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Phosphorus and potassium soil test and nitrogen leaf analysis as a base for citrus fertilization

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Abstract

A network of six NPK long-term field trials was carried out on different soils of citrus-producing regions of São Paulo state, Brazil, in order to estimate quantitative relations of fruit yield to NPK fertilization and to determine parameters for fertilizer recommendation based on soil testing and leaf analysis. The experiments were set up in an incomplete factorial design $1/2\ 4^3$ with 32 treatments, with four yearly rates of N (30, 100, 170 and 240 kg N/ha), P (9, 27, 45 and 63 kg P/ha) and K (25, 91, 157 and 223 kg K/ha). Four to seven harvests were recorded for the six experiments. Response surfaces of the type $y = bo + b_1N + b_{11}N^2 + b_2P + b_{22}P^2 + b_3K + b_{33}K^2 + b_{12}NP + b_{13}NK + b_{23}PK$ were adjusted to the average yields of each trial. Correlation were established for yield increases, expressed as relative yields, and results of soil analysis of P and K, and leaf analysis of N. Soil samples taken at 0-20 cm depth in the beginning of each experiment were analyzed for resin extractable P and exchangeable K using an ion-exchange resin procedure. Yield responses for phosphorus and potassium applications were observed respectively in soils with less than 20 mg dm^{-3} of P and 20 mmol$_c$ dm^{-3} of K^+. Yield responses to nitrogen were related to the total content of nitrogen in leaves, being largest for N values of 23 g kg^{-1} and smallest for N of 28 kg^{-1}. With these field information, a practical approach for fertilizer recommendation for citrus, based on soil analysis for P and K and leaf analysis for N, was developed.

Introduction

Soil testing has been widely used for fertilizer recommendation of annual crops. The success of this technique depends on previous calibration of the results of soil analysis with crop response to added fertilizer, as proposed by Bray (1948) and successfully applied to annual crops by several researchers, as Rouse (1968) in Alabama-USA, Raij (1974) and Raij et al. (1983, 1986) for tropical soils in Brazil.

The lack of calibration curves for perennial crops has limited the use of soil testing as a guide to assess fertilizer requirements of fruit crops. Besides, the field work necessary to obtain this information is much more laborious and costly than for annual or vegetable crops. Thus, leaf analysis is preferred for fertilizer recommendation for fruit crops and the use of soil testing is usually restricted to the assessment of lime requirement or to monitoring the buildup of soil fertility (Righetti et al., 1990).

The use of soil analysis as a guide for fertilizer recommendation for citrus has been questioned due to the lack of specific calibration between soil extractants for P and K and crop response (Hanlon et al., 1995), the absence of correlation between soil extractable K and leaf-K in calcareous soils (Reitz and Koo, 1959), and too excessive leaching of K in sandy soils (Koo, 1962). There has been efforts in Florida to calibrate soil K with the response to K fertilizer application (Hunziker, 1960) and to establish correlations between leaf P and soil P extracted by Mehlich 1 and Bray 1 solution (Anderson, 1983). Du Plessis (1977) demonstrated the importance of soil testing as an advisory tool for citrus fertilization in South Africa. Soil testing has been used also in Spain as a guide for the application of fertilizer N, P, and K (Legaz and Primo

Millo, 1985). In Brazil, the class limits of soil testing used for citrus have been adapted from annual crops (Grupo Paulista, 1988). Recent research by Cantarella et al. (1992), indicates that soil analysis can be used to predict fertilizer needs for citrus in that country. Therefore, the purpose of this research was to establish criteria for fertilizer recommendation for citrus in tropical soils, using data from Cantarella et al. (1992) and new experimental results.

Materials and methods

Six field experiments were conducted on different soils of the citrus-producing region of the State of São Paulo in at least 4 years old commercial groves. The rootstock and scion varieties used, as well as the plant spacing and year of planting, and periods in which data were collected from each experiment are presented in Table 1. From 4 to 7 harvests were obtained for each trial, comprising 30 site-years of information.

The experimental design was a fractional factorial of the (1/2) 4^3 type, with a total of 32 plots, distributed in two blocks, as proposed by Colwell (1978), and adjusted by Andrade and Noleto (1986) to allow calculations of all first order interactions. Details of the treatments are presented by Cantarella et al. (1992). Treatments consisted of four annual rates of N (30, 100, 170, and 240 kg N/ha, as nitrochalk), P (9, 27, 45 and 63 kg of P/ha, as triple superphosphate), and K (25, 91, 157 and 223 kg of K/ha, as potassium chloride), split into three applications during the rainy season. Fertilizers were applied in both sides of the plant rows, in bands whose widths were equal to the radius of the plant canopies. The groves were sprayed twice a year with a micronutrient solution containing Zn, Mn and B. In the beginning of the experiment, all areas were limed to increase the soil base saturation to 70% of the cation exchange capacity at pH 7 and thereafter, every three years.

Each plot consisted of 20 plants, of which the six centrally located were the sampling units. Yields were computed annually by summing up the fruit weights, if more than one harvest per year was necessary. Soil samples collected before the first fertilizer application were analyzed for ion exchange resin extractable P and exchangeable K, Ca and Mg by the methods described by Raij et al. (1986), and the results are presented in Table 2. Six month-old leaves, from fruit-bearing branches, were analyzed for total N (Bataglia et al., 1983). The average results of leaf N from samples collected every year from the treatments with the lowest N rate applied are presented in Table 2.

Response functions of the type $Y = b_0 + b_1N + b_{11}N^2 + b_2P + b_{22}P^2 + b_3K + b_{33}K^2 + b_{12}NP + b_{13}NK + b_{23}PK$ were adjusted to the yields of each trial, averaged over the years of data collection. In the above model, Y is fruit yield (t/ha), b is the regression coefficient, and N, P, and K are rates of N, P and K, in kg/ha, respectively. Quadratic functions for individual nutrients were then calculated by replacing the rates of application regarding the other two nutrients for the optimum rates to maximize fruit yield, so that the response function for each element was calculated with no limitation of the other two.

Relative yield was taken as the ratio of the yield obtained without application of a given nutrient, to the maximum yield of fertilized plots, expressed in percentage. The zero-nutrient rate-yield was calculated by extrapolation with the use of the quadratic-model yield function, averaged over all harvests of a given experiment, since a small rate of N, P and K was always applied. Plots of relative yield against soil P and K were used to calibrate the results of soil analysis and to define the classes of soil P and K availability. Likewise, a plot of relative yield against leaf N was used

Table 1. Location, year of planting, citrus varieties, and period of observation of the experiments

Location	Year of planting	Rootstock	Scion	Spacing	Observation period
				— m —	— year —
Monte Azul	1982	Rangpur lime	Pera	7.5×6.5	1987-1991
Matão	1981	Rangpur lime	Valencia	8.0×6.0	1987-1992
Pirassununga	1984	Cleopatra M.	Pera	7.5×4.0	1987-1994
Olímpia	1981	Rangpur lime	Natal	8.0×6.0	1987-1991
Botucatu	1982	Volkameriana	Lemon	8.0×6.0	1989-1995
Araraquara	1983	Rangpur lime	Pera	7.0×4.0	1987-1991

Table 2. Results of soil analysis prior to fertilizer application in the first year and the average leaf nitrogen of the treatment with 30 kg N/ha

Location	P-resin	pH	Exchangeable cations K	Ca	Mg	CEC	Base saturation	Organic matter	Leaf N
	mg dm^{-3}		——— mmol$_c$ dm^{-3}	———			%	—g kg^{1}	—
Monte Azul	14	5.5	3.1	26	10	58	67	15	23
Matão	09	5.6	2.9	22	09	53	64	19	25
Pirassununga	45	5.8	1.2	26	08	50	71	14	23
Olímpia	22	4.5	3.0	13	04	53	35	16	28
Botucatu	04	4.5	0.7	06	05	38	32	17	18
Araraquara	17	5.1	1.6	31	11	69	67	20	25

Table 3. Yield response functions, avereged from four to seven harvests, for each nutrient and locations, keeping constant the other nutrients at the optimum rates. Fruit yield (Y) is expressed in t/ha and nutrient rates in kg ha $^{-1}$ of N, P and K

Location	Nitrogen	Phosphorus	Potassium
Monte Azul	Y =17.8 + 0.117N - 0.000271N^2	Y = 29.9 - 0.117P + 0.00111P^2	Y = 32.9 - 0.041K + 0.00012K^2
Matão	Y =42.0 + 0.049N - 0.000112N^2	Y = 34.5 + 0.423P - 0.00371P^2	Y = 50.8 - 0.071K + 0.00021K^2
Pirassununga	Y =22.9 + 0.143N - 0.000356N^2	Y = 42.4 + 0.072P - 0.00057P^2	Y = 31.6 + 0.084K - 0.00024K^2
Botucatu	Y =61.6 + 0.098N - 0.000250N^2	Y = 24.3 + 0.016P + 0.00504P^2	Y = 49.8 + 0.137K - 0.00024K^2
Araraquara	Y =32.7 + 0.062N - 0.000142N^2	Y = 34.6 - 0.018P - 0.00015P^2	Y = 40.4 + 0.035K - 0.00014K^2
Olímpia	Y =23.6 - 0.020N + 0.000117N^2	Y = 27.6 - 0.108P + 0.00208P^2	Y = 26.8 - 0.020K + 0.00016K^2

to calibrate the results of plant analysis and to define the N nutritional status. For soil analysis, the ranges of relative yield corresponding to the availability classes were: 0–70%, very low; 70–90%, low; 90–100%, medium; and >100%, high (Raij et al., 1983).

The increases of fruit yield as a function of N, P, or K application for the various classes of soil P and K availability and leaf N were calculated with the use of the equations obtained by averaging the quadratic functions for each nutrient within previously defined classes.

Results and discussion

Results of soil analysis and citrus responses to P and K fertilization

The results of soil chemical analysis for P and K of the experimental areas sampled just before each experiment (Table 2), were plotted against the corresponding relative yield values, calculated by the yield response equations for these applied nutrients (Table 3).

The results of extractable resin P presented a significant correlation (r=0.92∗) with relative yield for the fit by a reciprocal linear regression (Figure 1), indicating that the ion-exchange resin is a suitable method to assess P availability in the soil for citrus orchards. Previous work with this extractant was published by Raij et al. (1983) for maize and Raij et al. (1986) for cotton, in similar soils from the State of São Paulo, Brazil. A comparison between the reciprocal linear equations adjusted by these authors with the ones of

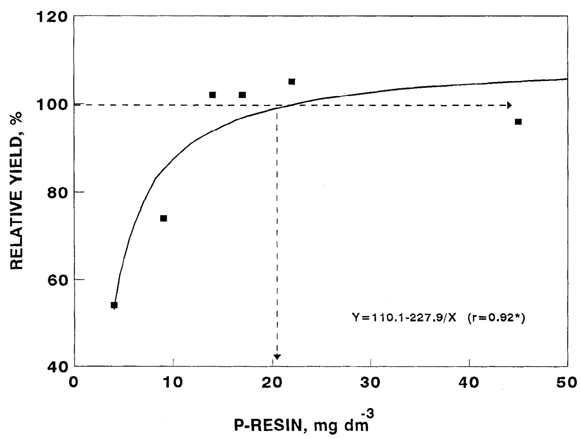

Figure 1. Correlation between resin extractable soil-P determined in samples taken at the beginning of each trial and the corresponding relative yields averaged over the years of data collection.

Table 4. Average results of leaf P recorded during at least four years and soil P from samples taken up at the end of experiments

P_2O_5 rates	Location				
	Botucatu	Matão	Pirassununga	Olímpia	Araraquara
			Leaf analysis		
kg/ha			g kg^{-1}		
9	1.26	1.26	1.21	1.38	1.34
27	1.36	1.33	1.16	1.35	1.31
45	1.42	1.30	1.17	1.34	1.36
63	1.45	1.27	1.27	1.27	1.36
Trends[a]	L**	Q**	NS	L*	NS
			Soil analysis		
kg/ha			mg dm^{-3}		
9	5.6	6.0	28.5	26.2	15.5
27	12.0	14.6	35.9	23.1	25.1
45	24.5	19.5	39.3	26.7	58.5
63	45.1	30.6	48.1	40.5	87.2
Trends[a]	L**	L**	L**	L**	L**

[a] L = Linear; Q = Quadratic; $^{*}p \leq 0.05$ and $^{**} = \leq p < 0.01$.

the present paper shows that annual crops, as corn and cotton, require P-resin values in the soil around 55 mg $dm^{-3}$for maximum yield, whereas citrus requires only 20 mg dm^{-3}. The more extensive rooting system and the longer time for P absorption by citrus favors absorption of P by diffusion from soil to roots through the soil solution. That might explain the differential requirements for P availability in the soil of the two plant groups.

For practical purposes, soil-P values, expressed in mg dm^{-3}, can be interpreted based on classes of availability, as was done by Raij et al (1983): very low – below 6; low – from 6 to 12; medium – from 13 to 30; and high – above 30. These classes are close to those proposed by Du Plessis (1977) for citrus in South Africa and also similar to the interpretation for soil-P used by Legaz and Primo Millo (1988), in Spain, based on Olsen's method. These classes are useful to predict citrus response to added P-fertilizer, as shown in Figure 3a. For very low or low soil-P the response to phosphorus application was pronounced, while for medium or high values of soil P no significant responses to P were observed.

The build-up of soil P, according to yearly application of P fertilizer rates, was evident by the soil analysis of the samples collected at the end of the experiments (Table 4). These results shown also that

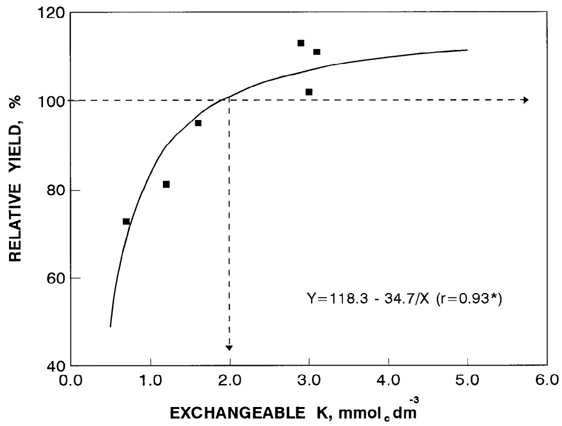

Figure 2. Correlation between exchangeable soil-K determined in samples taken at the beginning of each trial and the corresponding relative yields averaged over the years of data collection.

the ion-exchange resin procedure is adequate to evaluate the residual effects of sucessive P application in the soil. On the other hand, leaf analysis was not indicative of the responses to P application, indicating that it is not a good index to determine P availability in the soil for the citrus trees, as was previously reported by Du Plessis (1977).

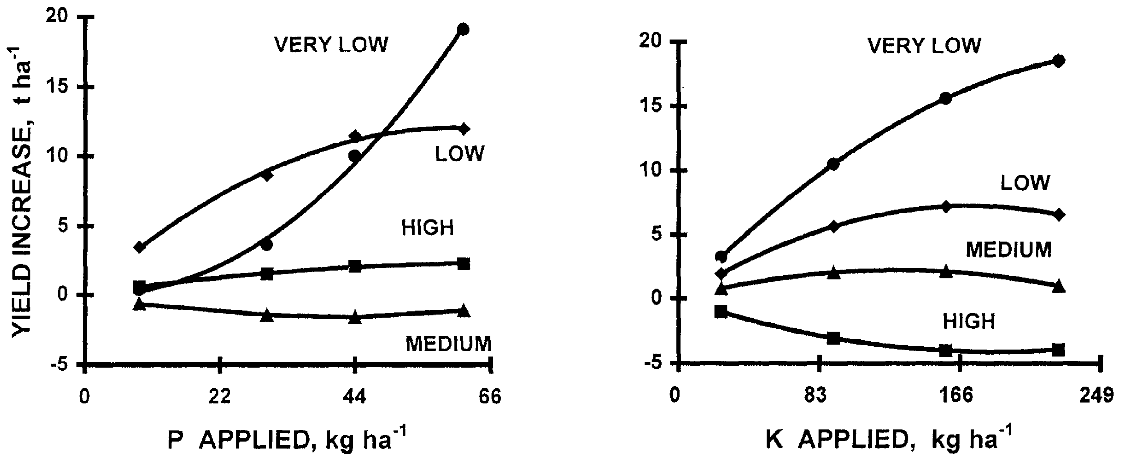

Figure 3. Fruit yield increases according to the classes of soil analysis for P and K as affected by annual rates of phosphorus and potassium applied.

Exchangeable potassium is considered a good index to determine K availability in soils for annual crops as demonstrated by Bray (1948), Rouse (1968) and Raij (1974). As for P, the relationship between relative yield of citrus and exchangeable K, was also described by a reciprocal linear equation, with a significant correlation coefficient of r = 0.93* (Figure 2). Maximum citrus yield was attained when soil-K was around 2.0 mmol$_c$ dm^{-3}, which is close to the value of 2.9 mmol$_c$ dm^{-3} observed by Hunziker (1968) in Florida citrus orchards and also, to the value 2.6 mmol$_c$ dm^{-3} found by Raij (1974) for bean, cotton and sugar cane in tropical soils. Therefore, the same class limits for soil-K interpretation used for annual or semi-perennial crops can also be used for citrus groves.

In calcareous soils, rich in calcium, the exchangeable K as an index of K availability for citrus, has been questioned due to a lack o correlation between soil-K and leaf-K (Reitz and Koo, 1959). In such soils, the concept of potassium saturation, in relation to cation exchange capacity, might assess better the K availability, as observed by Hunziker (1968) in Florida citrus orchards. As already demonstrated for soil-P, it was also possible to predict the responses of citrus to potassium fertilization by soil analysis (Figure 3b). The following classes, for soil-K, expressed as mmol$_c$ dm^{-3}, were established: very low – below 0.8; low – from 0.8 to 1.5; medium – from 1.6 to 3.0; and high – above 3.0. Pronounced citrus responses to potassium fertilization were observed when soil-K was very low or low, which is in agreement with Du Plessis (1977), who obtained citrus response to potassium application with exchangeable K less than 2.5 mmol$_c$ dm^{-3}. On the other hand, significant depressive effects of K fertilization on citrus yields were verified in three experiments, when soil exchangeable K was higher than 2.9 mmol$_c$ dm^{-3} (Figure 3b).

The build-up of potassium in the soils is evident for the samples collected at the end of the experiment (Table 5). The lower values for Botucatu and Pirassununga are probably due to higher leaching in these soils with lower clay content. The results of plant analysis was also indicative of the potassium accumulation due to fertilization, but as for phosphorus, differences between sites were indicative of other factors affecting K availability to citrus.

Leaf nitrogen and citrus yield

There is no reliable soil analysis procedure up to now to assess the N requirement of citrus plants but tissue tests have been widely used to determine the N status of this crop (Jones and Embleton, 1973; Du Plessis, 1977; Malavolta, 1992; Terblanche and Du Plessis, 1992; Hanlon et al., 1995). In Brazil, correlation between leaf analysis for N and citrus yield was first done by Gallo et al. (1966) with baianinha orange, but little further information is available and for this reason interpretation has been established mostly with data from the international literature.

Figure 4a shows the yield responses of orange expressed as relative yield, as a function of the N concentration in leaves collected from 6–7-month old

Table 5. Average results of leaf K recorded during at least four years and soil K from samples taken up at the end of experiments

K_2O rates	Location				
	Botucatu	Matão	Pirassununga	Olímpia	Araraquara
	Leaf analysis				
kg/ha	$g\ kg^{-1}$				
25	3.5	13.8	8.6	11.5	13.3
91	5.7	15.3	10.3	11.6	14.3
157	9.0	17.4	10.0	11.6	14.9
223	12.2	18.1	11.8	12.1	15.8
Trends[a]	L**	L**	L**	NS	L**
	Soil analysis				
kg/ha	$mmol_c\ dm^{-3}$				
25	0.9	2.1	0.4	1.3	1.3
91	1.0	2.9	0.9	2.0	2.6
157	2.0	3.9	1.0	2.5	4.0
223	2.0	4.3	1.5	3.1	5.1
Trends[a]	L**	L**	L**	L**	L**

[a] L = Linear; Q = Quadratic; $^{*}p \leq 0.05$ and $^{**} = \leq p < 0.01$.

fruiting terminals, in the plots that received only 30 kg/ha N per year. Leaf analysis of individual years were somewhat variable but a steady relationship with yield response to N application was obtained with the average of all years. This is in agreement with Guardiola et al. (1973), who stated that more emphasis should be placed on the trend since year to year variation in leaf N concentration is relatively large.

Using the equation of Figure 4a it was possible to estimate a value of leaf N of 26.8 g/kg, corresponding to nil yield response to the addition of N fertilizer. The results of Figure 4 agree with the leaf standards for oranges (5–7-month old, non fruiting terminals) of Southern Australia (Gallash, 1992), in which N contents from 22.0 to 23.9 g/kg are considered too low, 24.0 to 26.9, optimum, and 27.0 to 30.0, too high. Du Plessis et al. (1992), using the same leaf sampling method, considered 23–26 g/kg the optimum range for Valencia oranges. For leaves of oranges from nonbearing terminals in Florida, USA, the optimum range is 25–27 g/kg (Hanlon et al., 1995).

The yield increases in response to N fertilizer application, according to the classes of leaf N (Figure 4b) demonstrate that the tissue test is very effective to discriminate the N needs of citrus plants. When N concentration in leaves was around 28 g/kg practically no response to N was observed, whereas increase yield increments with application of N fertilizer occurred as the N leaf content decreased (Figure 4b).

The data of the lemon experiment are excluded from the calculations of Figure 4a because leaf N concentrations were lower and did not fit with the trends observed for orange. Plots that received 170 to 240 kg/ha N presented leaf N concentration around 22 g/kg, which may be considered adequate for this species. Du Plessis and Koen (1992) found that the optimum N concentration range for *Citrus limon*, from 5–6-month old leaves of fruit bearing terminals, varied from 17.5 to 22.0 g/kg. Previous results (Du Plessis, 1977) indicated that maximum yield of lemon was associated with leaf N content of no more than 23 g/kg. Our data indicate that for lemon grown in Brazil, the optimum range may be higher than in South Africa since a marked response to N application was observed when N in tissue was 18 g/kg (Figure 4b), but the upper limit seems to be the same.

The results of the present paper were used to support the fertilizer recommendation guide for citrus used in Brazil, which establishes the rates of N according to leaf analysis and expected fruit yield (Grupo Paulista, 1994).

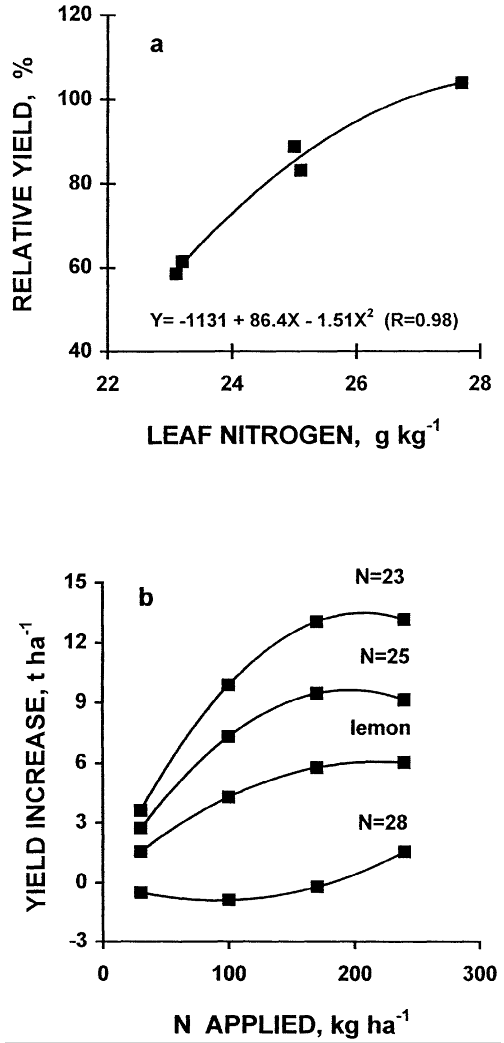

Figure 4. Correlation of leaf-N with relative yield (a) and citrus response to nitrogen according to the N concentration in leaves from 6-to-8-month-old fruiting terminals (b).

Conclusions

The results of the experiments indicate that the soil chemical analysis for resin extractable P and exchangeable K are effective criteria to evaluate nutrient availability for fertilizer recommendations for citrus. Leaf-N concentration from 6-to-8-month-old fruiting terminals is a good index to determine citrus nitrogen requirement.

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