Sweet orange trees grafted on selected rootstocks fertilized with nitrogen, phosphorus and potassium

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Abstract – The majority of citrus trees in Brazil are grafted on ‘Rangpur lime’ (*Citrus limonia* Osb.) rootstock. Despite its good horticultural performance, search for disease tolerant rootstock varieties to improve yield and longevity of citrus groves has increased. The objective of this work was to evaluate yield efficiency of sweet oranges on different rootstocks fertilized with N, P, and potassium. Tree growth was affected by rootstock varieties; trees on ‘Swingle’ citrumelo [*Poncirus trifoliata* (L.) Raf. × *C. paradisi* Macf.] presented the smallest canopy (13.3 m^3 in the fifth year after tree planting) compared to those on ‘Rangpur lime’ and ‘Cleopatra’ mandarin [*C. reshni* (Hayata) hort. ex Tanaka] grown on the same grove. Although it was observed an overall positive relationship between canopy volume and fruit yield (R^2 = 0.95**), yield efficiency (kg m^{-3}) was affected by rootstocks, which demonstrated ‘Rangpur lime’ superiority in relation to Cleopatra. Growth of citrus trees younger than 5-yr-old might be improved by K fertilization rates greater than currently recommended in Brazil, in soils with low K and subjected to nutrient leaching losses.

Index terms: citrus, growth, yields, canopy.

Laranjas-doce sobre diferentes porta-enxertos adubadas com nitrogênio, fósforo e potássio

Resumo – A maioria dos citros produzidos no Brasil são enxertados em limão ‘Cravo’ (*Citrus limonia* Osb.). Apesar das boas características agronômicas desse porta-enxerto, a procura por variedades tolerantes a doenças, para aumentar a produtividade e longevidade dos pomares cítricos, tem aumentado. O objetivo deste trabalho foi avaliar a eficiência de produção de frutos de laranjas-doce sobre diferentes porta-enxertos e adubadas com N, P e potássio. O crescimento das árvores foi afetado pelas variedades de porta-enxertos estudadas; plantas sobre citrumelo ‘Swingle’ [*Poncirus trifoliata* (L.) Raf. × *C. paradisi* Macf.] apresentaram o menor volume de copa (13,3 m^3 no quinto ano após plantio) quando comparadas àquelas em limão ‘Cravo’ e tangerina ‘Cleópatra’ [*C. reshni* (Hayata) hort. ex Tanaka] no mesmo pomar. Embora tenha sido observada uma relação positiva entre volume de copa e produção de frutos (R^2 = 0,95**), a eficiência de produção de frutos (kg m^{-3}) foi afetada pelos porta-enxertos, o que demonstrou a superioridade do limão ‘Cravo’ em relação à ‘Cleópatra’. O crescimento de árvores em formação, com menos que cinco anos de idade, pode apresentar resposta à adubação com K em doses superiores às recomendadas atualmente no Brasil, em solos com baixa reserva de K trocável e condições para perdas deste nutriente por lixiviação.

Termos para indexação: citro, crescimento, produtividade, cobertura de copas.

Introduction

Citrus industry in Brazil represents a major activity, accounting for 13.4 million metric tons of oranges produced in São Paulo State, in 2001/2002 (Abecitrus, 2003). About 75% of sweet orange trees in that region is grafted on ‘Rangpur lime’ (*Citrus limonia* Osb.), a superior cultivar characterized by high vigor and yield, earliness-to-bearing, and drought tolerance (Pompeu Junior, 2001). However, susceptibility of ‘Rangpur lime’ to citrus blight (Castle et al., 1993) and, more recently to citrus sudden death (MSC – from the Portuguese acronym) (Müller et al., 2002) has led to increased use of other rootstocks tolerant to these diseases to improve productivity and longevity of citrus groves.

Rootstocks determine the horticultural performance of citrus trees by affecting growth (Castle et al., 1993), fruit yield and quality (Castle et al., 1988), water relations (Castle & Krezdorn, 1977; Syvertsen, 1981), and nutrient requirements (Wutscher, 1989).

Size of canopy (tree height, width and volume) is positively related with fruit yield of citrus (Anderson, 1987; Obreza & Rouse, 1993). This relationship results on availability of leaf area for photosynthesis, flowering and fruit set within trees (Syvertsen & Lloyd, 1994), even though the number of fruit borne per unit of canopy volume may vary significantly among cultivar combinations. Therefore, this relationship may be used to characterize the yield efficiency of fruit production of trees.

The objective of this work was to evaluate yield efficiency of sweet oranges on different rootstocks fertilized with N, P, and potassium.

Material and Methods

This work was conducted in the major citrus producing areas of the State of São Paulo, Brazil, during 1995/1999.

Three citrus groves with 'Pêra' sweet orange [*C. sinensis* (L.) Osb.] on 'Rangpur lime' (RL) rootstock (*C. limonia* Osb.), with 'Valencia' sweet orange [*C. sinensis* (L.) Osb.] on RL and 'Cleopatra' (Cleo) mandarin [*C. reshni* (Hayata) hort. ex Tanaka] rootstocks, and with 'Natal' sweet orange [*C. sinensis* (L.) Osb.] on RL, Cleo and 'Swingle' (Sw) citrumelo [*Poncirus trifoliata* (L.) Raf. × *C. paradisi* Macf.] rootstocks were planted in the field in 1995. Pêra grove was located on an Alfisol (117.9 $mmol_c$ dm^{-3} CEC at 0–20 cm depth) on the southeast region of the State, where average temperature is below 20°C and there is no water deficit (1,760 mm mean annual rainfall). Other groves were in the north regions; Valencia grove was on an Alfisol (46.5 $mmol_c$ dm^{-3} CEC at 0–20 cm depth), and Natal grove was on an Oxisol (54.0 $mmol_c$ dm^{-3} CEC at 0–20 cm depth). Average temperature in this region is 23°C and mean annual rainfall is about 1,350 mm. Drought periods are common during the winter in this region. Natal grove was located on the uphill of the landscape. Therefore, drought stress was more severe.

Soils at each grove received dolomitic lime application in amounts calculated to raise base saturation (0–20 cm depth layer) to approximately 70% (Quaggio et al., 1992) before tree planting.

Fertilizer treatments were arranged in a fractional factorial design of the ½ (4^3) type, with a total of 32 treatments (Andrade & Noleto, 1986), which consisted of four nutrient rates calculated to be applied during five years: N (400, 1,000, 1,600 and 2,200 g $tree^{-1}$), P (180, 440, 700 and 960 g $tree^{-1}$), and K (240, 660, 1,080 and 1,500 g $tree^{-1}$). The same arrangement was used in all experimental groves. Annual rates of N, P, and K were adjusted to account for the tree age every year. Zinc (Zn), manganese (Mn), and boron (B) were applied by foliar spray according to Quaggio et al. (1997).

Experimental plots consisted of five trees with the middle three used for sampling. Tree growth was estimated by measuring longitudinal and transversal diameters of the canopy, and tree height using a ruler, during the summer in 1997, 1998, and 1999. Canopy volume (m^3) was calculated using the expression $V = 2/3\, \pi\, r^2\, h$, where V is the canopy volume; r is the canopy radius; and h is the canopy height. Fruit yield was computed annually by summing up weight of fruits, if more than one harvest per year were necessary.

Data for all groves (n = 192), collected in 1998 and 1999, were pooled in classes of production to verify the relationship of canopy volume and fruit yield. Data collected on Valencia and Natal groves, in 1999, were used to evaluate yield efficiency of citrus rootstocks among treatments. Linear models were estimated by using the GLM procedure of the SAS system (SAS Institute, 1996).

Results and Discussion

Tree growth increased from the third to the fifth year after planting in the field (Table 1). Overall average canopy volume varied from 3.9 m^3 in 1997 to 19.3 m^3 in 1999. Canopy volume and diameter of 5-yr-old citrus trees presented high correlation ($r = 0.98$; $P<0.0001$). Similarly, the correlation coefficient for canopy volume and plant height was 0.85 ($P<0.001$).

'Rangpur lime' and Cleo produced more vigorous trees than Sw rootstock (Table 1). This effect is characteristic for trifoliate rootstocks and some of its hybrids (Gardner & Horanic, 1967; Teófilo Sobrinho et al., 1973), and which intensity depends on the level of water deficit. Even though trees on Cleo are more vigorous than those on RL, the opposite was observed on Natal grove (Table 1), located on the uphill of the landscape, where

Table 1. Growth of ‘Valencia’ (V) and ‘Natal’ (N) sweet orange trees on ‘Rangpur lime’ (RL), ‘Cleopatra’(Cleo) mandarin, and ‘Swingle’(Sw) citrumelo represented by canopy measurements up to five years after tree planting in different groves(1).

Tree/ rootstock	1997			1998			1999		
	Diameter	Height	Volume	Diameter	Height	Volume	Diameter	Height	Volume
	--------------(m)------------		(m^3)	--------------(m)------------		(m^3)	--------------(m)------------		(m^3)
				Valencia grove					
V/RL	1,80 (0,13)	1,94 (0,09)	3,3	2,52 (0,19)	2,37 (0,14)	7,9	3,01 (0,21)	2,69 (0,19)	12,8
V/Cleo	1,77 (0,14)	1,97 (0,08)	3,2	2,59 (0,19)	2,50 (0,15)	8,8	3,35 (0,21)	3,03 (0,20)	17,8
				Natal grove					
N/RL	2,24 (0,18)	2,36 (0,12)	6,2	2,55 (0,29)	2,80 (0,27)	9,5	4,02 (0,20)	3,33 (0,14)	28,2
N/Cleo	2,05 (0,33)	2,00 (0,23)	4,4	2,40 (0,33)	2,74 (0,20)	8,3	3,88 (0,31)	3,12 (0,19)	24,6
N/Sw	1,60 (0,28)	1,65 (0,20)	2,2	2,05 (0,32)	2,36 (0,33)	5,2	3,08 (0,27)	2,68 (0,20)	13,3

(1)Numbers between brackets represent the standard error of the mean (n = 32).

more frequent water deficit probably limited greater growth of trees on Cleo – an intermediate drought tolerant rootstock (Davies & Albrigo, 1994). Trees on Sw are also considered intermediate drought tolerant (Hutchinson, 1974; Stuchi et al., 2000; Figueiredo et al., 2002). The Natal sweet orange, a late season variety has contributed to adverse effects of drought since crop load represents an important sink for water and carbohydrates during fruit maturation (Bustan et al., 1996) throughout the dry season. Thereafter, selection of scion and rootstock combinations considering grove elevation and soil properties is important for appropriate establishment of citrus groves.

Since fertilizer treatments affected growth of same age and scion/rootstock trees on all experimental groves (Mattos Junior, 2000), a significant relationship between canopy volume and fruit yield was verified (Figure 1). Young citrus trees require nutrients for growth and increasingly for fruit yield, which can lead to alternate bearing. This alternate behavior of trees probably determined the large variation in the data. Sixteen-percent fruit yield increase with an increase in canopy volume from 5 to 10 m^3 (Figure 1). On the other hand, an increase from 20 to 25 m^3, increased fruit yield in 26%. This pattern is possibly explained by the fact that rate of tree growth was smaller for plants with more than 10 m^3 in canopy volume, in which fruit load and nutrient sink effects became greater.

Growth and production parameters allowed estimating tree efficiency (kg of fruit per m^3 of canopy volume) for fruit yield as influenced by rootstocks and fertilizer rates for each rootstock variety. Yield efficiency of trees on RL and Cleo grouped within a similar trend

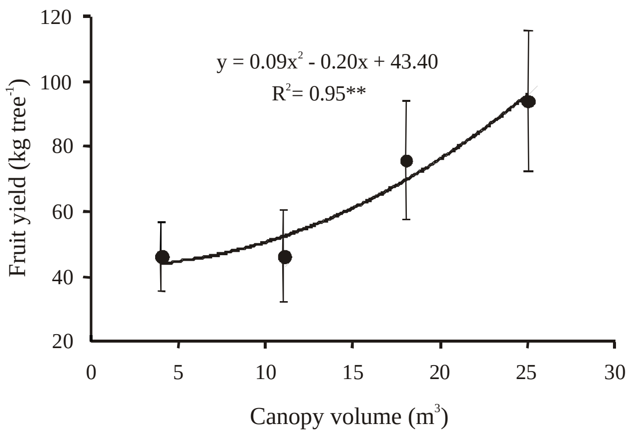

Figure 1. Fruit yield of five-year-old sweet orange trees related to canopy volume. Bars in each point represent the means±standard error.

(Figure 2). Trees on RL were more efficient for fruit production compared to those on the former rootstock, even though the proportion of canopy volumes of those was different between experimental groves and over the first years of tree evaluation (Table 1). On the other hand, trees on Sw, which presented smaller canopy, demonstrated that greater fruit yields per tree are only achieved at high tree yield efficiency (Figure 2). This latter observation is important to establish fertilization management of citrus orchards since nutrient requirements of trees on Sw would be greater for significant crops. Fruit yield of these trees increased with increasing rates of N and K, with fertilizer rates for maximum yield greater than those observed for trees either on RL or Cleo (Mattos Junior, 2000). Performance of those intermediate drought tolerant rootstocks might be improved with adoption of irrigation and correct selection of scion/rootstock combinations and local for grove establishment.

The N, P and K fertilization influenced tree growth, especially the average canopy volume on Pêra grove, in whith significant linear and quadratic responses to K and N fertilization were observed (Table 2). The effect of K rates on canopy volume was positive with an estimated increase on canopy volume from 16.6 to 20.2 m^3 and an increase on K rates from 250 to 1,500 g $tree^{-1}$ (with P = 170 and N = 2,200 g $tree^{-1}$) (Figure 3). Current fertilizer recommendations for young citrus trees (<5-yr-old) in Brazil suggest application of greater amounts of N and P than K (Quaggio et al., 1997). Potassium requirements of trees are only expected to be greater at high fruit yield since it is required in small quantities for vegetative growth, whereas K removal by fruit harvest is large (Mattos Junior et al., 2003). Data of the present work suggest that where low soil exchangeable K and high rainfall occur, K becomes a limiting nutrient for tree growth and therefore K recommendation for young citrus trees need to be better considered.

The lack of significant response of tree growth to P fertilization on Pêra grove can be explained by the fact that initial P level at soil surface was relatively high (22 mg dm^{-3}) and increased to above 60 mg dm^{-3} in the fifth year of P fertilizer application. There was no positive response of fruit yield for bearing trees when soil P levels are higher than 20 mg dm^{-3} (Quaggio et al., 1998).

Tree growth response was less clear on Valencia grove since only average canopy diameter was significantly affected by treatments either for trees on

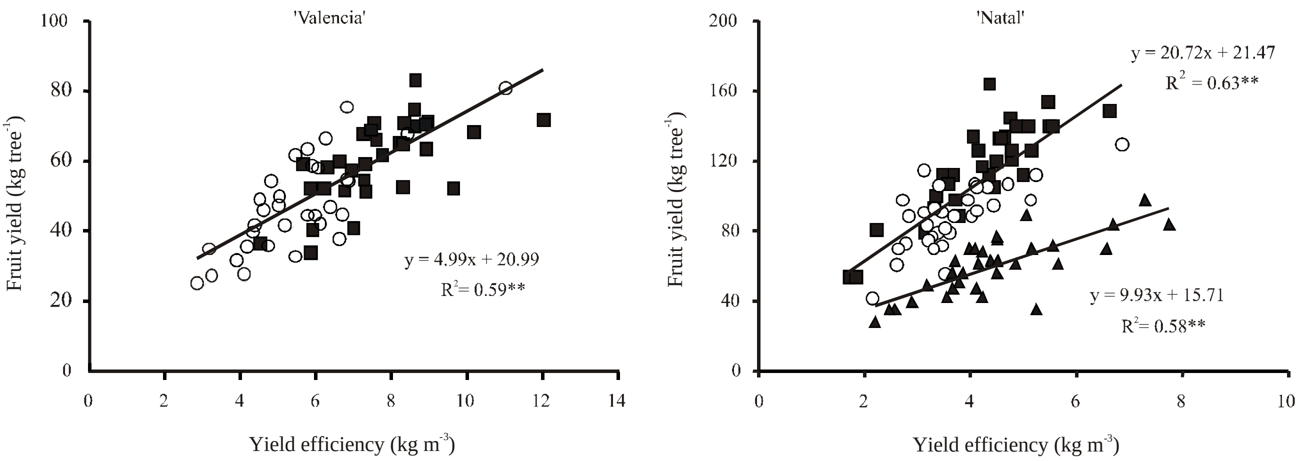

Figure 2. Yield efficiency of 'Valencia' and 'Natal' sweet oranges trees on 'Rangpur lime' (■),'Cleopatra' mandarin (○), and 'Swingle' citrumelo (▲) rootstocks.

Table 2. Regression models for average tree canopy volume in the forth and fifth years after tree planting as affected by NPK fertilization.

Tree(1)	Model coefficient(2)										R^2
	b_0	N	N^2	P	P^2	K	K^2	NP	NK	PK	
P/RL	17.4	-5.8E-03	2.2E-06**	5.7E-03	-2.9E-06	3.8E-03*	-1.2E-06	-1.5E-06	6.7E-07	-1.9E-06	0.54
V/RL	8.0	1.5E-03	-2.6E-07	-8.1E-04	3.9E-06	4.0E-03	-1.6E-06	-2.3E-06	-1.3E-08	-5.5E-07	0.31
V/Cleo	8.4	4.3E-03	-9.8E-07	1.7E-03	8.8E-07	1.1E-03	3.6E-07	-8.0E-07	-7.1E-07	3.6E-07	0.33
N/RL	24.8	-3.3E-04*	-1.2E-06	-1.8E-02	8.1E-06	1.2E-03	-7.8E-07	4.9E-06**	-6.0E-07	2.5E-06	0.40
N/Cleo	16.1	-5.1E-03	1.3E-06	1.7E-02	-1.3E-05	-1.8E-03	3.8E-06	1.9E-06	-2.5E-07	-6.8E-06	0.36
N/Sw	11.3	8.2E-05*	-1.1E-06	1.6E-03	-8.6E-06	-7.9E-04	1.0E-08	3.2E-06*	-1.6E-07	3.0E-06	0.46

(1)P: 'Pêra'; V: 'Valencia'; N: 'Natal' sweet oranges; RL: 'Rangpur lime'; Cleo: 'Cleopatra' mandarin; Sw: 'Swingle' citrumelo rootstocks. (2)$v = b_0+b_1N+b_2N^2+b_3P+b_4P^2+b_5K+b_6K^2+b_7NP+b_8NK+b_9PK$, where v is the average canopy volume (m^3) and N, P, and K are total rates of nutrient (g $tree^{-1}$) supplied during 5 years after tree plant. * and **Significant at 0.05 and 0.01 probability level, respectively.

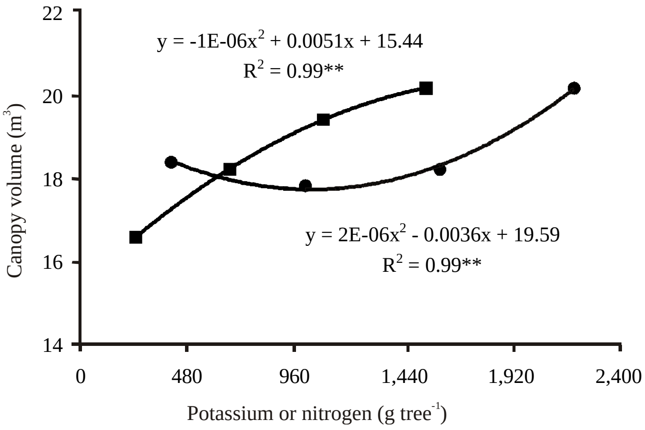

Figure 3. Growth of four- to five-year-old 'Pêra' sweet orange trees on 'Rangpur lime' rootstock as affected by N (●) and K (■) fertilization, at P rate of 170 g $tree^{-1}$.

RL or Cleo rootstocks (Mattos Junior, 2000). Other factors, such as soil acidity, probably limited tree growth in comparison with other groves. On the other hand, average canopy volume of trees either on RL or Sw showed significant effects of N and P fertilization on Natal grove (Table 2). The response models found for either rootstock estimated positive responses to N fertilization only at P rates above 700 g $tree^{-1}$ (with K = 240 g $tree^{-1}$).

Conclusions

1. 'Swingle' citrumelo induces smaller canopy than 'Rangpur lime' and 'Cleopatra' mandarin rootstocks.
2. There is a positive relationship between canopy volume and fruit yield, even though yield efficiency may vary for trees on 'Rangpur lime' and 'Cleopatra' mandarin.
3. Greater fruit yield of trees on Sw is achieved at higher tree efficiency compared with those on 'Rangpur lime' and 'Cleopatra' mandarin.
4. Potassium fertilization affects vegetative growth of young trees (<5-yr-old) where low levels of soil exchangeable K and the likelihood of leaching losses are limiting to citrus production.

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