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	
P	0-5	80
	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.

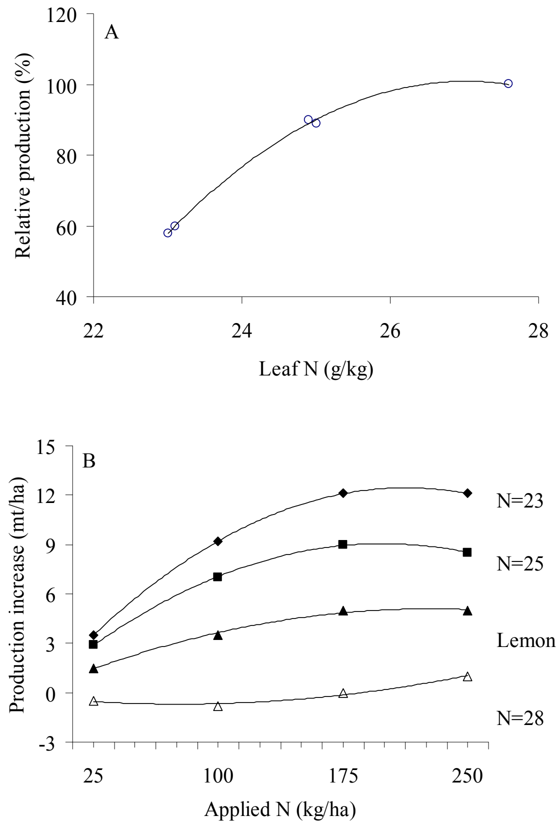

Fig. 4.1. Relative production of citrus fruits according to leaf percent N (A) and expected response to nitrogen fertilizer according to leaf %N (B), (Quaggio *et al*., 2002; Mattos. *et al*., 2003a).

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.

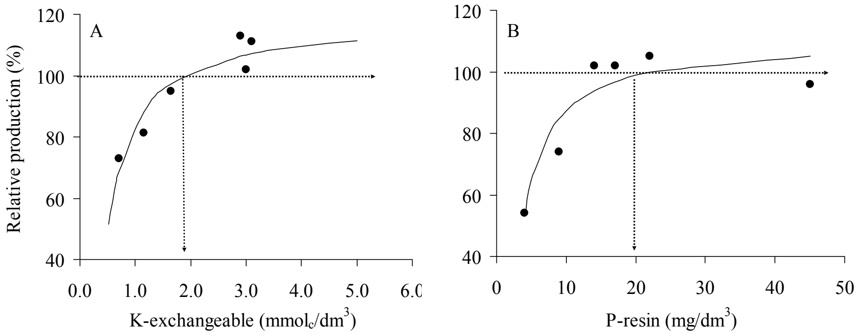

Fig. 4.2. Calibration curves for relative production of citrus according to soil exchangeable potassium (A) and P-resin (B), (Quaggio *et al.*, 1996a, 1998).

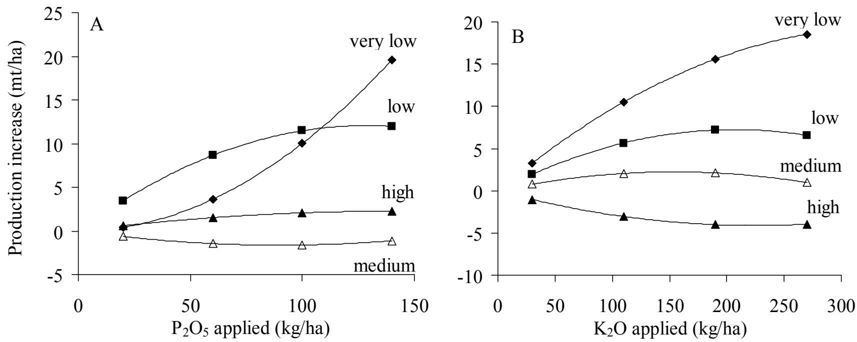

Fig. 4.3. Response to P and K fertilization at few levels of P-resin (A) and exchangeable K (B), (Quaggio *et al.*, 1996a, 1998).

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).

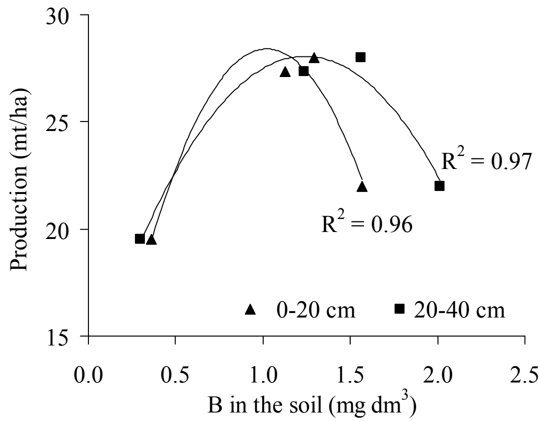

Fig. 4.4. Pera orange production according to soil boron content (B extracted with hot water).

4.5. References

Alva, A.K., and S. Paramasivam. 1998. Nitrogen management for high yield and quality of citrus in sandy soils. Soil Science Society America Journal 62:335-1342.

Bataglia, O.C., O. Rodriguez, R. Hiroce, J.R. Gallo, P.R. Furlani, and A.M.C. Furlani. 1977. Composição mineral de frutos cítricos na colheita. Bragantia 36:215-221.

Boaretto, A.E., R.M. Boaretto, T. Muraoka, V.F. Nascimento Filho, C.S. Tiritan, and F.A.A. Mourão Filho. 2002. Foliar micronutrient application effects on citrus fruit yield, soil and leaf concentrations and 65Zn mobilization within the plant. Acta Hort 594:203-209.

Boaretto, A.E., R.M. Boaretto, T.L.M. Contin, and T. Muraoka. 2004. É móvel ou imóvel o boro em laranjeiras? Laranja 25:195-208.

Brieger, F.G., and S. Moreira. 1941. Uniformidade da produção numa experiência de adubação de laranja baía. Bragantia 1:619-667.

Brown, P., and B.J. Shelp. 1997. Boron mobility in plants. Plant Soil 193:85-101.

Bustan, A., and E.E. Goldschmidt. 1998. Estimating the cost of flowering in a grapefruit tree. Plant Cell and Environment 21:217-224.

Camargo, O.A. 1991. Reações e interações de micronutrientes no solo. p. 233-272. *In*: M.E. Ferreira, and M.C.P. Cruz (ed.) Micronutrientes na agricultura. Piracicaba: Potafos/CNPq.

Cantarella, H., D. Mattos Jr., J.A. Quaggio, and A.T. Rigolin. 2003. Fruit yield of Valencia sweet orange fertilized with different N sources and the loss of applied N. Nutr. Cycling Agroecosystems 67:1-9.

Chapman, H.D. 1960. Leaf and soil analysis in citrus orchards – criteria for the diagnosis of nutrient status and guidance of fertilization and soil management. Riverside: Univ. of California. 53p. (Manual 25) 98.

Chapman, H.D. 1968. The mineral nutrition of citrus. p. 127-289. *In*: W. Reuther, L.D., Batchelor, and H.J. Webber (ed.) The citrus industry. 2, Riverside: Univ. of California.

Davies, F.S., and G.L. Albrigo. 1994. Citrus. Wallingford: CAB International. 254p.

Embleton, T.W., W.W. Jones, C.K. Labanauskas, and W. Reuther. 1973a. Leaf analysis as a diagnostic tool and guide to fertilization. p. 183-210. *In*: The citrus industry. Riverside: Univ. of California.

Embleton, T.W., H.J. Reitz, and W.W. Jones. 1973b. Citrus fertilization. p. 122-182. *In*: The citrus industry. Riverside: Univ. of California.

Embleton, T.W, E.F. Wallihan, and G.E. Goodall. 1965. Effectiveness of soil vs. foliar applied zinc and of foliar applied manganese on California lemons. Proceeding America Society Horticulture Science 86:253-259.

Erickson, L.C. 1968. The general physiology of citrus. *In*: W. Reuther, L.D., Batchelor, and H.J. Webber (ed.) The citrus industry. Riverside: University of California 2:86-126.

FAO. 2006. FAOSTAT. http://www.fao.org/.

Grupo Paulista de Adubação e Calagem para Citros. 1994. Recomendações de adubação e calagem para citros no Estado de São Paulo. 3rd ed. Laranja, 27p.

Hiroce, R., and J.O. Figueiredo. 1981. Influência de dez porta enxertos nos teores de nutrientes das folhas e na produção de frutas de laranjeira-barão [*Citrus sinensis* (L.) Osbeck]. p. 666-673. *In*: Congresso brasileiro de fruticultura, 6. Recife, 1981. Anais..., Recife: SBF.

Jackson, L.K., A.K. Alva, D.P.H. Tucker, and D.V. Calvert. 1995. Factors to consider in developing a nutrition program. p. 3-12. *In*: D.P.H. Tucker, A.K. Alva, L.K. Jackson, and T.A. Wheaton (ed.) Nutrition of Florida Citrus Trees. Gainesville: University of Florida. Kato, T. 1986. Nitrogen matabolism and utilization in citrus. Horticulture Reviews 8:181-216.

Lea-Cox, J.D., J.P. Syvertsen, and D.A. Graetz. 2001. Springtime 15Nitrogen uptake, partitioning and leaching losses from young bearing Citrus trees of differing nitrogen status. Journal America Society Horticulture Science 126:42-251.

Labanauskas, C.K., W.W. Jones, and T.W. Embleton. 1964. Effects of foliar applications of manganese, zinc and urea on yield and fruit quality of Valencia oranges and nutrient concentrations in the leaves, peel and juice. Proceeding America Society Horticulture Science 82:143-153.

Mattos Jr., D. 2000. Citrus response functions to N, P and K fertilization and N uptake dynamics. Tese (Ph.D. Agricultural and Life Sciences, Soil and Water Science Dept.) – Gainesville: University of Florida.

Mattos Jr., D., H. Cantarella, and B. van Raij. 1995a. Manuseio e conservação de amostras de solo para preservação do N inorgânico. Revista Brasileira Ciência Solo 19:423-431.

Mattos Jr., D., J.A. Quaggio, S.A. Carvalho, and M.F. Abreu. 1995b. Substratos para produção de mudas cítricas em recipientes: Caracterização da toxicidade de boro. Laranja 16:255-262.

Mattos Jr., D., J.A. Quaggio, and H. Cantarella. 2003. Manejo da Fertilidade do solo. p. 67-80. *In*: D. Mattos Jr., D. de Negri, and J.O. Figueiredo. Lima ácida Thaiti. Campinas: Instituto Agronômico.

Mattos Jr., D., D.A. Graetz, and A.K. Alva. 2003b. Biomass distribution and 15N-nitrogen partitioning in citrus trees on a sandy Entisol. Soil Science Society America Journal 67:555-563.

Mattos Jr., D., Alva, A.K., S. Paramasivam, and D.A. Graetz. 2003c. Nitrogen mineralization and volatilization in sandy Entisol under citrus trees. Communication in Soil Science and Plant Analysis 54:1803-1824.

Mattos Jr., D., J.A. Quaggio, H. Cantarella, and A.K. Alva. 2003. Nutrient content of biomass components of Hamlin sweet orange trees. Scientia Agrícola 60:155-160.

Mattos Jr., D., J.A. Quaggio, H. Cantarella, S.A. Carvalho. 2004. Modelos de resposta do tangor Murcott à fertilização com N, P e K. Revista Brasileira Fruticultura 26:164-167.

Medina, C.L., E.C. Machado, and M.M.A. Gomes. 1999. Condutância estomática, transpiração e fotossíntese em laranjeiras 'Valência' sob deficiência hídrica. Revista Brasileira Fisiologia Vegetal 11:29-34.

Moreira, S. 1960. Um novo problema para nossa citricultura. Revista de Agricultura 35:77-82.

Paramasivam, S., A.K. Alva, K. Hostler, G.W. Easterwood, and J.S. Southwell. 2000. Fruit nutrient accumulation of four orange varieties during fruit development. Journal Plant Nutrient 32:313-327.

Pompeu Jr., J. 1991. Porta-enxertos. 265-280. *In*: O. Rodriguez, F. Viégas, J. Pompeu Jr., and A.A. Amaro. Citricultura brasileira. Campinas: Fundação Cargill.

Quaggio, J.A., J. Teófilo Sobrinho, and A.R. Dechen. 1992a. Response to liming of 'Valencia' orange tree on Rangpur lime: Effects of soil acidity on plant growth and yield. Proceeding Introduction Society Citriculture 2:628-632.

Quaggio, J.A., J. Teófilo Sobrinho, and A.R. Dechen. 1992b. Magnesium influences on fruit yield and quality of 'Valencia sweet orange on Rangpur lime. Proceeding Introduction Society Citriculture 2:633-637.

Quaggio, J.A. 1996. Análise de solo para citros: Métodos e critérios para interpretação. p. 95-114. *In*: SEMINÁRIO INTERNACIONAL DE CITROS –NUTRIÇÃO E ADUBAÇÃO, 4. Donadio, L.C., Baumgartner, J.G. (coord.). Bebedouro, Campinas Fundação Cargill.

Quaggio, J.A., V. Rossetti, and C.M. Chagas. 1996. Anormalidades de tangerinas Poncãn no Estado de Minas Gerais, provocadas por deficiência de boro. Bragantia, 55:157-162.

Quaggio, J.A., H. Cantarella, and D. Mattos Jr. 1996a. Soil testing and leaf analysis in Brazil - recent developments. Proceeding Introduction Society Citriculture 2:1269-1275.

Quaggio, J.A., B. van Raij, and C. Toledo Piza Jr. 1997. Frutíferas. p. 121-153. *In*: B. van Raij, H. Cantarella, J.A. Quaggio, and A.M.C. Furlani (ed.) Recomendações de adubação e calagem para o Estado de São Paulo. 2nd ed. Campinas: Instituto Agronômico e Fundação IAC.

Quaggio, J.A., H. Cantarella, B. van Raij. 1998. Phosphorus and potassium soil test and nitrogen leaf analysis as a basis for citrus fertilization. Nutrient Cycling in Agroecosystems 52:67-74.

Quaggio, J.A., and C.T. Pizza Jr. 2001. Fruteiras tropicais. *In*: M.E. Ferreira, M.C.P. Cruz, B. van Raij, and C.A. Abreu (ed.) Micronutrientes e elementos tóxicos na agricultura. Jaboticabal: CNPq/Fapesp/Potafos. p. 459-492.

Quaggio, J.A., D. Mattos Jr., H. Cantarella, E.L.E. Almeida, and S.A.B. Cardoso. 2002. Lemon yield and fruit quality affected by NPK fertilization. Science Horticulture 96:151-162.

Quaggio, J.A., D. Mattos Jr., H. Cantarella, and A. Tank Jr. 2003. Fertilização com boro e zinco no solo em complementação à aplicação via foliar em laranjeira Pêra. Pesquisa Agropecuária brasileira 38:627-634.

Raij, B. van, J.C. Andrade, H. Cantarella, and J.A. Quaggio (ed.). 2001. Análise química para avaliação da fertilidade de solos tropicais. Campinas: Instituto Agronômico.

Raij, B. van, H. Cantarella, J.A. Quaggio, and A.M.C. Furlani. 1997. Recomendações de adubação e calagem no Estado de São Paulo. 2nd ed. Campinas: Instituto Agronômico.

Reuther, W. Citru. 1977. *In*: P.T. Alvin, and T.T. Kolzowski (ed.) Ecophysiology of tropical crops. New York: Academic Press 409-440.

Rodriguez, O., and S. Moreira. 1968. Citrus nutrition – 20 years of experimental results in the State of São Paulo, Brazil. Proceeding Introduction Society Citriculture 1:1579-1586.

Rodriquez, O., S. Moreira, J.R. Gallo, and J. Teófilo Sobrinho. 1977. Nutritional status of citrus trees in São Paulo, Brazil. Proceeding Introduction Society Citriculture 1:9-12.

Smith, P.F. 1966. Leaf analysis of citrus. p. 208-228. *In*: N.F. Childers (ed.) Nutrition of fruit crops. New Jersey: Somerset Press.

Spiegel-Roy, P., and E.E. Goldschmidt. 1996. Biology of citrus. Cambridge: Cambridge University Press.

Syvertsen, J.P., and J. Lloyd. 1994. CO2 assimilation of *Citrus* leaves: From mesophyll conductance to gross primary productivity of trees in different climates. Acta Horticulture 416:147-154.