Nutrient Management for High Citrus Fruit Yield in Tropical Soils

By Dirceu Mattos Junior, José Antônio Quaggio, Heitor Cantarella, Rodrigo Marcelli Boaretto, and Fernando César Bachiega Zambrosi

Current recommendations for nutrient management of citrus in tropical conditions are summarized based on the use of soil and leaf analyses, fruit yield, and characteristics of tree varieties commercially grown in Brazil.

Citrus fertilizer recommendations in Brazil largely began as adaptations of scientific information and fertilizer recommendations available in Florida and California. However, inherent differences between varieties and soils (i.e. acidic, low fertility, high P fixation) all pointed to the need for a regionally-adapted approach.

Since the 1980s, the Instituto Agronômico of Campinas (IAC) has worked to develop methods for simultaneously extracting P, Ca, Mg, and K. Extensive research on liming and fertilization has demonstrated the importance of correcting soil acidity. Subsequent work revealed the critical importance of Ca and Mg in tropical soils and their effects on citrus production and fruit quality (Quaggio et al., 1992a, b). Calibration curves for P and K have allowed estimation of concentrations of soil nutrients, above which no increase in fruit yield is expected (Quaggio et al., 1996, 1998). Mathematical models fitted to these data, allowed the concept of economy to be introduced to the fertilizer recommendations, considering soil and leaf analysis as criteria for assessing soil N availability, and fruit yield as an index of nutritional balance in citrus orchards (Cantarella et al., 1992). Scientific contributions on the effects of fertilization on fruit quality have been incorporated into these recommendations (Quaggio et al., 2005). More recently, with the significant increase in the area of citrus production under irrigation, studies on the efficiency of fertigated systems in tropical soils have also been developed.

Soil Analysis Guidelines

Guidelines for the interpretation of soil macro- and micronutrients fertility specific to citrus are provided in **Tables 1** and **2**. As a general recommendation, citrus growers should maintain soil levels for nutrients and base saturation within the adequate ranges, thus preventing deficiencies or excesses, since both limit the productivity and quality of fruits.

Leaf Analysis Guidelines

Citrus stores significant amounts of nutrients in tree biomass, part of which is available to be redistributed mainly to developing organs such as leaves and fruits (Mattos Jr. et al., 2003b). For this reason, leaf analysis is a useful tool to complement the analysis of soil fertility and also to assess the nutritional balance of citrus plants. Moreover, in the case of N, where methods of soil analysis lack consistency in diagnosis, citrus leaf N analysis has been used as a criterion for evaluating its availability (Quaggio et al., 1998).

Guidelines used for interpretation of leaf analysis are provided in **Table 3**. Orchard fertilization programs should

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; B = boron; Cu = copper; Fe = iron; Mn = manganese; Zn = zinc; Mo = molybdenum; Al = aluminum.

Table 1. Guidelines for interpretation of soil analysis for macronutrients and base saturation in the topsoil of citrus orchards.

Interpretation class	P-resin, mg/dm^3	exch-K, $mmol_c/dm^3$	Mg, $mmol_c/dm^3$	Base saturation, %
Very low	<6	<0.8	<2	<25
Low	6-12	0.8-1.5	2-4	25-50
Optimum	13-30	1.6-3.0	5-9	51-70
High	>30	>3.0	>9	>70

Quaggio et al. (2010).

Table 2. Guidelines for interpretation of soil analysis for micronutrients in the topsoil of citrus orchards.

	B	Cu	Mn	Zn
Interpretation class†	- - - - - - - - - - - - - mg/dm³ - - - - - - - - - - - - -			
Low	<0.6	<2.0	<3.0	<2.0
Optimum	0.6-1.0	2.0-5.0	3.0-6.0	2.0-5.0
High	>1.0	>5.0	>6.0	>5.0

†B extracted with hot water; Cu, Mn, and Zn extracted with DTPA.
Quaggio et al. (2010).

Table 3. Guidelines for interpretation of orange tree leaf analysis based on 4 to 6-month old spring flush leaves from fruiting terminals.

Nutrient	Low	Optimum	High
	- - - - - - - - - - - - - g/kg - - - - - - - - - - - - -		
N	<23	23-27	>30
P	<1.2	1.2-1.6	>2.0
K	<10	10-15	>20
Ca	<35	35-45	>50
Mg	<3.0	3.0-4.0	>5.0
S	<2.0	2.0-3.0	>5.0
	- - - - - - - - - - - - - mg/kg - - - - - - - - - - - - -		
B	<80	80-160	>160
Cu	<10	10-20	>20
Fe	<49	50-120	>200
Mn	<34	35-50	>100
Zn	<34	35-50	>100
Mo	<2	2-10	>10

Quaggio et al. (2010).

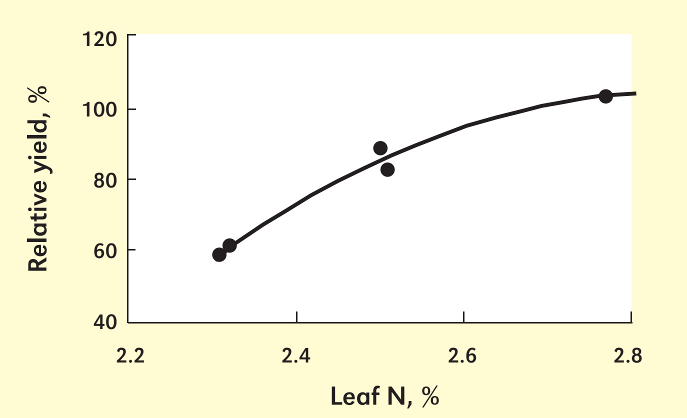

Figure 1. Response of citrus fruit yield in relation to leaf N content (Quaggio et al., 1998).

Brazil is the world leader in the production of citrus, with an annual volume of 18 to 20 million t of fruit, or 20% of the world's total.

also be adjusted so that the leaf nutrient concentrations are maintained within the optimum range.

Soil Liming

Soil acidity is recognized as a major factor of low crop yields due to Al toxicity, Mn toxicity in some species, low levels of Ca and Mg, and for reducing the availability of other nutrients such as P. The main causes of soil acidification of citrus orchards in the tropics include continued use of acidifying N fertilizers, the use of fertigation, and pest control largely based on forms of elemental S.

Much of the response of citrus to lime is due to the high demand of Ca by trees (Mattos Jr. et al., 2003b). Citrus also demand significant amounts of Mg commonly supplied as dolomitic limestone. The need for lime is calculated based on an established calibration curve. The goal is to raise the base saturation (V) to 70% in the topsoil (0 to 20 cm depth), determined at pH 5.5 ($CaCl_2$ 0.01 mol/L) (Quaggio et al., 1992b). It is also recommended to manage lime application so levels of Mg in the soil are raised and maintained to a minimum of 5, or ideally 9 $mmol_c/dm^3$ (Quaggio et al., 1992a). The calculation of lime requirement is made by the following formula:

Lime (t/ha) = CEC (BS_2 - BS_1)/10 ECCE
where:
CEC = Soil cation exchange capacity, $mmol_c/dm^3$;
BS_1 = Current soil base saturation (%), 0 to 20 cm depth layer;
BS_2 = Soil base saturation recommended for citrus, equal to 70%, and
ECCE = Effective Calcium Carbonate Equivalent (%) based on the combined effect of chemical purity and fineness of grind of limestone applied.

The evaluation of soil acidity should be a routine practice within the management program of an orchard. Fertilizers in citrus are generally applied in bands that extend from under the tree to a just beyond the tree line. Thus the application of lime should also be applied in larger amounts in these locations.

Fertilizer Application

The recommendations of N, P and K fertilizer rates vary with orchard age (i.e. planting, young trees <5-years-old, and mature trees), citrus fruit type, rootstock, and the quality and market destination of the fruit (i.e. fresh or industrial). Leaf N content has proven to be a good indicator to recommend N fertilizer rates (**Figure 1**). Orange and mandarin response to N fertilization is lowest for foliar N concentrations above 2.8% (Quaggio et al., 1998; Mattos Jr. et al., 2004).

Since citrus trees store a large amount of N that can be easily redistributed to developing organs such as leaves and fruit, a reduction of the N fertilization may not affect fruit yield immediately. However, when leaf N levels are below those recommended, trees may suffer from gradual reduction in growth, which consequently will lead to losses in fruit production in subsequent years. The lack of N, or excess, affects size and quality of fruits (Quaggio et al., 2006a). High doses of N increase the number of fruits on the tree at the expense of fruit size. Fertilization with K also affects the size of the fruit, but excessive amounts can cause production losses largely due to an imbalance created with leaf Ca and Mg (Mattos Jr. et al., 2004). Furthermore, management of N fertilizers is important to ensure its efficient use in the production system. Urea, the most common source of N in Brazil, is subject to higher losses through volatilization of ammonia (NH_3) if no incorporation (mechanical or irrigation/rainfall) occurs. Volatilization losses may vary from 15 to 45% of N applied to the soil surface (Cantarella et al., 2003; Mattos Jr. et al., 2003b).

For P and K, calibrations of soil analysis based on extraction of nutrients with ion exchange resins are provided in **Figure 2**. The critical level for soil K availability is similar to that used for annual crops (2.0 $mmol_c/dm^3$), but for P the critical level for citrus is lower (18 to 20 mg/dm^3).

Fertilization of mature orange orchards should be conducted in the rainy season based on the recommendation guidelines presented in **Table 4**, because the demand for nutrients for citrus is highest in early spring, when vegetative growth is more intense, and extends until early fall, when nutrient reserves in the trees must be maximum to ensure optimum flowering and fruit set (Bustan and Goldschmidt, 1998). The application of N and K in 3 or 4 splits during the year increases fertilizer efficiency by reducing losses of soil nutrients with water drainage, which occurs mainly in sandy soils, and favors proper timing of nutrient supply at different

Table 4. Fertilizer recommendations for mature orange trees based on soil and leaf analyses, and fruit production classes.

Production class, t/ha	Leaf N, g/kg			P-resin, mg/dm^3				Exch-K, $mmol_c/dm^3$			
	<23	23-27	>27	<5	6-12	13-30	>30	<0.7	0.8-1.5	1.6-3.0	>3.0
	N, kg/ha			P_2O_5, kg/ha				K_2O, kg/ha			
<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	40
41 - 50	220	200	160	140	120	100	0	180	140	100	50
>50	240	220	180	160	140	120	0	200	160	120	60

stages of development of citrus (flowering to fruit maturation). It is recommended to apply 30 to 40% of N and K at flowering.

Fertigation

The area under citrus irrigation in São Paulo, Brazil has significantly increased in recent years, with most of it under drip irrigation. Fertigation is a technique that allows the application of fertilizers to plants through irrigation water. In this system one can lower the dose of fertilizer application with a consequent increase in the number of applications.

When nutrients are supplied with irrigation water, efficiency of nutrient absorption is increased because of more uniform distribution of fertilizers and the possibility to fine-tune the application of nutrients to the demands of trees in different phenological stages (Alva et al., 2008). Results of research in tropical soils have shown that citrus fertilizer efficiency increases up to 25% with drip irrigation compared to conventional, granular application (Quaggio et al., 2006b). Thus, in drip-fertigated orchards, rates of N and K can be reduced by up to 20% (**Table 4**). As fertilizers in drip fertigation are applied in a localized form, there is greater concentration of anions and cations in soil solution in relation to conditions found with granular applications. Therefore, fertigated orchards present greater potential for nutrient losses by leaching and for soil acidification. In tropical soil conditions, phosphoric acid is not recommended as a source of P.

Micronutrients

Foliar fertilization has been the most important practice used to apply micronutrients in citrus, not only because the amounts required are small, but also to avoid adsorption of metal elements to soil colloids, which reduces the availability of metal micronutrients to the plants. The application of B to citrus should preferably be made to the soil (Boaretto et al., 2011). However, the addition of the micronutrient to NPK mixtures often causes problems of segregation, because of the difficulty of obtaining an efficient granulated source of B. Therefore, it is most practical and efficient to apply boric acid dissolved with herbicides. Depending on the rootstock, 2 to 3 kg B/ha is recommended regardless of of the orchard's age.

Micronutrients such as Mn, Zn, and B have low mobility in phloem (Embleton et al. 1965; Boaretto et al., 2004, 2008). Therefore, general recommendations for foliar application to citrus are to prepare mixtures of salts and urea (5 g/L), in the concentrations (mg/L) of Zn (500 to 1,000), Mn (300 to 700), B (200 to 300), and Cu (600 to 1,000). Quantities of the fertilizer products vary with the type of salt used (i.e. chloride, nitrate and sulfate).

Foliar applications should be made in the spring and summer when leaves are young and have a poorly developed cuticle. This facilitates absorption and supply to developing organs. BC

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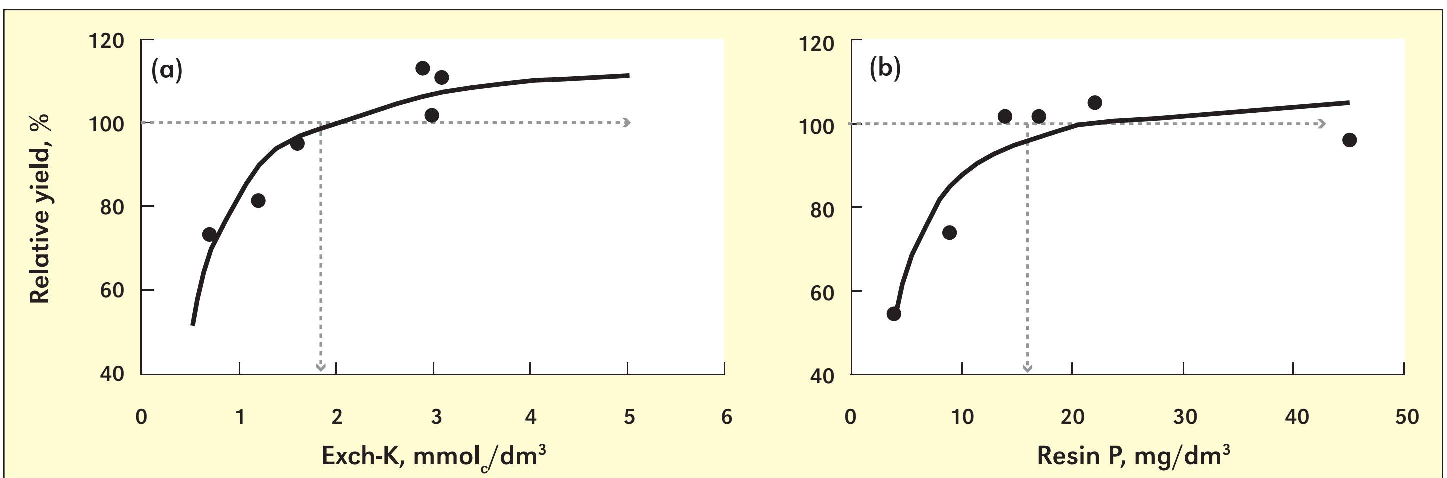

Figure 2. Calibration curve for relative production of citrus in relation to the contents of exchangeable-K (a) and P-resin (b) in the soil. (Quaggio et al., 1998).

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São Paulo State has approximately 80% of the production of oranges in Brazil within an area of 550,000 ha. This production is intended primarily to produce concentrated orange juice.

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11th International Conference on Precision Agriculture Set for July 15-18

The International Society of Precision Agriculture (ISPA) is organizing the 11th International Conference on Precision Agriculture (ICPA) to be held at the Hyatt Regency in Indianapolis, Indiana, USA from July 15th to July 18th, 2012.

Precision agricultural techniques, technologies, and its applications continue to grow across the globe and so does the precision agricultural community. The 11th ICPA is envisioned to be the largest ever with over 600 attendees anticipated from all over the U.S. and from over 50 other countries. The 11th ICPA will highlight significant research and applications in precision agriculture, and will showcase emerging technologies and information management. The conference will offer oral and poster presentations, exhibits, and opportunities for discussion and exchange of information in various aspects of precision agriculture.

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