm^3)			
		<5	6-10	11-15	<30	31-60	61-90	91-120
	kg/ha	------- P_2O_5 (kg/ha) ------			------------ K_2O (kg/ha) -------------			
After planting								
1st to 2nd month	60	120	80	40	90	75	60	45
4th to 5th month	80	-	-	-	120	100	80	60
6th to 7th month	90	-	-	-	135	110	90	75
8th to 9th month	90	-	-	-	135	115	90	60

Complementary information:

Planting densities: The recommended doses in the table presume there are planting densities of around 40,000 plants/ha (cv. Pérola). For densities of around 50,000 plants/ha, recommended for the cv. Smooth Cayenne, the doses should be increased by 25%.

Phosphate fertilization: If convenient for the producer, this could be done at the time of planting, in the pits or ridges.

Liquid fertilization: Having the option of fertilizing through liquids, to supply nitrogen and potassium, should be promoted a larger partitioning of the fertilizers (monthly or bi-weekly intervals). Liquid fertilization is also recommended for supplemental applications of magnesium and of micro-nutrients.

Induction of flowering: Ninth or tenth month after planting.

Source: Souza *et al.*, 2001.

10.5.1. Method of fertilizer application

Fertilizers can be applied either as solids or liquids. Applied as solids, fertilizers can be applied into the planting pits or furrows (the option most used for organic phosphate applications) or as a side dressing, the fertilizer being directed to the bases of the oldest leaves (the option most used for N and K fertilizers, but also used for water-soluble P fertilizers).

Application of solid fertilizers is done by hand, using simple tools like spoons. Irrespective of the method of application used, fertilizers should not be allowed to fall into the upper youngest leaves or into the "eye" of the plant, because of the damage they may cause. After the applying fertilizers to the soil surface, they should be covered with soil from the space between rows. This practice helps reduce the loss of nutrients and in fixing the plant in the soil.

Liquid fertilizers are applied to the leaves as a foliar spray. The architecture of the plant and the morphological and anatomical characteristics of its leaves favors foliar absorption of nutrients. This method of application, which is widely adopted by some producers, is frequently used to apply N, P, Mg and micro-nutrients, it is rarely used for the application of P. Foliar application is done using spray booms attached to backpacks or tractor mounted tanks.

Spraying should not be done in the hottest hours of the day to prevent leaf burning and excessive run-off and accumulation of solutions in the leaf axes should be avoided. Generally, the concentration of fertilizers in the solution should not exceed 10%, and in large plantations it is normal to spray at night. Another precaution that should be taken, when applying several fertilizers by foliar spray, is to verify the compatibility of the products being used.

Fertigation can be successful when used with overhead spray irrigation or with high frequency localized irrigation. Nitrogen is most often applied with irrigation, followed by K. Calcium, Mg, S and micro-nutrients may also be applied by fertigation. Fertigation with P is not common; P fertilizers are usually applied only once as a solid before planting. They are put in the planting pits or furrows, or as a soil cover, within 30 to 60 days after planting. There is, however, an option for applying P with the irrigation water, using diammonium phosphate (DAP, 45% P_2O_5), monoammonium phosphate (MAP, 48% P_2O_5) and phosphoric acid (40 or 52% P_2O_5).

Souza and Almeida (2002) presented two alternatives for applying N and K by fertigation. Either they can be applied at increasing amounts of N and K at equal intervals of time or in equal amounts of N and K at decreasing intervals of time. In these alternatives the total amount to be applied is given in 16 applications.

10.5.2. Timing of fertilization

Fertilization should be done during the vegetative phase of the plant's life cycle, i.e. from the planting until the induction of flowering. This is the period in which the plant uses the applied nutrients most efficiently. For crops grown without irrigation and when solid fertilizers are used, the timing of the application should take into account the distribution of the regional rains such that the application coincides with good soil moisture.

In general, applying nutrients during the reproductive phase of the plant is not recommended because there is usually little positive effect. However, there are special situations, as in the case of a malnourished plant at flower initiation, when the application of nutrients can result in positive effects on the weight and/or quality of the fruit. In these circumstances liquid fertilizers should be used until 60 days after induction of flowering.

10.6. References

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11. Soursop

(*Annona muricata* L.)

Alberto Carlos de Queiroz Pinto[1]

11.1. Introduction

Soursop (*Annona muricata* L.) is grown in many tropical countries, for example Angola, Brazil, Columbia, Costa Rica, Cuba, Jamaica, India, Mexico, Panama, Peru, Porto Rico and Venezuela (Pinto and Silva, 1994). The generic name *Annona* means "annual harvest" in Latin (Lizana and Reginato, 1990). *Annona* species have many characteristics in common with many other tropical fruit species, especially the height of the plant, root system, flower biology, and type of fruit type (Ochse *et al.,* 1974).

Soursop is considered a bush plant, the height varying from 4 to 8 m, depending on factors like climate, soil and crop management. It tends to have an extended growth. The flowers are hermaphrodite and emerge from the branches and trunk in groups of two to four flowers with three green sepals and six petals arranged in two whorls. The fruit is a spiny berry with many carpels commonly called "spines" or "barbs" with a weight varying from 0.9 to 10 kg (León, 1987).

The root system consists of a main (or tap) root, 1.5 to 1.8 m long, and abundant lateral roots (Pinto and Silva, 1994). The tap root is not as vigorous and does not grow as deep as that in other tropical fruit trees, like the mango (*Mangifera indica* L.). These characteristics are very important when planning fertilization and making decisions about managing this crop.

11.2. World production and trends

There is very little literature about this crop with the exception of information from Mexico, Brazil and Venezuela. In the Americas, Mexico is the most important producer of soursop and in 1997 it was grown on approximately 5,900 ha and produced about 35,000 mt of fruit. In 1987, in Venezuela, there were about 3,500 ha and total production was about 10,000 mt (Hernández and Nieto Angel, 1997).

Brazil grows approximately 2,000 ha with an estimated production of about 8,000 mt, almost completely for sale in the internal market. Owing to the

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favorable climate, about 90% of the total Brazilian production comes from the north-eastern region of Brazil. In the state of Ceará, located in the Brazilian north-east, there is an estimated 500 ha of soursop, and the fruit goes mainly to produce juice (Bandeira and Braga Sobrinho, 1997).

Soursop is rich in mineral salts, principally calcium (Ca) and potassium (K), and its flavor is enjoyed as juice and jam. It is considered to be a commercial fruit mainly grown for the internal market and selling in the local in Brazilian currency for about R$ 2.50 kg/fruit. Very little of the fruit is exported and there is little growth in exports which rely on the actions of a few pulp and juice manufacturers in the north-east of Brazil.

11.3. Climate and soil

11.3.1. Climate

The genus *Annona* includes, for the most part, tropical and subtropical plants, although a few species develop in temperate climates. Many species grow at low altitudes and those with a wide adaptation to altitude are also the species most adapted to variations in latitude. The optimal range of latitude is between 27ºN and 22.5ºS (Nakasone and Paull, 1998).

Soursop is the most tropical of the *Annona* species and is considered a plant of low altitudes and a hot and humid climate. It is grown primarily at altitudes lower than 900 m above sea level (Zayas, 1966). However, good productive orchards are found at altitudes of up to 1100 m (Pinto and Silva, 1994). Soursop adapts well to Savanas and tropical humid regions, *i.e.* A and Aw type climates, where the annual precipitation generally exceeds evapo-transpiration (Ayoade, 1991).

Two important climatic factors are rain, principally when out of season, and strong winds. Both, when they occur in great intensity and during flowering, greatly reduce pollination (Nakasone and Paull, 1998).

Although the photoperiod is not an important physiological factor for the annonas, excessive shading induces poor setting of the fruit. Therefore, pruning, plant spacing and fertilization are some of the very important practices in orchard management. Soursop is very demanding of light and shading the plants greatly reduces the production of fruit (Villachica *et al.,* 1996). Soursop grows and produces well at 21 to 30ºC, being very sensitive to severe changes in temperature, especially if the limit of 12ºC is reached (Pinto and Silva, 1994). Nakasone and Paull (1998) considered that the best temperature range was between 15 and 25ºC.

11.3.2. Soil

Soursop will grow in a wide variety of soils, from sandy to clay loams, but it prefers deep soils with good aeration (Melo *et al.,* 1993; Ledo, 1992). Good drainage is necessary for good root development, and, especially, to avoid problems of root diseases. Soil pH should be between 6.0 and 6.5 (Pinto and Silva, 1994).

11.4. Soil and crop management

Soil preparation for a soursop orchard includes land clearing, aeration, ploughing, application of lime, if necessary, and appropriate fertilization.

Soil sampling and analysis are precede aeration and ploughing. The amounts of lime and fertilizer to apply are decided on the basis of the analytical data. Where the soil is acidic, which is very common in Brazil, liming is extremely important not only to adjust the pH to 6.0 to 6.5, the best range for soursop, but also to achieve a base saturation of between 60 and 70% (Pinto *et al.,* 2001). Liming is also recommended when the subsoil to a depth of 60 cm is acidic, *i.e.* Al saturation >20% and/or Ca <0.5 $cmol_c/dm^3$ (Andrade, 2002).

Fertilization is generally recommended for soils deficient in phosphorus (P) and potassium (K), and the fertilizers are broadcast onto the soil around the plant, followed by incorporation into the soil (Andrade, 2004). The recommendation for P fertilizer is based on the amount of clay and the quantity of plant-available P determined by soil analysis (Table 11.1).

Table 11.1. Phosphorus fertilizer application according to percent clay in the soil and level of plant-available phosphorus in the soil.

Clay concentration	Phosphorus availability in the soil (mg/kg)		
	0-10	10-20	>20
g/kg	---------- P application, P_2O_5 (kg/ha) ----------		
≤150	60	30	0
160-350	100	50	0
300-600	200	100	0
>600	280	140	0

Source: Sousa and Lobato, 2004.

Correcting soil fertility where an orchard is to be planted has a cost, which must be considered. If fertilizer is broadcast over the whole area of the orchard annual plants should be grown between the rows of soursop to provide some economic return to the grower before the soursop starts to produce harvestable fruits three years after planting the trees.

Soursop can be propagated from seed ("loam tree") and by budding. The height of the plant is not greatly affected by budding and the majority of producers prefer using grafted seedlings rather than seeded seedlings. Propagation by seed or graft is done in plastic bags in a growth medium that varies from region to region. The constituents in the growth medium in the nursery phase are very important. Depending on the material and quantity used, there is the possibility of interfering with seed germination and of phytotoxicity burning the young leaves and causing the death of the seedlings (Pinto and Silva, 1994).

Although there is variation in the recommended use of nutrients in different regions, Pinto (1996) recommends the following constituents for each m^3 of growth medium (about 700 kg): 300-350 kg of local soil, 300-350 kg cured bovine manure, 300-500 g lime and 400-600 g of single superphosphate. After preparing the mixture it should be exposed to sunlight to eliminate diseases. Rego (1992) studied the effect of cured bovine manure applied at 0, 5, 10, 15, and 20% of the growth medium on the growth of seedlings over a period of four months. The author concluded that 15% manure was the most effective.

After germination and during seedling growth, nitrogen (N) should be applied every 21 days as a solution of ammonium sulphate at 5 g/L water. After the fourth month the seedlings should receive micro-nutrients as a foliar spray bimonthly using a commercial product in a 1-2% solution (Pinto and Silva, 1994).

11.5. Mineral nutrition

11.5.1. Uptake and export of nutrients

When the plants are producing fruit, the amount of fertilizers required should be based not only on soil and leaf analysis, but also the nutrients removed in the harvested fruits. In fact the nutrients removed in the fruit are an excellent guide to establish a fertilization programme for any fruit tree in is production phase (Mengel and Kirkby, 1987; Torres and Sánchez López, 1992; Hermoso and Farré, 1997). The quantity of each nutrient removed in the fruit varies between varities but, on average 10 mt fruits remove 27 kg N (Table 11.2).

The amount of nutrients in soursop fruits produced in Venezuela and in Brazil differs greatly in K and Ca but is similar for the other macro-nutrients (Table 11.3). In Paraiba state, Brazil, the quantity of micro-nutrients per tonne of soursop fruit is: Fe, 8.03 g; Cu, 1.65 g; Mn, 2.71 g; Zn, 3.71 g; and B, 2.75 g (Silva *et al.,* 1984), with Fe being the largest amount.

Table 11.2. Amount of macro-nutrients in some tropical and subtropical fruits (kg/mt fruit).

Nutrient	Avocado[1]	Pineapple[1]	Orange[1]	Banana[1]	Soursop[2]
Macro-nutrient			kg/mt		
N	2.80	0.90	1.20	1.70	2.70
P	0.35	0.12	0.27	0.22	0.54
K	4.53	2.00	2.60	5.50	3.60
Ca	0.13	0.10	1.05	0.21	0.26
Mg	0.20	0.16	0.20	0.27	0.24

Source: [1]Marchal and Bertin, 1980; [2]Silva *et al*., 1984.

Table 11.3. Amount of macro-nutrients in harvested soursop (kg/mt fruit) grown in Venezuela and in Brazil.

Nutrient	Venezuela[1]	Brazil[2]
Macro-nutrient	kg/mt	
N	2.97	2.70
P	0.53	0.54
K	2.53	3.60
Ca	0.99	0.26
Mg	0.15	0.24

Source: [1]Avilan *et al*., 1980 ; [2]Silva *et al*., 1984.

11.5.2. Functions and importance of macro-nutrients

Nitrogen (N): Deficiency of N causes an intense yellowing in the oldest leaves because if the supply of N is limited it is mobilised and transported to the youngest tissues, principally for growth. Symptoms of deficiency in young plants (seedlings) appear in the first 30-40 days after germination. Generally, plants of the genus *Annona* when N is deficient show a visual progression in the symptoms to intense yellowing and loss of leaves. Other than yellowing of the leaves, young plants are markedly smaller in height and have a very premature loss of leaves.

Phosphorus (P): Deficiency of P is seen by an irregular chlorosis of the basal leaves with many showing a dark green coloring. With increasing deficiency, the leaves become small and take on irregular shapes. Deficient plants grow very slowly and have brown spots on the leaves with necrosis on the lamina margins, followed by the leaves falling off the plant.

Potassium (K): In general, K deficient plants do not have the ability to transport sugars produced by photosynthesis in the leaves to the other organs, principally the fruit. Potassium can move from the oldest organs, primarily the leaves, to the youngest or to growth. Brownish spots start at the apex and the basal portion of the leaf lamina and gradually merge. In seedlings these symptoms first appear eight months after sowing the seed when the size of the leaves is reduced and they become yellow and fall off. Deficient plants produce fewer flowers but there is no loss of yield.

Calcium (Ca): Symptoms of Ca deficiency are manifest 30 days after sowing and appear first at the points of growth, like buds and the young leaves because Ca is not mobile within the plant. About 70 days after sowing, the leaves show interveinal chlorosis, stop growing and become curled.

Magnesium (Mg): Unlike Ca, Mg is mobile in plants so that initially deficiency symptoms occur in the oldest leaves. In nursery conditions, an interveinal chlorosis starts in the leaves about 50 days after sowing and progressively the leaves become totally necrotic. The adequate ratio of Ca: Mg is 3: 1 because a greater proportion than this of Ca induces Mg deficiency. In the same way, elevated ratios of K induce deficiencies of Mg and Zn.

Sulphur (S): Like calcium, the first symptoms of S deficiency occur in the youngest leaves because S is largely immobile in the plant. In nursery conditions, young S deficient plants are intensely yellow and atrophied after about 75 days.

11.5.3. Functions and importance of micro-nutrients

Boron (B): Like Ca, B is immobile in phloem and for this reason the first symptoms of its deficiency occur in the young leaves. In seedlings still in the nursery, deficiency symptoms appear around 70 days after sowing, when the seedling leaves have an intense green color with chlorosis of the lamina. By 140 days after sowing the plants have atrophied. Maintaining adequate amounts of plant-available B and Ca during flowering and the first stages of fruit production reduces the possibility of internal darkening of the pulp, which is common in annonas.

Iron (Fe): Like Ca and B, the redistribution of Fe in the plant is practically zero. Thus the initial symptoms of Fe deficiency occur in the young leaves and are characterized by partial chlorosis with yellowish-green coloration of the lamina, which with time becomes totally yellow except in the region around the veins.

Zinc (Zn): Plants with Zn deficiency frequently show interveinal chlorosis in the leaf lamina area and appear pale-green in color. Deficient plants have irregularly distributed, small, branched and hardened leaves at the apex of new branches, and this is known as leaf rosette.

The observation and identification of the nutrient deficiency symptoms in the field can be done quickly but it requires very experienced people. Therefore, not only field observation, but also soil, fruit and leaf analysis are very important to determine the nutritional state of the plant. To aid the determination of macro- and micro-nutrient deficiencies in plants, including the annonas, the symptoms have been described by many authors (Avilan, 1975; Navia and Valenzuela, 1978; Mengel and Kirkby, 1987; Torres and Sánchez, 1992; Silva and Silva, 1997). Finally, there is evidence that well nourished plants are more resistant to pests and diseases, producing a larger yield of good quality fruits.

11.6. Fertilization

At planting: Adequate fertilization of the planting pit is a basic condition for excellent seedling growth that will result in a productive adult plant producing good quality fruit. The amount of fertilizer to apply is based on soil analysis and on the volume of pit, which is usually 60 x 60 x 60 cm.

In Venezuela it is recommended to mix 250 g of a 10-10-15 or 10-15-15 fertilizer with 5 kg of corral manure (Araque, 1971). For the acidic soils of the Cerrados, Andrade (2004) suggests the following quantities of manure, lime and fertilizer per pit: 21.6 L of cured bovine manure or 5.4 L poultry manure; 216 g lime (PRNT 100%); 151 g P_2O_5 (367 g of triple superphosphate); 1.0 g B; 0.5 g Cu; 1.0 g Mn; 0.05 g Mo and 5.0 g Zn. Nitrogen and K, at 20 g/plant, should be applied around the plant in three portions at intervals of 30 days between each application (Andrade, 2004). In pit fertilization with micro-nutrients it has been quite common to use 100 g/pit of F.T.E. formula BR-12. For virgin soil, when soil analysis results are not available, the following quantities (kg/ha) of micro-nutrients should be applied broadcast: B, 2 kg; Cu, 2 kg; 6 kg Mn; 6 kg Zn (Galrão, 2004).

During growth: After planting the seedlings, the amounts of fertilizer applied during the next three years should be based on chemical analysis of the soil (Table 11.4) as recommended by Silva and Silva (1997).

Table 11.4. Nitrogen, phosphorus and potassium for soursop according to the age of the plant and the availability of soil phosphorus and potassium.

Age	N	P-resin (g/dm^3)			K-exchangeable (g/dm^3)		
		0-10	11-20	>20	0-45	46-90	>90
Yr	g/plant	P_2O_5 (g/plant)			K_2O (g/plant)		
0-1	40	0	0	0	60	40	30
1-2	80	80	60	40	80	60	40
3-4	120	120	80	60	120	80	60
>4	180	120	80	40	180	120	60

Source: Silva and Silva, 1997.

Fertilizer should be applied around the plant but only lightly incorporated into the soil to avoid damaging the developing root system whilst putting the fertilizer near them. In a dryland plantation, the annual fertilization with P should be done in a single application at the beginning of the rainy season. The required quantity of N and K fertilizer should be divided into three and one third applied at the beginning, in the middle and at the end of the rainy season. The amount of fertilizer applied can be changed from one year to another. At the end of the first year after planting, the fertilizer given in the second year should be based on soil analysis and for the third year on the basis of leaf analysis.

During production: Torres and Sánchez López (1992) recommend different quantities of nutrients depending on the region, *i.e.* the InterAndean Valley, the Atlantic Coast and Eastern Plains of Columbia. These authors suggest that the amount of N fertilizer for plants between three and six years old should be based on the amount of soil organic matter, whilst for P and K they should be based on the level of plant available P and K in the soil. Because N and K are the nutrients in greatest demand by soursop, the amounts should increase proportionally with the age of the plant and its level of production. However, care should be taken to give excess N because this causes the plants to grow too quickly and produce less fruit. Soursop's large demand for K means that the concentration of K in the leaf should not be less than 10 g/kg to ensure that K is not limiting growth. On sandy soils and others where there is a risk of N and K being lost by leaching, N and K fertilizers should be applied six times during the growing season. For adult plants fertilizers should be applied beneath the crown in an area including two thirds of the radius beneath the crown and extending one more quarter from the edge of the crown's projection (Fig. 11.1).

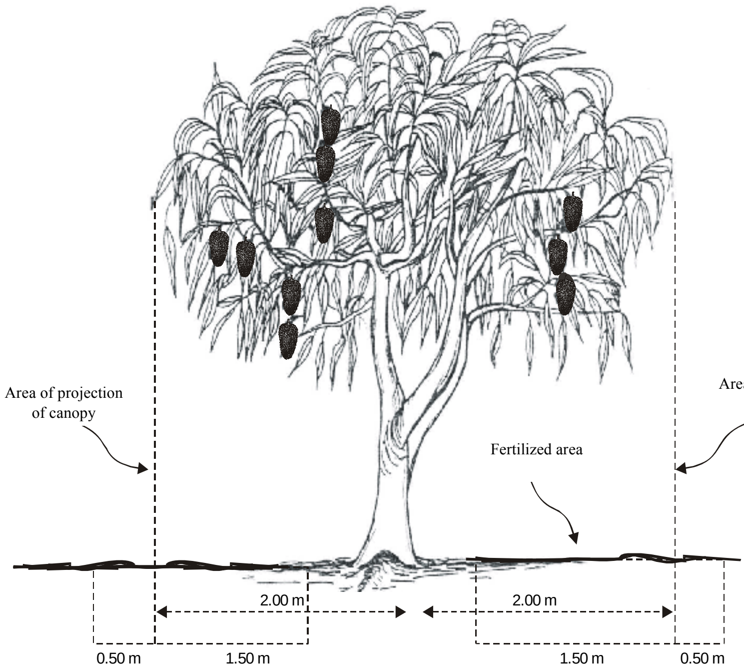

Fig. 11.1. Fertilizer should be applied on both sides of adult plants and cover two thirds of the radius of the crown and one more quarter beyond the edge of the crown (Pinto, A.C. de Q., 2001).

In general, soursop is sensitive to Zn and B deficiency. To prevent deficiency, 2 g m^{-2} B can be incorporated monthly into the 10 cm of soil beneath the plant's crown before irrigation and a 0.1% solution of zinc sulphate applied as a foliar spray. Galrão (2004) recommends the following quantities of micro-nutrients during the production phase of the adult plant: 2.0 g B, 3.0 g Cu, 4.0 g Mn and 5.0 g Zn, all incorporated into the soil below the crown projection together with other fertilizers, at the start of fruit production.

There has been little research on foliar applications of both macro- and micro-nutrients for soursop. When the fruit is mature the absorption of nutrients diminishes and foliar applications of nutrients are more effective at this time.

Today producing fruit by organic systems of production is an excellent method for increasing the value of the fruit. However, there is serious lack of information regarding appropriate methods of growing annonas, especially soursop, by organic methods. One of the few exceptions is that of Bonaventure

(1999) for cherimoya (*Annona cherimola Mill.*). He recommends using microorganisms and algae, as well as a bio-activator, which accelerates the metabolism and increases the production of this important annona.

Currently, the use of organic compost and mulching with organic material in soursop plantations has been recommended because the plants respond both in growth and yield. Organic compost and mulching facilitates not only the development of vigorous and abundant roots, but also improves moisture retention in the soil and minimises the risk of soil erosion.

As with other perennial fruit trees, chemical soil and plant tissue analysis are the techniques most used to evaluate the nutritional state of the plants. In some cases, for example, leaf analysis may indicate deficiency of Mg but the cause may be in the soil where there may be too little Mg or an excess of Ca. Currently, some researchers have also tested the analysis of fruit tissue (Stassen 1997) to complement soil and leaf analysis.

Soil sample collection in soursop orchards in the production phase is the same as that recommended for other crops, but the soil should come from within the crown projection.

The recommended method for leaf sampling for nutrient content depends on the age of the plant, the position of the leaf within the crown, the variety and whether the branches are with or without fruit and the period of sampling. Laprode (1991) suggests that the leaves should be taken from the third and fourth pairs of intermediate branches in the crown and of the four cardinal points. Pinto and Silva (1994) recommend that the leaves should be 8 to 9 months old, taken from healthy plants free from residues from any foliar sprays.

In general, the sample should consist of 100 leaves for every five hectares by taking four leaves per plant from a group of 25 plants randomly selected in the orchard. For a more uniform sample it is recommended to divide the orchard into sections of similar soil characteristics, and in each section separate the plants by chronological age. Collect only healthy leaves from plants that have not been recently fertilized, avoiding the period of flowering and periods of intense rain.

Soil and leaf analysis data are interpreted using calibration curves for each nutrient, based on the correlation between the composition of each nutrient and the productivity of the fruit tree (Silva *et al.,* 2002).

Isolated leaf analysis is not sufficient for precise interpretation and diagnosis of the nutrient status of the plant because of the many factors that cause variation in leaf nutrient status. In general, the composition of N is about ten times that of P and twice that of K. Gazel Filho *et al.* (1994), analysed leaves from a range of one-year-old soursop varieties growing in Cerrado do Amapá, Brazil. The varieties were: Blanca, Lisa, Morada, Soursop A, Soursop B, FAO II and Matriz

CPATU 415. The content of macro-nutrients in g/kg ranged from: 19.6 to 20.4 for N; 1.2 to 1.4 for P; 14.9 to 17.2 for K; 12.0 to 15.2 for Ca and 1.9 to 2.2 for Mg. The authors only found significant differences for Ca and Fe and the largest concentrations were in cv. Morada with 15.2 g/kg Ca and 215.8 mg/kg Fe.

This result seems to contradict the belief that the nutrient composition of the leaves is genetically controlled and this may vary with variety. However, in this case many of these analyses were made on different leaves, whether they showed deficiency or not and came from branches with or without fruit. Some authors point out that the comparison of leaf composition between macro- and micro-nutrients is important in leaves with and without visible deficiency. Avilan (1975) in Venezuela and Silva *et al.* (1984) in Brazil (Table 11.5) made these comparisons.

Table 11.5. Normal concentrations of macro-nutrients and some micro-nutrients in soursop leaves in Venezuela and Brazil.

Plant part	N	P	K	Ca	Mg	S	B
	g/kg						mg/kg
Normal leaves[1]	17.6	2.9	26.0	17.6	0.20	-	-
Deficient leaves[1]	11.0	1.1	12.6	10.8	0.08	-	-
Normal leaves[2]	25.0-28.0	1.4-1.5	26.1	8.2-16.8	3.6-3.8	1.5-1.7	35-47
Deficient leaves[2]	13.0-16.0	0.6-0.7	26.4	4.5-8.1	0.7-0.8	1.1-1.3	6-14

Source: [1]Avilan, 1975 in Venezuela; [2]Silva *et al.*, 1984 in Brazil.

Normal leaf concentrations for N and K in soursop grown in Brazil are 1.6 to 2.0 times greater than those in deficient leaves. The difference in N composition between normal and deficient leaves in Venezuela was much greater than that in Brazil but the difference in K was small.

11.7. Irrigation

In general, because soursop grows in the humid tropics it needs extra water by irrigation to guarantee adequate growth and fruit yield especially during periods of drought. George *et al.* (1987) described a common disorder in annonas, especially in soursop and sweetsop, which is a hardening of the pulp with brownish lumps. It is suspected that this symptom is caused by sudden movements of water within the pulp that, together with the deficiency of B, produces a more serious manifestation of the symptom. This disorder is very common in north-eastern Brazil, especially in dryland orchards or irrigated orchards with limited water supplies. The occurrence of any water stress generally slows the growth of young plants, preventing vegetative growth and decreasing the size of the fruit, highlighting the importance of irrigation for soursop.

11.7.1. Irrigation methods

The selection of the most appropriate irrigation method is directly associated with three factors: technical, economical and human (Silva *et al.,* 1996). Soil factors related to water infiltration, water management, with respect to its quality, quantity and availability, climatic factors and plant features are important technical factors. For example, the spray method is recommended only in areas where water is not limiting and the gradient of the surface is not greater than 16% (Nunes, 1997). The price of the system and its installation and maintenance costs are very important economic factors. Finally, for success in the installation and operation of the system, the quality of the available labour should not be disregarded.

Simple irrigation methods are used in many regions in north-east Brazil, depending on economic conditions, quantity of water available and the type of soil. At Fazenda Bom in the municipality of Trairi, in Ceará state, the soil is a Quartz Neosol (Sandy Quartz). There they use a simple yet effective installation comprised of a flexible hose at the end of which is a hard PVC ring with 0.5 cm diameter holes giving a flow of water of about 20 to 30 L/h. Each plant is watered for 1-2 hours at 7 to 14 day intervals.

Currently, localized drip and jet irrigation are recommended especially where there is a shortage of water. In these systems, water is applied only to the soil in the region of the root system, thus reducing water loss by evaporation and limiting the area infested by weeds. Overall, the great disadvantage of drip irrigation is the need to use filters to avoid blockages in the system where water quality is poor and insoluble fertilizers are used. Therefore, for success with drip irrigation, the system should be installed adequately following the method proposed by Bucks and Davis (1986).

11.7.2. Water requirements

The amount of water required varies from one area to the next and depends on climatic conditions, soil type and growth stage of the plant. For example, the dry period in the Cerrados of Brasilia coincides with lower solar radiation and low temperature that create a comparatively smaller evapo-transpiration demand than in the north-east of Brazil. Consequently, water deficiency in the Cerrados is less serious than that in the north-east. An adult plant requires much more water than a young plant and Latosol soils retain much more water than Quartz Neosols. Soursop orchard of adult plants with a 3 m radius crown and a density of 204 plants/ha (spacing 7 x 7 m), using jet irrigation to cover 60% of the crown area with water, requires a daily input of approximately 63 L/plant, or 3.72 mm/plant, which is equivalent to 1,000-1,200 mm of yearly rainfall (Pinto *et al.,* 2001).

It is estimated that the annual water needs of soursop for growth and production are about 1,000 to 1,200 mm/plant. In regions where the annual precipitation is equal to or greater that 1,600 mm, the cv 'Morada' produces up to 10 kg fruit/plant. In the Brazilian semi-arid regions, where annual precipitation is about 500 mm, this same variety only produces more than 3 kg fruit/plant if it is adequately irrigated.

11.7.3. Fertigation

Compared to applying fertilizers to the soil, the application of nutrients in the irrigation water allows a faster response by the crop, better control of the quantity of nutrients used and larger yields of better quality fruits.

Water quality is just as important as the quantity to be applied and the period of application, because elements like calcium could precipitate with phosphates and cause blockage of the emitters (Pinto and Silva, 1994). Equally, producers of soursop should be concerned about the presence of sodium in the water, because it accumulates in the soil, especially in shallow and poorly drained soils. It goes without saying that salting severely damages growth and production of soursop. Mansour (1997) commented that sodium chloride, calcium chloride and calcium carbonate all adversely affect the growth of annonas and drastically reduce the total dry weight of the plants, especially at a leaf concentration of 0.3% Na. Elevated levels of any of these salts causes leaves to burn and fall. Also, elevated levels of B and Cl in irrigation water induce phytotoxicity and injuries to the leaves and fruit that are difficult to control (Pinto and Silva, 1994).

11.8. References

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Acronyms, Symbols and Abbreviations

Acronyms

EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária, Brazil
FAO	Food and Agricultural Organization of the United Nations
FAOSTAT	FAO Statistical Database
IBGE	Instituto Brasileiro de Geografia e Estadistica
IFA	International Fertilizer Industry Association
IPI	International Potash Institute

Symbols

Al	Aluminium
B	Boron
C	Carbon
Ca	Calcium
$CaCO_3$	Calcium carbonate
Ci	Curie
$CaSO_4$	Calcium sulphate
Cu	Copper
Fe	Iron
K	Potassium
KCl	Potassium chloride (=MOP)
KNO_3	Potassium nitrate (=NOP)
K_2O	Potash
K_2SO_4	Potassium sulphate (=SOP)
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
NH_3	Ammonia
NH_4	Ammonium
NO_3	Nitrate
NaCl	Sodium chloride

P	Phosphorus
P_2O_5	Phosphate
S	Sulphur
SO_4	Sulphate
Zn	Zinc

Abbreviations

AS	Ammonium sulphate
CAN	Calcium ammonium nitrate
CEC	Cation exchange capacity
cm	centimeter
d	days
dS/m	deci Siemens per meter
DAP	Diammonium phosphate
DTPA	Diethylene triamine pentaacetic acid
EC	Electrical conductivity
EDTA	Ethylene diamine tetraacetic acid
ET	Evapo-transpiration
FTE	Fritted trace elements
g	gram
h	hours
ha	hectare
HEDTA	N-(2-hydroxyethyl)ethylenediaminetriaceticacid
IBA	Indole butyric acid
K_c	Crop coefficient
kPa	Kilopascal
kg	kilogram
Kr	Evaporation reduction coefficient of soil
L	liter
m	meter
MAP	Monoammonium phosphate
mg	milligram
min	minutes

ml	milliliter
mM	millimole
MOP	Muriate of potash, potassium chloride
MPa	Megapascal
msec	milliseconds
mt	metric tonne
NOP	Nitrate of potash, potassium nitrate
PR	Phosphate rock
PRNT	Neutralization index
sec	seconds
SOM	Soil organic matter
SOP	Sulphate of potash, potassium sulphate
SSP	Single superphosphate
TSP	Triple superphosphate
UAN	Urea ammonium nitrate
yr	years

Appendix of Chapter 1: Plates Acerola

Plates by courtesy of J.R. Paiva.

Plate 1.1.
Acerola cherries.

Plate 1.2.
Acerola tree.

Appendix of Chapter 2: Plates Banana

Visiul symptoms of potassium deficiency in banana

Source: P. Imas, IPI.

Plate 2.1.

Plate 2.2.

Plate 2.3.

Mild (Plate 2.1), moderate (Plate 2.2) and severe (Plate 2.3) deficiency symptoms of K.

Appendix of Chapter 3: Plates Cashew

Visiul symptoms of mineral deficiencies in cashew

Plate 3.1. Nitrogen deficiency: normal leaf, left; mild deficiency, center; severe deficiency, right.

Source: R. Avilán, 1971.

Plate 3.2. Calcium deficiency: normal leaf, right; deficient leaf, left.

Source: R. Avilán, 1971.

Plate 3.3. Magnesium deficiency: normal leaf, left; deficient leaf, right.

Source: R. Avilán, 1971.

Plate 3.4. Sulfur deficiency:
normal leaf, left;
deficient leaves center and right.

Source: R. Avilán, 1971.

Appendix of Chapter 4: Plates Citrus

Visiul symptoms of mineral deficiencies in citrus

Plate 4.1. Symptoms of phosphorus deficiency. Older leaves are yellowish or pale brown. The symptoms are not always easy to identify, but trees with P deficiency tend to lose leaves, have a non-vigorous aspect and the leaves have a certain “transparency”. The fruits and cores tend to open.

Courtesy of J.A. Quaggio.

Plate 4.2. Symptoms of potassium deficiency. The oldest leaves take on a pale-yellow, mat coloration. Fruit size is greatly diminished and fruits may fall to the ground in large numbers when deficiency is severe.

Courtesy of J.A. Quaggio.

Plate 4.3. Symptoms of magnesium deficiency. Interveinal chlorosis appears on the old leaves.

Courtesy of
D. Mattos Jr.

Plate 4.4. Symptoms of zinc deficiency. Young leaves have interveinal chlorosis, reduced growth and a lanceolated appearance.

Courtesy of:
D. Mattos Jr.

Appendix of Chapter 5: Plates Coconut - Green Dwarf Variety

Visiul symptoms of mineral deficiencies and toxicity in coconut

Plates by courtesy of L.F. Sobral.

Plate 5.1. Nitrogen deficiency.

Plate 5.2. Potassium deficiency.

Plate 5.3. Magnesium deficiency.

Plate 5.4. Boron deficiency, advanced stage.

Plate 5.5. Boron toxicity.

Appendix of Chapter 6: Plate Guava

Plate 6.1. Guava fruits.

Courtesy of W. Natale.

Appendix of Chapter 7: Plate Mango

Visiul symptoms of mineral deficiencies in mango

Plate 7.1. Greenish blotches in mangos collected from trees with leaf composition of nitrogen greater than 1.2%.

Courtesy of A.C.Q. Pinto.

Appendix of Chapter 8: Plates Papaya

Visiul symptoms of mineral deficiencies in papaya

Plate 8.1. Base leaves yellowed by nitrogen deficiency.

Courtesy of A.N. da Costa.

Plate 8.2. Deficiency of Mg symptom in the mature leaves completely expanded.

Courtesy of A.N. da Costa.

Plate 8.3. Fruits deformed by a deficiency of boron.

Courtesy of A.M.G. Oliveira.

Appendix of Chapter 10: Plates Pineapple

Visiul symptoms of mineral deficiencies in pineapple plants

Plates by courtesy of D.H. Reinhardt.

Plate 10.1. Nitrogen deficiency (pale-green color), in contrast with normal plants (dark green color).

Plate 10.2. Potassium deficiency symptoms.

Plate 10.3.
Typical symptoms of magnesium deficiency grown in soil with pH 7.7.

Plate 10.4.
Symptoms of copper deficiency.

Plate 10.5.
Symptoms of iron deficiency.