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Response of Young Citrus Trees on Selected Rootstocks to Nitrogen, Phosphorus, and Potassium Fertilization

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ABSTRACT

The majority of the citriculture in Brazil is located in the state of São Paulo, with a total production area of 700,000 ha. Trees are grafted mostly on 'Rangpur' lime (RL; *Citrus limonia* Osbeck) rootstock. Despite its good horticultural performance, use of other rootstocks has increased with the search for disease-tolerant varieties to improve grove productivity and longevity. Furthermore, there is a lack of information on young tree response to fertilization, and optimal nutrient requirements of different scion/rootstock combinations for maximum fruit yield. A network of field experiments was conducted to study the differential response of young sweet orange trees on selected rootstocks to nitrogen (N), phosphorus (P), and potassium (K) fertilization. The application of soil and leaf analyses to develop optimal fertilizer recommendations was evaluated. Experiments were conducted in three locations using fractional factorial design of one-half ($4 \times 4 \times 4$) type with four rates of N, P, or K calculated to be applied for five years after tree planting. Fruit yield response was evaluated during the last two years and correlated with soil and leaf analyses data. The trees on RL rootstock demonstrated increased efficiency of nutrient use and fruit production compared with those on 'Cleopatra' mandarin (CL; *C. reshni* hort. ex Tanaka) or 'Swingle' citrumelo [SW; *Poncirus trifoliata* (L.) Raf. × C. × *paradisi* Macfad.] rootstocks. The trees on SW rootstock appeared to require greater N and K rates than those on RL rootstock. Phosphorus requirement was greater for 'Natal' or 'Valencia' trees on CL than on RL rootstock. These results will become

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the basis for revising current fertilizer recommendation guidelines for young trees in Brazil.

Keywords: orange, nutrient management, recommendation, fruit yield

INTRODUCTION

The majority of the Brazilian citrus-growing area is located in the State of São Paulo, with 165 million trees, of which about 40 million are less than five years old. Despite the significance of the local citrus industry to the economy, there is a lack of information about the response of young citrus trees to fertilization (Mattos, 2000).

The current guidelines for nitrogen (N), phosphorus (P), and potassium (K) fertilization for citrus for young (<5 years old) and bearing trees in Brazil are based on soil and leaf analyses and yield expectancy (Quaggio et al., 1998). The growth rate of young trees is greater than that of bearing trees. Thus, the availability of nutrients to satisfy the rapid tree growth and development is important. The bearing trees have greater nutrient demand for fruit production and quality. The recommendations for young trees include 80–400 g N tree^{-1} yr^{-1}, 0–130 g P tree^{-1} yr^{-1}, and 0–330 g K tree^{-1} yr^{-1}, and are adjusted based on the tree age. Soil analysis is also used to adjust the P and K needs.

At present, 'Rangpur' lime (RL; *Citrus limonia* Osbeck) rootstock represents $\approx$80% of the Brazilian citriculture. However, there is an emerging need to find a substitute for this variety because of its susceptibility to diseases such as citrus blight (Wutscher et al., 1980) and, more recently, citrus sudden death (=CSD) (Müller et al., 2002). An increase in the use of disease resistant-varieties is expected to occur shortly. 'Cleopatra' (CL; *C. reshni* hort. ex Tanaka) and 'Sunki' [*C. sunki* (Hayata) hort. ex Tanaka] mandarins are tolerant to CSD (Müller et al., 2002) and blight (Timmer et al., 2000), and 'Swingle' citrumelo [SW; *Poncirus trifoliata* (L.) Raf. × *C.* × *paradisi* Macfad.] is resistant to gummosis caused by *Phytophthora* (Castle et al., 1993) and also to CSD (Müller et al., 1980). In addition, trees on this latter rootstock have produced fruit with favorable attributes such as size and juice quality (Castle et al., 1988).

Mandarins represent 13% of this citriculture, whereas SW rootstock accounts for 6%. In this scenario, it is challenging to find information that supports the adoption of those less-important rootstocks for planting new groves. The needed information includes estrategies for best nutrient management.

Fertilizer recommendations for non-bearing citrus trees in Florida include a range of rates for each of the first three years (Ferguson et al., 1995). Nitrogen rates vary, according to tree age, from 70 to 400 g N tree^{-1} yr^{-1}, whereas P and K are applied respectively in amounts equivalent to 0.4 and 0.8 of N required by trees planted on previously uncropped soils. In previously cropped soils, rates of P may be reduced or omitted if soil test results indicate adequate P levels ($>$30 g kg^{-1}, extracted by Mehlich-1). Although fertilizer guidelines make reference to a number of factors that influence fertilizer requirements, these current fertilizer recommendations for citrus in Florida do not account for differences in nutrient requirements of citrus scion and rootstock combinations.

The objectives of this study were (1) to establish N, P, and K rates for maximum fruit yield of young trees (<5 years old) in the State of São Paulo, Brazil, and (2) to evaluate the responses of selected scion/rootstock combinations to fertilization.

MATERIALS AND METHODS

Citrus Groves Characteristics

Three citrus groves with 'Pêra' sweet orange [*Citrus sinensis* (L.) Osbeck] on RL at 7×3 m spacing (=site 1), 'Valencia' sweet orange (*C. sinensis*) on RL and CL rootstocks at 7×3 m spacing (=site 2), and 'Natal' sweet orange (*C. sinensis*) on RL, CL, and SW rootstocks at 7×4 m spacing (=site 3) were used in this study. The experiments were conducted without irrigation in the main citrus-producing areas of the state of São Paulo, Brazil. Site 1 was located in Santa Cruz do Rio Pardo, the southeast region of the state, where annual average temperature is <20°C, rainfall is 1760 mm, and water deficit is negligible. The soil was an Alfisol [O.M. (organic matter) = 23 g kg^{-1}, pH (0.01 mol L^{-1} $CaCl_2$)= 5.9, P resin = 22 g dm^{-3}, CEC (cation exchange capacity) = 117.9 $mmol_c$ dm^{-3}, exchangeable K = 0.9 $mmol_c$ dm^{-3}, and base saturation = 83% at 0–20 cm depth layer]. The other two sites were located in the central (Matão) and northwest (Bebedouro) regions of the state, with an average temperature of 23°C and annual rainfall of 1350 mm. Drought periods are common during the winter in these regions. In site 2, the soil was an Alfisol [O.M. = 16 g kg^{-1}, pH (0.01 mol L^{-1} $CaCl_2$) = 5.5, P resin = 9 g dm^{-3}, CEC = 46.4 $mmol_c$ dm^{-3}, exchangeable K = 1.4 $mmol_c$ dm^{-3}, and base saturation = 63%–0–20 cm depth layer] and in site 3, an Oxisol [O.M. = 24 g kg^{-1}, pH (0.01 mol L^{-1} $CaCl_2$) = 5.3, P resin = 10 g dm^{-3}, CEC = 54.0 $mmol_c$ dm^{-3}, exchangeable K = 2.0 $mmol_c$ dm^{-3} and base saturation = 53% 0–20 cm depth layer]. Soils at sites 2 and 3 received dolomitic lime application in amounts calculated to raise soil base saturation into the plough layer to ≈70% before tree planting (Quaggio et al., 1991).

Experimental Design

Experiments were arranged in a fractional factorial design of one-half ($4 \times 4 \times 4$) type, as proposed by Colwell (1978), and adapted by Andrade and Noleto (1986). A residual mean square was obtained through high-order interactions that provided an upper limit for the value of the error, and as such interactions were small in comparison with the error, they were used to provide an estimate of the experimental error (John and Quenouille, 1977). Confounding of unlike treatment effects was used to reduce the size of the experiment, increasing the efficiency of the model to measure meaningful effects. Therefore, experiments consisted of only a fraction of the complete factorial combinations, for a total of 32 treatments per site without replication and divided into two blocks (Table 1).

Table 1
Treatment description and total nutrient rates applied during five years after tree planting

	Nutrients		
Treatment†	N	P	K
Block I		g per tree	
111	400	180	240
122	400	440	660
133	400	700	1080
144	400	960	1500
212	1000	180	660
221	1000	440	240
234	1000	700	1500
243	1000	960	1080
313	1600	180	1080
324	1600	440	1500
331	1600	700	240
342	1600	960	660
414	2200	180	1500
423	2200	440	1080
432	2200	700	660
441	2200	960	240
Block II			
114	400	180	1500
123	400	440	1080
132	400	700	660
141	400	960	240
213	1000	180	1080
224	1000	440	1500
231	1000	700	240
242	1000	960	660
312	1600	180	660
321	1600	440	240
334	1600	700	1500
343	1600	960	1080
411	2200	180	240
422	2200	440	660
433	2200	700	1080
444	2200	960	1500

†1, 2, 3, and 4 represents the nutrient level within treatments.

The RL rootstock was used as a reference variety present in experimental sites.

The experimental plots consisted of five uniform trees within a row of which the middle three were used for sampling. In sites 2 and 3, five plants of each rootstock in a given treatment were planted in separate rows placed side by side within the plot. As all rootstocks tested were not present in the experimental sites, the effect of rootstocks were analyzed individually rather than as subplots.

Treatments consisted of four N, P, or K rates calculated to be supplied form the first to the fifth year after tree planting (grams per tree): N (400, 1000, 1600, and 2200, as ammonium nitrate), P (180, 440, 700, and 960, as triple superphosphate), and K (240, 660, 1080, and 1500, as potassium chloride). Fertilizer mixtures were applied annually in amounts that corresponded to 7%, 14%, 18%, 26%, and 35% of the total rates (Table 1), from the first to the fifth year, respectively. Mixtures were applied on the soil surface and around the tree, about 50 to 200 cm away from the trunk, according to tree age. Phosphorus was applied in a single dose beginning at spring leaf flush, while amounts of N and K were equally divided into three applications following a 75-d interval each. Zinc (Zn), manganese (Mn), and boron (B), were applied by foliar spray as recommended by Quaggio et al. (1996).

Soil samples were taken from the 0–20 cm depth layer in the fifth year after tree planting, within the band of fertilization, for determination of pH (0.01 mol L^{-1} $CaCl_2$), resin-extractable P and K, and base saturation (V%) using the methods described by van Raij et al. (2001). Six-to eight-month-old spring flush leaves were collected around the canopy rom fruiting terminals in the fourth and fifth years for analysis of various mineral elements according to Bataglia et al. (1983). Fruit yield was measured annually by summing the weight of fruit, if more than one harvest per year was necessary. Fruit harvest occurred at maturity, when the total soluble solids/acidity ratio was in the range of 12–14, and acidity was less than 0.8% (w/v) as determined by standard methods of analyses (Redd et al., 1986).

Data were tested for significant differences among treatments using the analysis of variance (ANOVA) test in a randomized complete block. Response functions of the type: $\hat{Y} = b_0 + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5K + b_6K^2 + b_7NP + b_8NK + b_9PK$ were computed for each experiment, where $\hat{Y}$ is the dependent variable, b_0 to b_9 are the regression coefficients, and N, P, and K are the total rates of N, P, and K applied during five years, using the GLM procedure of the SAS system (SAS, 1996). Dependent variables were (1) the cumulative fruit yield for the fourth and fifth years after tree planting, and (2) the average leaf-nutrient concentrations for the same period.

If, for exemple, responses were observed only for N, the response function was simplified to $\hat{Y} = b_{0'} + b_{1'}N + b_2N^2$, calculated by substituting values of P and K equal to the lowest rate tested and estimating new regression coefficients (i.e., $b_{0'}$ and $b_{1'}$) so that non-significant coefficients did not affect the new model (Cantarella et al., 1992).

Linear regression analysis was used to estimate correlations between soil chemical characteristics, leaf nutrient concentration, and cumulative fruit yield for data from selected experimental sites.

RESULTS AND DISCUSSION

Responses to Nitrogen, Phosphorus, and Potassium Fertilization

Nitrogen

Fruit yield and leaf-N content of citrus trees was affected by N rates, and the response varied among sites and within scion/rootstock combinations evaluated in this study (Table 2). 'Natal' sweet orange on SW rootstock (site 3) showed a quadratic yield response to N fertilization, which increased from 22 to 38 t ha^{-1} with an increase in N rate from 400 to 1500 g per tree (Figure 1A). This represented about 70% increase in fruit yield that was not observed for other rootstocks. Leaf N concentrations of trees on SW varied from 29 to 32 g kg^{-1} and followed a pattern similar to that observed for fruit yield. On the other hand, N concentration in the leaves of trees on either RL or CL did not vary with N rates, and were about 31 and 26 g kg^{-1}, respectively (Figure 1B).

Differences between these two latter rootstocks were similar to 'Valencia' sweet orange's response to N at site 2, despite the differences between scion (Figures 1C and D). At both sites, levels for fruit yield and leaf-N concentration were greater in the trees on RL rootstock than in those on other rootstocks. An exception was at site 3 where, at the highest N rate, no differences were observed in leaf N of trees on RL and SW rootstocks.

Additional data evaluated in this study revealed that trees on RL rootstock produced more fruits per unit volume of canopy than those on CL, even though the proportions of canopy volumes of the two rootstocks were different between sites 2 and 3, and over the first years of tree evaluation (Quaggio et al., 2004).

Because the RL responses to N application were not significant with the scion varieties tested, we suggest that this rootstock was more effective than the others in using soil-available nutrients and in producing fruits.

Furthermore, differences in fruit yield per area basis of trees on either RL or CL compared with trees on SW rootstock were atributted to the reduced plant vigor induced by SW. In the fifth year after tree planting in site 3, trees on RL or CL presented canopy volume about twice of that observed for those on SW (=13 m^3) (Quaggio et al., 2004). This effect is characteristic for trifoliate rootstocks and some of their hybrids (Gardner and Horanic, 1967).

The negative linear term of the response model for N additions in site 1 (Table 2) points to the effect of increased soil acidity at the surface layer,

Table 2
Response functions for cumulative fruit yield of young sweet orange trees on selected rootstocks at three experimental sites

Tree Site†	Model coefficient‡										R^2	CV
	B_0	N	N^2	P	P^2	K	K^2	NP	NK	PK		
	Fruit yield, t ha^{-1}§											%
P/RL; 1	38.3	−2.71E-03	5.19E-06	3.07E-02	1.13E-05	4.01E-02**	−1.03E-05	−2.08E-05**	−2.70E-07	−1.64E-05*	0.75	8.4
V/RL; 2	24.3	2.07E-03	1.49E-06	2.45E-02	−5.01E-06	9.39E-03	−1.50E-07	−6.57E-06	−3.00E-08	−8.46E-06	0.21	18.3
V/CL, 2	18.6	7.66E-03**	1.31E-06	−9.17E-03*	2.01E-05	−1.63E-02	9.00E-06	−9.37E-06	−1.60E-07	9.10E-06	0.52	25.9
N/RL, 3	58.2	−6.67E-03	1.51E-06	−2.99E-04	5.95E-06	2.63E-02	−4.04E-06	1.52E-05	−7.08E-06	−1.60E-05	0.29	16.3
N/CL; 3	30.7	6.94E-03	−2.41E-06	4.64E-02	−4.77E-05*	−4.61E-03	1.34E-05	1.22E-05	−7.91E-06*	−1.15E-05	0.49	15.4
N/SW; 3	10.0	3.23E-02	−7.95E-06*	1.36E-03	1.84E-06	4.54E-03	1.17E-05*	2.50E-07	−1.43E-05**	−5.38E-06	0.61	17.8

†P = ‘Pêra,’ V = ‘Valencia,’ and N = ‘Natal’ sweet oranges; RL = ‘Rangpur’ lime, CL = ‘Cleopatra’ mandarin, and SW = ‘Swingle’ citrumelo rootstocks.

‡$Y = b_0 + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5K + b_6K^2 + b_7NP + b_8NK + b_9PK$. Rates of N, P, and K are total g N, P, or K per tree applied from the first to the fifth years after tree planting.

§Fruit yield = cumulative value for the 4th and 5th year after tree planting ($n = 32$).

*,**Significant at $P = 0.05$ and 0.01, respectively.

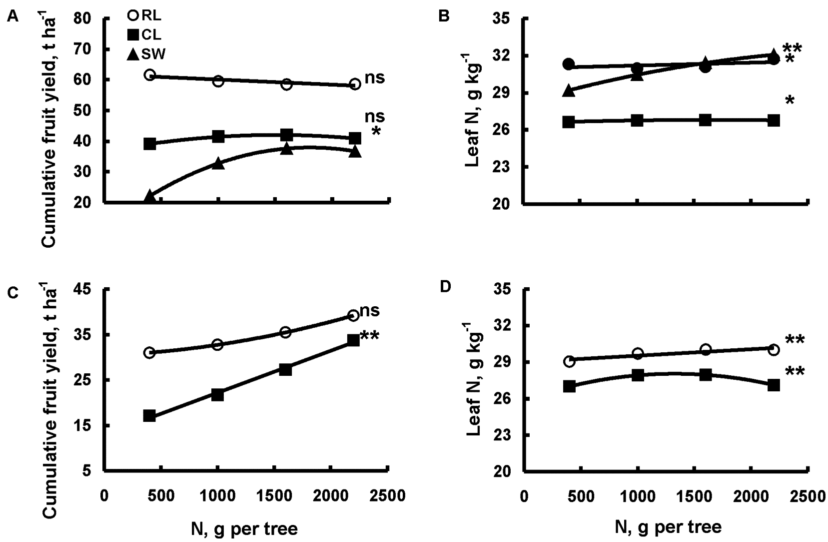

Figure 1. Response of 'Natal' (A and B = site 3) and 'Valencia' (C and D = site 2) sweet oranges on different rootstocks to N fertilization. Data estimated by response models with P = 180 and K = 240 g of nutrient per tree.

and consequently the reduced nutrient availability and increased aluminum toxicity to citrus trees, caused by N fertilization (data not shown). Further data analysis showed that cumulative fruit yield (CFY), in tons per hectare, at this site increased as soil pH increased from 4.5 to ≈6 ($CFY = 6.79pH^2 + 92.28pH - 228.75$; $R^2 = 0.58$; $P < 0.05$) (Mattos, 2000).

Phosphorus

The trees on CL in sites 2 and 3 were more responsive with P fertilization compared with those on other tested rootstocks. Fruit yield of 'Natal' sweet orange on CL with P fertilization increased up to the rate of 700 g of P tree^{-1} at site 3 (Figure 2A). The linear yield response to P fertilization was also apparent in 'Valencia' sweet orange on the same rootstock over the entire range of P rates evaluated in this study (Figure 2C). These P rates required to optimize growth and yield of young trees were greater than those currently recommended for citrus in Brazil (Quaggio et al., 1996).

Other evidence of the differential response of rootstocks to P fertilization is also shown in Figure 2. The concentration of P in the leaves of 'Natal' sweet orange at site 3 increased linearly (1.5 to 1.8 g kg$^-$1) for trees on CL in response to P rates. On the other hand, this same variety on either RL or SW rootstocks showed no major increase of leaf P with P rates. Leaf P of 'Valencia' on CL at site 2 varied from 1.4 to 2.3 g kg^{-1}, while levels of P for trees on

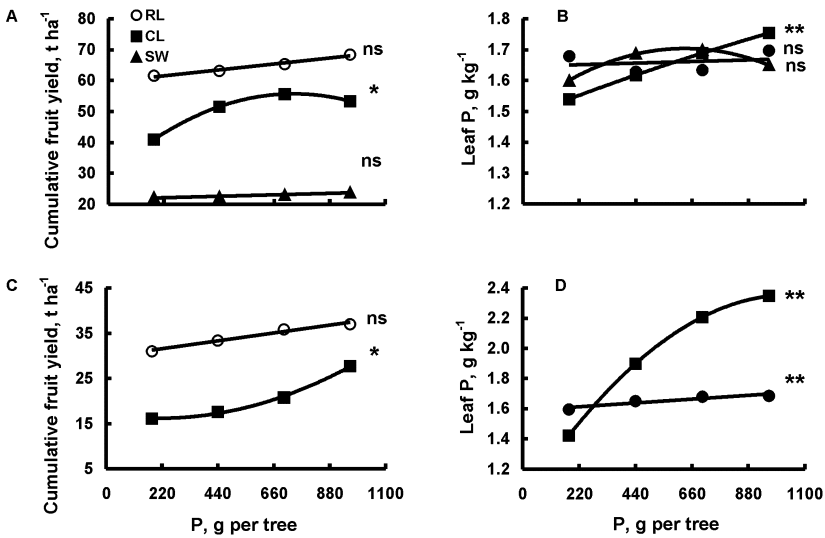

Figure 2. Response of 'Natal' (A and B = site 3) and 'Valencia' (C and D = site 2) sweet oranges on different rootstocks to P fertilization (data estimated by response models with N = 400 and K = 240 g of nutrient per tree; in the case of trees on CL, yield response was estimated with N = 2200 g per tree).

RL was about 1.6 g kg^{-1} and did not change significantly with fertilization (Figure 2D).

Samiullah and Narasimham (1979) reported that leaf P concentration of sweet orange was lowest for trees on CL compared with that of trees on 'Troyer' citrange [*P. trifoliata* (L.) Raf. × *C. sinensis* (L.) Osbeck], 'Volkamer' lemon (*C. volkameriana* V. Ten. & Pasq.), or 'Rough' lemon (*C. jambhiri* Lush.) rootstocks. Because these latter two citrus rootstocks present characteristics similar to RL, e.g., tree vigor and fruit quality, it is possible that differences in leaf-nutrient content are in agreement with our results if trees were grown in soil with low available P. Wutscher (1989) also reported low concentration of N and P in the leaves of several sweet orange cultivars on CL compared with other rootstocks.

Figure 3 shows the close relationship between P fertilization and P concentrations at the soil (resin extracted) and in the leaves of 'Valencia' orange trees on CL at site 2. Relative fruit yield increased above critical levels for soil P (20 mg dm^{-3}) established for bearing trees (Quaggio et al., 1998). Similarly, leaf P concentration was greater than the adequate level for bearing trees (1.2–1.6 g kg^{-1}) suggested by Quaggio et al. (1996). Young trees (five years old) have a smaller root system and grow faster than older trees; therefore, the former demand higher concentrations of soil P, as the volume of soil explored by roots

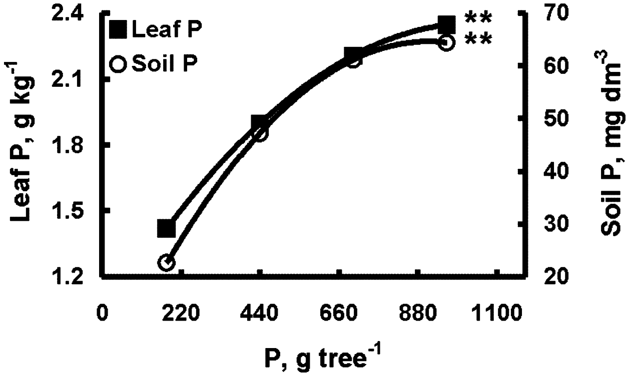

Figure 3. Correlation between P fertilization and both soil-available P and leaf P concentration for 'Valencia' sweet orange trees on 'Cleopatra' mandarin rootstock at site 2 (data were estimated by response models with N = 400 and K = 240 g of nutrient per tree).

is smaller and the band where fertilizer is applied to the soil surface changes annually as the canopy diameter increases.

The significant NP interaction for fruit yield at site 1 (Table 1) demonstrated an antagonism between those two nutrients at high N rates. Wallace (1990) reported a severe antagonism for N and P fertilization of 'Valencia' orange trees, which resulted in significant decrease of fruit yield.

Current recommended rates of N and P fertilizers for young citrus trees in Brazil run up to 1140 g N and 460 g P per tree up to the age of five years (Quaggio et al., 1996). The results of this study demonstrated that the above N and P rates are not adequate for trees on the same rootstock. Leaf nutrient analysis showed that the critical limits of leaf concentration of N and P for young trees could be greater than those reported by Quaggio et al. (1996) for bearing trees. Willis et al. (1990), and Obreza and Rouse (1993) found that leaf concentration of selected nutrients in young trees tended to be greater than those recommended for bearing trees in Florida (Koo et al., 1984).

Potassium

The increase in fruit yield due to K fertilization was marked for trees on SW compared with that of the trees on the other two rootstocks at site 3 (Figure 4A). 'Natal' sweet orange on this rootstock showed a yield increase of 22 to 45 t ha^{-1} when K rates increased from 240 to 1500 g tree^{-1}. The response of 'Valencia' trees on CL and RL to K fertilization presented trends similar to those obtained at site 2 (Figure 4A and C), although fruit yield estimated for trees on CL was not meaningfully affected by fertilization. The very significant response of

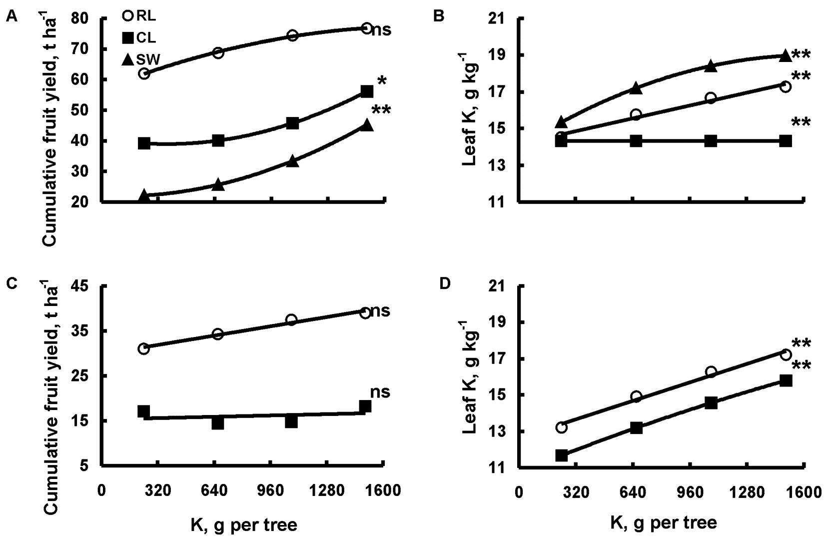

Figure 4. Response of 'Natal' (A and B = site 3) and 'Valencia' (B and C = site 2) sweet oranges on different rootstocks to K fertilization (data were estimated by response models with N = 400 and P = 180 g of nutrient per tree).

'Pêra' sweet orange on RL to K fertilization (Table 1, Figure 5A) demonstrated that, where soil-K reserve is low and leaching losses of this nutrient are most probable, greater rates of fertilizer are required for high fruit yields. Results of soil analysis for this experiment were presented by Mattos (2000) and revealed that maximum exchangeable K observed in the plough layer at site 1 was 2.0 $mmol_c\ dm^{-3}$. This level was attained at the highest rate of fertilizer applied and was less than half of that observed at sites 2 and 3.

With an increase in K rates, leaf K increased for the 'Natal' trees on SW and RL rootstocks, while the trees on CL rootstock showed no response (Figure 4B). Our data are in agreement with the findings of Wutscher (1989), in which K requirement for trees on SW rootstock was greater than that for citrus trees on other rootstock varieties. For 'Valencia' on CL at site 2, leaf K increased linearly with increased K rates.

The fruit yield response in the case of Pêra cultivar on RL rootstock was linear to K fertilization at site 1 (Table 1, Figure 5A). The model allowed estimation of fruit yield increase of about 50% with an increase in K rates of from 240 to 1500 g $tree^{-1}$. The current citrus fertilization recommendations for young trees in Brazil suggest 620 g K per tree during five years after tree planting (Quaggio et al., 1996). This rate appears to be inadequate for low-K soils, based on the results of this study regarding the response to K fertilization observed at site 1. Average K concentration in the leaves from fruiting terminals was also increased by K fertilization over the entire range of K rates evaluated,

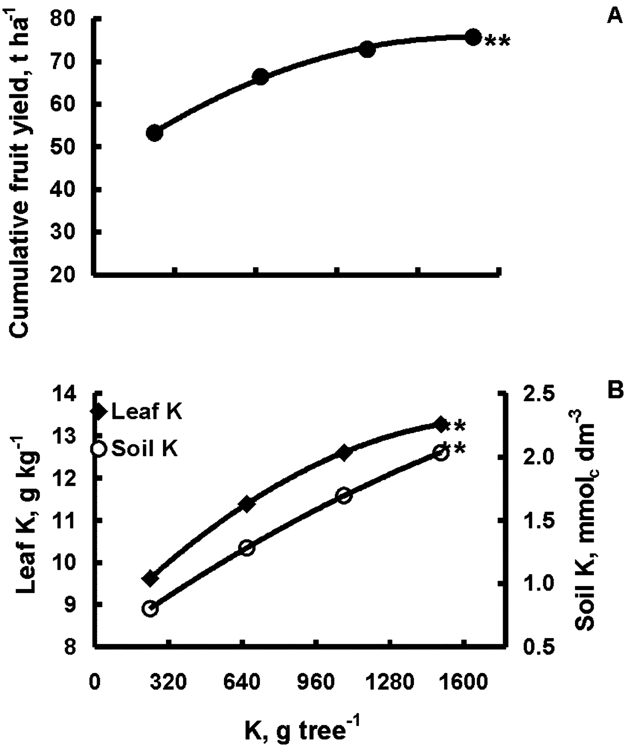

Figure 5. Response of 'Pêra' sweet orange on 'Rangpur' lime to K fertilization (A), and its effects on concentration of leaf K and soil-exchangeable K (B) at site 1 (data estimated by response models with N = 400 and P = 180 g of nutrient per tree).

i.e., 240–1500 g tree^{-1} (Figure 5B). The results also showed a good correlation between the leaf K and soil-exchangeable K in response to an increase in K rates (Figure 5). The relationships between increased rates of K and citrus production were non-significant in Florida (Hunziker, 1960; Koo, 1962; Hanlon et al., 1995). On the other hand, studies conducted in the State of São Paulo, Brazil, have shown the relationship between fruit yield of bearing sweet orange (Cantarella et al., 1992) and lemon [*C. limon* (L.) Burm f.] (Quaggio et al., 2002) trees and exchangeable K levels, following application of K rates ranging from 25 to 225 kg K ha^{-1}yr^{-1}.

Maximum fruit yield of 'Pêra' on RL trees was observed with a soil-exchangeable K level of about 2.0 mmol$_c$ dm^{-3} (Figure 5), which is in agreement with the critical level of K in the soil related to fruit yield as reported by Quaggio et al. (1998).

This study associated knowledge on soil chemical characteristics and plant response to nutrient availability to support growers with needed information for sound nutrient management of citrus groves. Therefore, the data in these experiments have been used to update the fertilizer recommendations for establishing young citrus groves in Brazil.

CONCLUSIONS

Trees on 'Rangpur' lime demonstrated the ability to use N, P, and K more efficiently, and consequently produced more fruits than trees on 'Cleopatra' mandarin and 'Swingle' citrumelo rootstocks. On the other hand, those on 'Swingle' citrumelo showed a higher demand for either N or K in order to reach a level of fruit production similar to that obtained by trees on 'Cleopatra' rootstock. Furthermore, 'Cleopatra' mandarin required more P than either 'Swingle' citrumelo or 'Rangpur' lime with both 'Natal' and 'Valencia' sweet oranges.

Superior fruit yield of trees on 'Cleopatra' and 'Swingle' was attained at higher rates of nutrients than are currently recommended in Brazil. The results also demonstrated a good correlation between fruit yield and soil P and K, with critical levels of 60 mg kg^{-1} and 2.0 $mmol_c$ dm^{-3}, respectively.

Leaf nutrient concentrations varied in response to applied nutrients and were correlated with response observed for fruit yield. Adequate concentrations of leaf nutrients of trees on 'Rangpur' lime rootstock appeared to be close to the values reported for bearing trees. Trees on 'Cleopatra' mandarin showed adequate P levels $\approx$2.2 g kg^{-1}, and those on 'Swingle' citrumelo showed N and K levels of 30 and 18 kg^{-1}, respectively.

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