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.

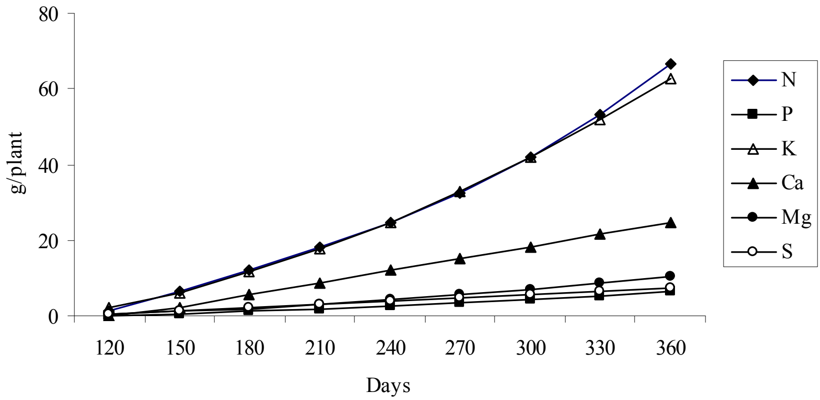

Fig. 8.1. Rate of macro-nutrient absorption by the papaya.
Adapted from: Cunha, 1979.

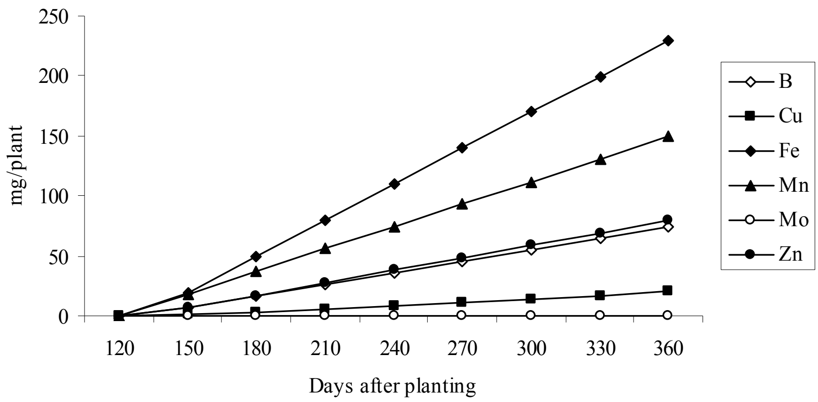

Fig. 8.2. Rate of micro-nutrient absorption by the papaya.
Adapted from: Cunha, 1979.

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:

$$Tr = 0.56 \times ET$$

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.

8.7. References

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