Soluble Solids Accumulation in 'Valencia' Sweet Orange as Related to Rootstock Selection and Fruit Size

Graham H. Barry[1] and William S. Castle
Citrus Research and Education Center, University of Florida, 700 Experiment Station Road, Lake Alfred, FL 33850-2299

Frederick S. Davies
Department of Horticultural Sciences, University of Florida, P.O. Box 110690, Gainesville, FL 32611-0690

ADDITIONAL INDEX WORDS. *Citrus sinensis*, juice quality, soluble solids concentration (SSC)

ABSTRACT. **Juice quality of 'Valencia' sweet orange [*Citrus sinensis* (L.) Osb.] trees on Carrizo citrange [*C. sinensis* x *Poncirus trifoliata* (L.) Raf.] or rough lemon (*C. jambhiri* Lush.) rootstocks was determined for fruit harvested by canopy quadrant and separated into size categories to ascertain the direct role of rootstock selection on juice soluble solids concentration (SSC) and soluble solids (SS) production per tree of citrus fruit. SS production per fruit and per tree for each size category was calculated. Juice quality was dependent on rootstock selection and fruit size, but independent of canopy quadrant. Fruit from trees on Carrizo citrange had >20% higher SSCs than fruit from trees on rough lemon, even for fruit of the same size. Large fruit accumulated more SS per fruit than smaller fruit, despite lower juice content and SSC. Within rootstocks, SS content per fruit decreased with decreasing fruit size, even though SSC increased. Rootstock effect on juice quality was a direct rather than an indirect one mediated through differences in fruit size. The conventional interpretation of juice quality data that differences in SSC among treatments, e.g., rootstocks or irrigation levels, or fruit size, are due to "dilution" of SS as a result of differences in fruit size and, hence, juice volume, is only partly supported by these data. Rather, accumulation of SS was greater for fruit from trees on Carrizo citrange than rough lemon by 25% to 30%.**

Citrus rootstocks have well-known effects on tree vigor and size, yield, fruit size, and various fruit quality factors (Castle, 1987; Castle et al., 1993; Wutscher, 1979, 1988). Rootstocks have been characterized according to the rate of vegetative development of a tree's canopy on a particular rootstock, and scion precocity and productivity (Castle et al., 1993). Generally, scion cultivars budded on invigorating rootstocks, e.g., rough lemon (*Citrus jambhiri* Lush.), produce more and larger fruit with lower soluble solids concentration (SSC) and titratable acidity (TA) than trees on less invigorating rootstocks such as Carrizo citrange [*C. sinensis* (L.) Osb. x *Poncirus trifoliata* (L.) Raf.] (Castle et al., 1993; Reitz and Embleton, 1986).

The quantity of soluble solids (SS) produced is the basis for compensating sweet orange [*C. sinensis* (L.) Osb.] growers for their product in Florida's citrus processing industry. SS production per unit area is dependent on SS production per tree, and the number of trees per hectare, or tree density. Soluble solids production by a tree is a function of crop size (number of fruit), fruit size distribution, and juice volume and SSC of individual fruit. Numerous factors can influence SS production per tree, including rootstock selection, and within-tree factors such as crop load and fruit size. SS production per tree and per hectare is often higher for trees on rough lemon than trees on Carrizo citrange because trees on rough lemon produce fruit with lower SSC and juice content, but their relatively high yields more than compensate for the better juice quality of fruit from trees on Carrizo citrange (Castle et al., 1993).

To explain juice quality differences of fruit from trees borne on different rootstocks, Gardner (1969) used a reciprocal fruit grafting technique whereby 'Valencia' sweet orange fruit taken from a tree on rough lemon (low quality) were grafted to a tree on sour orange (high quality), and vice versa. The grafted fruit developed the size and juice quality characteristics of the rootstock on which fruit completed their growth. Gardner (1969) concluded that the tree foliage supplies carbohydrates to fruit, but the rootstock determines the amount. Although it is unclear how rootstocks exert their influence on juice quality in *Citrus* spp., plant water relations, mineral nutrition, and phytohormones have been proposed as being among the most important factors involved (Castle, 1995). In addition, the larger fruit size associated with invigorating rootstocks and the inverse relationship between juice SSC and TA, and fruit size (Harding and Lewis, 1941; Miller, 1990) may imply that fruit borne on trees on invigorating rootstocks have lower SSC due to larger fruit size.

The objective of this study was to determine the relative functions of rootstock selection and fruit size in the accumulation of SS among 'Valencia' sweet orange trees and individual fruit.

Materials and Methods

SITE AND PLANT MATERIAL. The experiment was conducted in a commercial citrus orchard near Ft. Basinger, Fla. (lat. 27°34´N, long. 81°09´W; elev. 14 m). The soil type is Myakka fine sand (a

Received for publication 23 Feb. 2003. Accepted for publication 14 Oct. 2003. Florida Agricultural Experiment Station Journal Series No. R-09362. This study was made possible by partial funding from Capespan International, South Africa and Tropicana Products Inc., Fla. The authors acknowledge the cooperation of Lykes Bros. Inc., Fla., and Jim Baldwin, Jean Eelman, and Linda Barry for technical assistance. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.
[1]Present address: Citrus Research International, Dept. of Horticultural Science, Univ. of Stellenbosch, Private Bag X01, Matieland, 7602, South Africa; gbarry@sun.ac.za.

sandy, siliceous, hyperthermic Aeric Haploquod of the Spodosol order), which is common in a flatwoods landscape position. This is a poorly drained, slightly acidic (pH 5), sandy soil with a thin organic matter layer (spodic hardpan) ≈12 cm thick and located ≈64 cm deep in the soil profile. Prior to planting, the soil was drained to lower the naturally perched water table by installing drainage ditches. Raised beds ≈1.2 m in height were formed to facilitate surface drainage and to increase rooting depth. Trees were planted in a double-row system, 15 m between bed-middles, 7.5 m between tree-rows on the bed, and 3.8 m between trees within rows, with a density of 230 trees/ha. Water was applied using a Netafim® single-line drip irrigation system with emitters spaced at 0.72-m intervals and an application rate of 1.2 $L \cdot h^{-1}$ according to crop requirement and prevailing environmental conditions recorded using a nearby automated weather station.

'Valencia' sweet orange trees on Carrizo citrange or rough lemon rootstocks planted in Mar. 1992 in a north-south row orientation were used in this study. Trees on the two rootstocks were planted in adjacent orchards with similar site and soil conditions, and received the same cultural practices. Healthy trees with uniform crop load and tree size within each rootstock were selected.

Treatments and data collection. The factors investigated included rootstock (Carrizo citrange and rough lemon), canopy quadrant (southeast, southwest, northeast, and northwest), and fruit size category (six commercial size categories) (Table 1). Three replications of two-tree plots per rootstock were used. Whole-tree crops were harvested by quadrant on 18 Mar. 1999 and 9 Mar. 2000 at the start of the commercial harvest period. Fruit were separated into commercial size categories, or counts, using an automated fruit-sizing system (Colour Vision Systems, Australia) at the Univ. of Florida's Citrus Research and Education Center (CREC) packinghouse facility in Lake Alfred, Fla.

Little to no fruit were available of the two extreme fruit size categories. Therefore, juice quality of 50-fruit samples of each of fruit size categories 125, 100, 80, and 64 was determined at the CREC's official juice testing facility. Juice was extracted and tested for SSC and TA using an automated hydrometer and titrator, respectively, as found in commercial citrus processing facilities. The ratio of SSC : TA was calculated from those data. When juice volume was insufficient, because of too few fruit falling into a given size category, SSC and TA were analyzed manually using a portable temperature-compensated refractometer (ATAGO Co., Japan), and titration with 0.3125 N NaOH and 0.5% phenolphthalein solution, respectively. SS production on a whole-tree basis of each fruit size category was calculated as the product of the weight of fruit harvested for each fruit size category, juice content, and SSC. SS production on a per fruit basis for each fruit size category was calculated as the product of the average fruit weight for fruit in each size category, juice content, and SSC.

Table 1. Commercial fruit size categories (number of fruit per 18.2-kg carton) and associated fruit diameters for sweet oranges.

Fruit size category (no. of fruit per 18.2-kg carton)	Fruit diam range (mm)	Avg fruit diam (mm)
50	86–95	90
64	81–90	84
80	75–83	78
100	68–76	73
125	63–70	67
163	57–63	60

Statistical analysis. Due to a limitation of the experimental design wherein rootstock treatments could not be randomly allocated to blocks, juice quality and whole-tree SS production data were initially analyzed separately for each rootstock type as two randomized complete-block designs, then combined and re-analyzed as a split-split-plot using PROC GLM (SAS Institute, 1996) to make comparisons between rootstocks. In the latter case, rootstock was the whole-plot unit, tree canopy quadrant was the sub-plot unit, and fruit size category was the sub-sub-plot unit. Means were separated by least significant difference (LSD). In addition, regression analysis of juice quality variables with fruit size as the independent variable was used to quantify fruit size effects on juice quality.

Results and Discussion

Individual fruit juice quality. 'Valencia' sweet orange juice quality was dependent on rootstock selection and fruit size, but independent of canopy quadrant. Fruit from trees on Carrizo citrange had significantly higher juice content, SSC, and ratio in both seasons than fruit from trees on rough lemon, but there was no significant difference in TA between rootstocks (Table 2; Figs. 1 and 2). Rootstock selection was a major factor affecting juice quality in 'Valencia' sweet oranges, with consistent effects over two seasons, and rootstock made a large contribution (≈70%) to variation in SSC and ratio (data not shown). SSC of fruit from trees on Carrizo citrange was >20% higher than that of fruit from trees on rough lemon, which is similar to other observations (Wutscher, 1988). This rootstock difference occurred even when fruit of the same size were compared. Within Florida's citrus-producing region, no other factor had such a large effect on SSC (Barry, 2000; Barry et al., 2000, 2003).

Fruit juice content, SSC, and ratio were not affected by canopy quadrant (Table 2), although there was a significant but small difference in TA among quadrants in Mar. 1999. These data may initially appear to contradict the canopy position effects reported by Sites and Reitz (1949). However, no account was taken of upper vs. lower and inner vs. outer canopy positions in our study, as was the case with Sites and Reitz (1949).

There were highly significant differences in all juice quality variables among fruit size categories (Table 2; Figs. 1 and 2). The relationships between SSC or TA, and fruit size were consistent and highly significant (Table 3). Small fruit had significantly higher SSC and TA (Figs. 1 and 2) than large fruit. However, due to the higher juice acidity in smaller fruit, ratio did not consistently increase with decreasing fruit size (Figs. 1 and 2). The relationship between juice content and fruit size was not consistent across fruit sizes (Table 3). Larger fruit (count 64) did tend to have lower juice content than fruit from smaller size categories, but there was little to no difference in juice content among the smaller sizes (Figs. 1 and 2).

The inverse relationship between juice quality (SSC and TA) and fruit size confirms the important role of fruit size as a factor affecting juice quality in 'Valencia' sweet orange (Harding and Lewis, 1941; Miller, 1990). Under diverse growing conditions (two seasons and contrasting rootstocks), the high r^2 values indicate the robustness of this relationship. However, the lack of effect of fruit size on juice content may be due to experimental error associated with the juice extraction technique, especially when small amounts of fruit were available in the extreme size

Table 2. Analysis of variance of juice quality variables for two rootstocks, four tree canopy quadrants, and four fruit size categories in Mar. 1999 and Mar. 2000 of 'Valencia' sweet orange fruit from trees on Carrizo citrange and rough lemon rootstocks at Ft. Basinger, Fla.

Source of		Juice content[y]		SSC[x]		TA[w]		Ratio[v]	
variation	F ratio[z]	1999	2000	1999	2000	1999	2000	1999	2000
Rootstock (R)	$MS_R/MS_{T(R)}$	0.0326[u]	0.0128	0.0004	0.0009	0.3453	0.8930	0.0148	0.0414
Carrizo citrange		59.2[t]	59.9	12.5	11.8	0.81	0.81	15.3	14.8
Rough lemon		56.5	55.6	10.1	9.8	0.78	0.80	12.9	12.4
Quadrant (Q)	$MS_Q/MS_{Q\times T(R)}$	0.3602	0.6931	0.3396	0.0503	0.0126	0.0921	0.3423	0.7443
SE		56.9	57.6	11.3	10.8	0.79	0.80	14.2	13.6
SW		57.8	58.1	11.3	10.9	0.81	0.81	14.0	13.6
NE		58.5	58.3	11.1	10.7	0.78	0.79	14.2	13.6
NW		58.2	57.3	11.3	10.9	0.81	0.82	14.0	13.4
Fruit size (FS)	MS_{FS}/MS_E	0.0003	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002
R × Q	$MS_{R\times Q}/MS_{Q\times T(R)}$	0.6657	0.9419	0.8170	0.6161	0.2266	0.3375	0.2100	0.1651
R × FS	$MS_{R\times FS}/MS_E$	0.0146	0.3745	0.0001	0.8001	0.0071	0.0014	0.0001	0.0735
Q × FS	$MS_{Q\times FS}/MS_E$	0.0681	0.8165	0.0478	0.4224	0.0424	0.9848	0.4657	0.9304
R × Q × FS	$MS_{R\times Q\times FS}/MS_E$	0.2781	0.6798	0.0341	0.6738	0.0961	0.7855	0.1825	0.7649

[z]F ratio for main-plot (rootstock), sub-plot (quadrant), sub-sub-plot (fruit size category), and interactions. Denominator mean squares: T(R) = trees nested within rootstock, Q×T(R) = quadrant × trees nested within rootstock.
[y]Juice content, w/w.
[x]Soluble solids concentration.
[w]Titratable acidity.
[v]Ratio of SSC : TA.
[u]Probability values for main effects and interactions.
[t]Means of juice quality variables for rootstock and quadrant main effects (n = 3, two-tree plots).

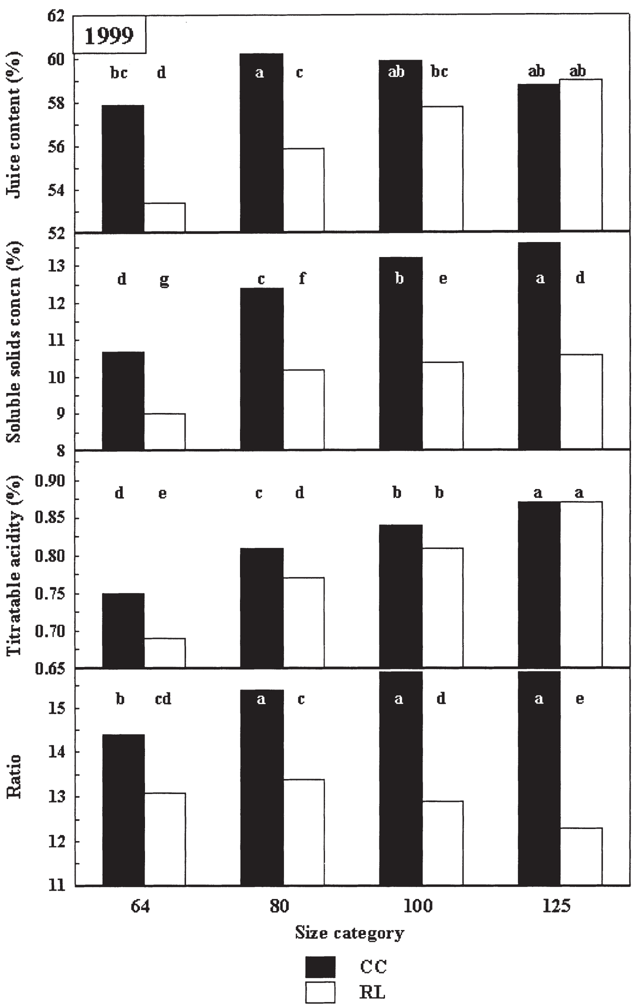

Fig. 1. Juice content, soluble solids concentration, titratable acidity, and ratio of 'Valencia' sweet orange trees on Carrizo citrange (CC) and rough lemon (RL) rootstocks in Mar. 1999 at Ft. Basinger, Fla. (n = 3, two-tree plots). Bars with the same letter are not significantly different ($P \leq 0.05$; LSD).

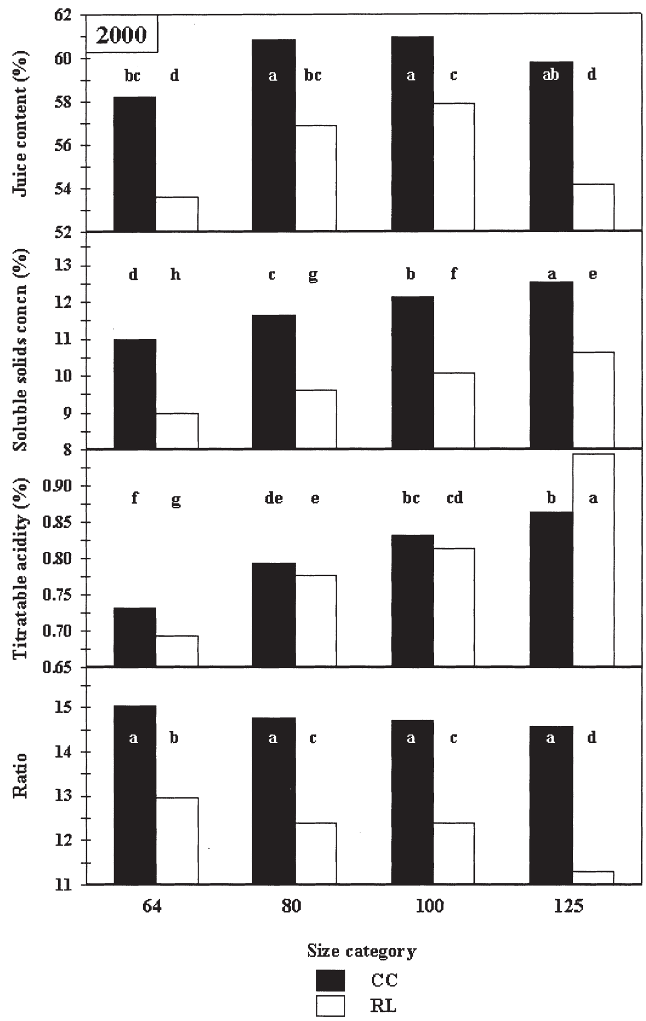

Fig. 2. Juice content, soluble solids concentration, titratable acidity, and ratio of 'Valencia' sweet orange trees on Carrizo citrange (CC) and rough lemon (RL) rootstocks in Mar. 2000 at Ft. Basinger, Fla. (n = 3, two-tree plots). Bars with the same letter are not significantly different ($P \leq 0.05$; LSD).

Table 3. Coefficients of determination for linear relationships between juice quality variables and fruit size of 'Valencia' sweet orange fruit from trees on Carrizo citrange and rough lemon rootstocks at Ft. Basinger, Fla.

	Carrizo citrange		Rough lemon	
Linear	1999	2000	1999	2000
relationship	$r^{2\,z}$	r^2	$r^{2\,z}$	r^2
Juice content vs. fruit size	0.02^{NS}	0.04^{NS}	0.43*	0.01^{NS}
SSC vs. fruit size	0.92*	0.75*	0.60*	0.69*
TA vs. fruit size	0.42*	0.45*	0.80*	0.68*

[z]Coefficient of determination; n = 3, two-tree plots.
[NS, *]Nonsignificant or significant at $P \leq 0.001$, respectively.

categories. This effect is also reflected in the high sample-to-sample variation for juice content, which may have led to spurious data for juice content of fruit from extreme size categories.

Fruit of the same size but from trees on different rootstocks had significantly different SSC (Figs. 1 and 2). In Mar. 1999, count 100 fruit from trees on Carrizo citrange had 13.2% SSC vs. 10.5% SSC for fruit from trees on rough lemon. In 1999, SSC differences between rootstocks for fruit of the same size ranged from 1.7% to 3.0%, and in Mar 2000 this difference was ≈2.0%. Fruit of the same size from trees on Carrizo citrange also tended to have higher juice content than those from trees on rough lemon (Figs. 1 and 2).

Whole-tree soluble solids production. Total SS production per tree did not differ between rootstocks in Mar. 1999. Previous data suggest that trees on rootstocks that tend to impart higher fruit yields, i.e., invigorating rootstocks like rough lemon, tend to produce more SS per tree (Castle et al., 1993) due to larger fruit yield rather than higher juice quality. Despite a >20% lower fruit yield in 1999, total SS production per tree was similar for trees on Carrizo citrange to trees on rough lemon (Table 4). In Mar. 2000, trees on Carrizo citrange produced >70% higher SS per tree than trees on rough lemon (Table 4) because of the atypically low fruit yield produced by the trees on the latter rootstock, and the accompanying change in fruit size distribution. Yield declined among the trees on rough lemon from 1999 to 2000 due to greasy spot (*Mycosphaerella citri* Whiteside) fungal disease, but did not change among the trees on Carrizo citrange (Table 4). Therefore, the 2000 data are less useful, but they illustrate the combined effects of fruit yield, and juice content and SSC on whole-tree SS production. Citrus trees often produce higher proportions of large fruit when fruit yield is low as occurred among the trees on rough lemon in 2000 (Table 4). The percentage of large (count 64) fruit increased from 6.7% to 45.6% from 1999 to 2000. Large fruit accumulated more SS per fruit than smaller fruit, despite lower juice content and SSC (Table 4). The higher proportion of large fruit, however, did not compensate for the lower fruit yield of the trees on rough lemon in 2000.

Fruit yield was the principal component of whole-tree SS production of 'Valencia' sweet orange, and fruit size was the next most important component. Among fruit size categories, the count with the highest yield contributed most to whole-tree SS production, irrespective of juice SSC and content. The largest proportion of fruit weight for trees on Carrizo citrange was in count 100 in both seasons. In 1999, 47% of SS production per tree on Carrizo citrange was from count 100, and 35% in 2000. For trees on rough lemon, the largest proportion of fruit weight in 1999 was count 100, and count 64 and larger in 2000. In 1999, 45% of SS production per tree on rough lemon was from count 100, and nearly 42% from count 64 in 2000. Regression analysis of SS production per fruit size category against fruit yield per fruit size category showed that 99% of variation in SS production was attributed to variation in yield of fruit in that fruit size category. Therefore, whole-tree SS production can be optimized primarily by increasing fruit yield, and secondarily by increasing fruit size. Increasing yield would have a greater impact on whole-tree SS production than increased fruit size.

Within rootstocks, SS content per fruit decreased with decreasing fruit size, even though SSC increased (Table 4). However, when comparing rootstocks, fruit from trees on Carrizo citrange had ≈30% greater SS content than those on rough lemon in 1999, when mean fruit size between rootstocks was not different (data

Table 4. Mean yield, juice content, soluble solids concentration (SSC), soluble solids (SS) production per tree, and SS production per fruit by fruit size category (count) of 'Valencia' sweet orange trees on Carrizo citrange and rough lemon rootstocks harvested in Mar. 1999 and Mar. 2000.

	Fruit size[z]		Yield[y] (kg)		Juice content[x] (%)		SSC[w] (%)		SS[v] (kg/tree)		SS[u] (g/fruit)	
Rootstock	Count	Wt (g)	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
Carrizo citrange	64	284	9.4	19.2	57.9	58.2	10.7	11.0	0.58 (6.6)	1.23 (14.2)	17.6	18.2
	80	228	29.1	32.8	60.2	60.8	12.4	11.7	2.17 (24.8)	2.33 (27.0)	17.0	16.2
	100	182	52.1	40.7	59.9	60.9	13.2	12.2	4.12 (47.1)	3.03 (35.1)	14.4	13.5
	125	146	23.4	27.3	58.8	59.8	13.6	12.5	1.87 (21.4)	2.04 (23.6)	11.7	10.9
Mean[t]			<u>114</u>	<u>120</u>	59.2	59.9	12.5	11.8	<u>8.74</u>	<u>8.63</u>	14.7	16.8
Rough lemon	64	284	9.2	43.3	53.4	53.6	9.0	9.0	0.44 (5.4)	2.09 (41.8)	13.6	13.7
	80	228	42.2	28.4	55.9	56.9	10.1	9.6	2.38 (29.4)	1.55 (31.0)	12.9	12.5
	100	182	60.7	18.3	57.8	57.9	10.4	10.1	3.65 (45.1)	1.07 (21.4)	10.9	10.6
	125	146	25.9	5.1	59.0	54.2	10.6	10.6	1.62 (20.0)	0.29 (5.8)	9.1	8.4
Mean[t]			<u>138</u>	<u>95</u>	56.5	55.6	10.1	9.8	<u>8.09</u>	<u>5.00</u>	11.4	16.1
P values[s]			0.0292	0.0787	0.0326	0.0128	0.0004	0.0009	0.2315	0.0115		

[z]Fruit size category: count = number of fruit per 18.2 kg commercial carton, and mean fruit weight per count.
[y]Total fruit weight per count, number underlined is rootstock total.
[x]Juice content of fruit, w/w.
[w]Juice soluble solids concentration.
[v]Soluble solids production; multiply by 2.2 to convert kg SS/tree to lb SS/tree. Numbers in parenthesis represent percentage of rootstock total, number underlined is rootstock total.
[u]Soluble solids content per fruit.
[t]Rootstock mean, or total when underlined; n=3, two-tree plots.
[s]Probability value, rootstock effect.

not shown). In 2000, when fruit were ≈25% heavier from trees on rough lemon than Carrizo citrange (data not shown), there was no difference between rootstocks in SS content per fruit (Table 4). Overall, trees on rough lemon need to produce ≈30% higher fruit yield than trees on Carrizo citrange to yield similar SS production per tree.

Fruit of the same size from the two rootstocks had large differences in juice content, SSC (≈25%), and SS per fruit. Therefore, any rootstock effect on juice quality was direct rather than an indirect effect mediated through fruit size effects on juice quality. Rootstock, irrigation and other treatment effects on juice quality have often been interpreted as a "dilution" of SS because of differences in fruit size and juice volume (Albrigo, 1977; Ketsa, 1988; Sites and Camp, 1955; Ting and Attaway, 1971). That interpretation is only partly supported by these data and an alternative hypothesis is proposed to explain differences in SSC among rootstocks. When fruit from different rootstocks were the same size (1999), there was ≈30% difference in SS content between rootstocks, and when fruit from trees on rough lemon were ≈25% larger (2000), fruit had similar SS content. Therefore, it is suggested that accumulation of SS was greater for fruit from trees on Carrizo citrange than rough lemon. This difference in accumulation of SS between these rootstocks is estimated to be 25% to 30%.

Inherent differences in whole-tree physiology may explain the observed differences in carbohydrate accumulation among fruit from trees on different rootstocks. Citrus trees on invigorating rootstocks have higher net CO_2 assimilation (A_{CO2}) than trees on less invigorating rootstocks (Morinaga and Ikeda, 1990). Alternatively, differences in resource partitioning between trees on rootstocks of contrasting vigor may explain differences in carbohydrate accumulation, although this hypothesis has apparently not been tested. However, the balance in photoassimilate partitioning between vegetative vs. reproductive organs, as measured by harvest index (Goldschmidt and Koch, 1996), or insoluble (cell wall) vs. soluble components of fruit may contribute to SS accumulation. Differences in A_{CO2} and resource partitioning may be mediated via differences in plant water relations due to root distribution and water uptake ability among rootstock selections (Castle and Krezdorn, 1975, 1977), vessel element anatomy of trunk xylem (Vasconcellos and Castle, 1994), root hydraulic conductivity (Syvertsen and Graham, 1985; Syvertsen et al., 2000), and active accumulation of solutes via osmotic adjustment (Yakushiji et al., 1996, 1998).

We conclude that whole-tree SS production is mainly a function of fruit yield and the distribution of fruit sizes. The lower concentrations of SS, but generally higher SS contents, of larger fruit suggest that any management strategies to produce sweet oranges for juice should emphasize cultural practices that improve fruit yield. Further, the data are appropriate for modeling whole-tree SS production based on the economic relationships among rootstock, fruit size distribution, and juice quality factors. Our results indicated that there can be circumstances when it would be preferable to choose an appropriate rootstock based on juice quality rather than fruit yield.

Literature Cited

Albrigo, L.G. 1977. Rootstocks affect 'Valencia' orange fruit quality and water balance. Proc. Intl. Soc. Citricult. 1:62–65.

Barry, G.H. 2000. Sources of variation in juice quality of 'Valencia' sweet orange [*Citrus sinensis* (L.) Osb.]. PhD Diss., Dept. Hort Sci., Univ. of Fla.

Barry, G.H., W.S. Castle, and F.S. Davies. 2000. Juice quality of 'Valencia' sweet orange among citrus-producing regions in Florida and between canopy positions. Proc. Intl. Soc. Citricult. 1:308–314.

Barry, G.H., W.S. Castle, F.S. Davies, and R.C. Littell. 2003. Variability in juice quality of 'Valencia' sweet orange and sample size estimation for juice quality experiments. J. Amer. Soc. Hort. Soc. 128:803–808.

Castle, W.S. 1987. Citrus rootstocks, p. 361–399. In: R.C. Rom and R.F. Carlson (eds.). Rootstocks for fruit crops. Wiley, New York.

Castle, W.S. 1995. Rootstock as a fruit quality factor in citrus and deciduous fruit crops. N.Z. J. Crop and Hort. Sci. 23:383–394.

Castle, W.S. and A.H. Krezdorn. 1975. Effect of citrus rootstocks on root distribution and leaf mineral content of 'Orlando' tangelo trees. J. Amer. Soc. Hort. Sci. 100:1–4.

Castle, W.S. and A.H. Krezdorn. 1977. Soil water use and apparent root efficiencies of citrus trees on four rootstocks. J. Amer. Soc. Hort. Sci. 102:403–406.

Castle, W.S., D.P.H. Tucker, A.H. Krezdorn, and C.O. Youtsey. 1993. Rootstocks for Florida citrus, 2nd ed. Univ. of Fla. Coop. Ext. Serv. Publ. SP-42.

Gardner, F.E. 1969. A study of rootstock influence on citrus fruit quality by fruit grafting. Proc. First Intl. Citrus Symp. 1:359–364.

Goldschmidt, E.E. and K.E. Koch. 1996. Citrus, p. 797–823. In: E. Zamski and A.A. Schaffer (eds.). Photoassimilate distribution in plants and crops. Marcel Dekker, New York.

Harding, P.L. and W.E. Lewis. 1941. The relation of size of fruit to solids, acid, and volume of juice in the principal varieties of Florida oranges. Proc. Fla. State Hort. Soc. 54:52–56.

Ketsa, S. 1988. Effects of fruit size on juice content and chemical composition of tangerine. J. Hort. Sci. 63:171–174.

Miller, W.M. 1990. Internal quality attributes of the Florida Valencia orange and their relationship to fruit density measurements. Appl. Eng. Agr. 6:461–464.

Morinaga, K. and F. Ikeda. 1990. The effects of several rootstocks on photosynthesis, distribution of photosynthetic product, and growth of young satsuma mandarin trees. J. Jpn. Soc. Hort. Sci. 59:29–34.

Reitz, H.J. and T.W. Embleton. 1986. Production practices that influence fresh fruit quality, p. 49–78. In: W.J. Wardowski, S. Nagy, and W. Grierson (eds.). Fresh fruit citrus. AVI, Westport, Conn.

SAS Institute. 1996. SAS user's guide: Statistics, Version 5 Edition. SAS Inst., Cary, N.C.

Sites, J.W. and A.F. Camp. 1955. Producing Florida citrus for frozen concentrate. Food Technol. 9:361–365.

Sites, J.W. and H.J. Reitz. 1949. The variation in individual Valencia oranges from different locations of the tree as a guide to sampling methods and spot-picking for quality. Part I. Soluble solids in the juice. Proc. Amer. Soc. Hort. Sci. 54:1–9.

Syvertsen, J.P. and J.H. Graham. 1985. Hydraulic conductivity of roots, mineral nutrition, and leaf gas exchange of citrus rootstocks. J. Amer. Soc. Hort. Sci. 110:865–869.

Syvertsen, J.P., L.S. Lee, and J.W. Grosser. 2000. Limitations on growth and net gas exchange of diploid and tetraploid Citrus rootstock cultivars grown at elevated CO_2. J. Amer. Soc. Hort. Sci. 125:228–234.

Ting, S.V. and J.A. Attaway. 1971. Citrus fruits, p. 107–169. In: A.C. Hulme (ed.). Biochemistry of fruits and their products. Academic, New York.

Vasconcellos, L.A.B.C. and W.S. Castle. 1994. Trunk xylem anatomy of mature healthy and blighted grapefruit trees on several rootstocks. J. Amer. Soc. Hort. Sci. 119:185–194.

Wutscher, H.K. 1979. Citrus rootstocks, p. 237–269. In: J. Janick (ed.). Hort. Rev. AVI, Westport, Conn.

Wutscher, H.K. 1988. Rootstock effects on fruit quality, p. 24–34. In: J.J. Ferguson and W.F. Wardowski (eds.). Factors affecting fruit quality. Citrus Short Course Proc., Fruit Crops Dept., Univ. of Fla., Gainesville.

Yakushiji, H., K. Morinaga, and H. Nonami. 1998. Sugar accumulation and partitioning in Satsuma mandarin tree tissues and fruit in response to drought stress. J. Amer. Soc. Hort. Sci. 123:719–726.

Yakushiji, H., H. Nonami, T. Fukuyama, S. Ono, N. Takagi, and Y. Hashimoto. 1996. Sugar accumulation enhanced by osmoregulation in Satsuma mandarin fruit. J. Amer. Soc. Hort. Sci. 121:466–472.