

Performance of ‘Valencia’ Sweet Orange Trees on 12 Rootstocks at Two Locations and an Economic Interpretation as a Basis for Rootstock Selection

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Abstract. Two field experiments with ‘Valencia’ sweet orange [*Citrus sinensis* (L.) Osb.] trees propagated on 12 rootstocks were conducted in commercial orchards. The objectives were to compare rootstock horticultural performance between two locations with soils representative of the Central Florida Ridge (AP) and coastal flatwoods (I), the major citrus-growing regions in Florida, and to see if financial analysis would provide an improved basis for interpreting rootstock performance. The randomized complete-block trials involved six-tree plots replicated eight or 10 times at planting densities of 358 trees (AP) or 252 trees (I)/ha, respectively. Tree growth and survival, yield, and juice quality were measured for 15 years. When losses occurred, trees were replaced annually with another one on the same rootstock. The data of seven rootstocks were subjected to a financial interpretation of three scenarios: tree loss and tree loss with or without tree replacement using the discounted cash flow and internal rate of return methods at a 15% rate. At the flatwoods location, when differences among replications became apparent on several rootstocks, soil data were collected to study its possible association to tree performance; also in this trial, 400-kg fruit samples were differentially harvested in 2 successive years from mature trees on each of five commercial rootstocks when the juice soluble solids/acid ratio was near 15. The juice was extracted, pasteurized, and evaluated for flavor by an experienced taste panel. The horticultural data obtained for trees on specific well-studied rootstocks [Volkamer (*C. volkameriana* Ten. & Pasq.)] and rough (*C. jambhiri* Lush.) lemons, Carrizo citrange [*C. sinensis* × *Poncirus trifoliata* (L.)], sour orange [*C. aurantium* (L.)], Cleopatra mandarin (*C. resini* Hort. ex Tan.), trifoliolate orange (*P. trifoliata*), a selection of sweet orange (*C. sinensis*), and Swingle citrumelo (*C. paradisi* Macf. × *P. trifoliata*) at both locations were typical of their well-documented performance in Florida and elsewhere. Tree losses were virtually only from citrus blight and ranged from none (sour orange) to greater than 50% (Volkamer and rough lemons) at both locations, although tree loss began later at the Central Florida location. ‘Valencia’ cuttings (only at the flatwoods site) were long-lived and cropped well for their smaller size compared with the budded trees. Taste panelists were not able to distinguish differences over two seasons among pasteurized ‘Valencia’ juices produced from trees on different rootstocks and normalized by soluble solids/acid ratio. Yield and planting density were the main factors affecting financial outcome; also, in the highly variable soils of the coastal flatwoods, trees growing in sites with greater depth to an argillic layer had 30% to 200% higher yields. Trees on Volkamer lemon had only ≈50% survival at both locations but had the highest (\$7,338/ha I) or one of the highest cash flows (\$13,464/ha AP) as compared with one of the commercial standards, Carrizo citrange (\$6,928 I; \$16,826 AP), which had only ≈25% tree loss. Inclusion of financial analysis, with certain limitations, was concluded to considerably improve rootstock selection decisions compared with selection based only on horticultural data.

Most tree fruit industries succeed on the availability of suitable high-quality scions and rootstocks and profitable combinations as dictated by a wide range of factors (Castle and Gmitter, 1998). Choosing a citrus rootstock is commonly determined by compati-

bility with the scion; its tolerance to various pests, diseases, soil, and site, and other environmental conditions; and the influence of the rootstock on yield and fruit quality (Castle, 1987, 1995; Wutscher, 1979). Sometimes a rootstock is developed or evaluated

for a specific purpose, e.g., tree size control, tolerance to certain specific circumstances like high pH or calcareous soils, sites prone to flooding, nematodes, or virus or viroid diseases (Bauer et al., 2005; Castle and Baldwin, 2005; Castle and Phillips, 1977, 1980; Castle et al., 2004, 2009; Phillips and Castle, 1977).

Choosing a citrus rootstock is a deliberate action aimed at specific objectives and designed to ensure tree survival, long-term performance, and profit. The foundation of those decisions has been identifying and characterizing rootstock traits in screening trials, formal field trials in which significant variability can occur between and within sites (Bevington and Cullis, 1990; Castle, 1983; Castle and Baldwin, 1995; Castle et al., 2000; Economides, 1993; Foguet, 2000; Hutchison et al., 1992; Roose et al., 1989; Stover and Castle, 2002; Wheaton et al., 1991, 1995a, 1995b; Wutscher and Bistline, 1988; Wutscher and Bowman, 1999; Wutscher and Hill, 1995), commercial experience, and more recently, the use of molecular marker techniques to assess germplasm in advance of field trials (Gmitter et al., 2007; Ling et al., 2000). Typically, the information gathered from those combined sources is assembled into summary charts that are used as a guide for rootstock selection (Castle et al., 1993, 2006; Ferguson et al., 1990; Newcomb, 1978). It is uncommon that additional or better selection criteria have been developed for making citrus rootstock decisions. The generalities of the charts are usually compiled from years of research and commercial evaluation. They represent both the inherent weaknesses and strengths associated with selection guides: weakness in that the rootstock characterizations are often derived from local or regional experiences and may be based on limited information; and strength in that the traits given in a chart are usually accurate and, thus, reliable in guiding the selection process. However, the charts do not directly provide any information about profitability or risk.

Using a rootstock selection chart has risks. Individual traits listed in a selection chart may not have equal importance in the selection process. The Florida citrus industry, for example, is largely composed of orange groves with fruit grown for juice products. Growers are compensated for juice soluble solids content. Fresh fruit citrus growers, like with other tree crops, earn their income by selling a high-quality product defined by such factors as fruit size, internal quality, and external color. The choice of citrus rootstocks in those two instances may be different.

An alternative approach is to complement horticultural performance data with economic analysis as has been applied in apple (Robinson and Hoying, 2004; Robinson et al., 1991, 2007) and citrus (Boswell et al., 1975, 1978) planting systems research to determine profitability. The commercial apple industry has steadily moved to increased planting density supported by research results. Those studies have shown that high yields can be obtained over a range of planting systems and densities, but when

the horticultural outcomes were subjected to a financial interpretation, there were optimum densities. Those studies were also useful in demonstrating how profitability responded to changes in fruit prices, the cost of nursery trees, and yield. One of the earliest reports in Florida about "Economic Aspects of Citrus Stocks and Scions" (Ziegler, 1966) took up the issue of risk in association with matching scions and rootstocks based primarily on the body of knowledge available, i.e., the greater the knowledge, the lower the risk. The favorable financial consequences of matching scion-rootstock combinations and planting density were demonstrated later in Florida field trials (Muraro et al., 1995; Wheaton et al., 1995a) and California (Boswell, et al., 1975, 1978). Nevertheless, financial interpretations are not a routine part of citrus scion and rootstock breeding and evaluation programs (Bevington and Cullis, 1990; Breed et al., 1996; Foguet, 2000; Rouse, 2000).

Our objectives were to: 1) conduct a long-term field test of citrus rootstocks to gather routine horticultural data and observe responses to citrus blight; and 2) determine if adding financial interpretations would result in an improved means for selecting a rootstock, one that would be robust enough to be useful across a range of experimental conditions. Furthermore, we hypothesized that yield would be the primary factor determining profitability in an orange grove of fruit grown for processing and would be of sufficient significance to override other normally important factors such as site conditions, disease tolerance, and fruit juice quality.

Materials and Methods

Plant materials. Rootstock seedlings grown from Florida seed sources were propagated with a commercial 'Valencia' nucellar clone (V-S-SPB-1-21-30XE) in the field nursery of the Citrus Budwood Registration Bureau, Florida Division of Plant Industry, Winter Haven.

Trial locations. The trees were planted in commercial groves located near Avon Park (lat. 27°34'02" N; long. 81°28'08" W) and Indiantown (lat. 27°00'53" N; long. 80°33'56" W) in Feb. 1977 and Nov. 1976, respectively. The Avon Park grove typifies the Central Florida

Ridge with Astatula sand soil (Typic Quartzipsamments), a deep, well-drained soil with little organic matter or cation exchange capacity and an acid pH. The Indiantown grove typifies the coastal flatwoods with soils of three series: Riviera and Pineda (Arenic Glossoqualls) and Holopaw (Arenic Ochraqualls). The dominant soils at the trial are Riviera and Pineda. The soils of these series are Alfisols characterized by an A horizon with 1% to 5% organic matter underlain at ≈60 to 90 cm from the surface by a highly leached B/E horizon of sandy loam to sandy clay loam texture (10% to 25% clay) that is a natural internal barrier to drainage. Because such sites are poorly drained, their use for citrus requires ditching followed by the forming of two-row beds. The latter process involves cutting furrows and moving soil laterally to form beds between adjacent furrows. Thus, natural variability among soil types and any additional variability resulting from the bedding process are site factors that can have a considerable impact on the variability within a rootstock trial and individual tree performance. In the Indiantown trial, the trial site was ditched only around the perimeter forming a "bed" with 13 rows. The outer rows included soil materials excavated from the ditch. The interior rows were shallow single-row beds; thus, the trees were planted in only lightly disturbed soil.

Trial design and management. The Avon Park trial was planted in a split plot design with four replications of the main plot treatments: commercial preplant fumigation with methyl bromide or no fumigation. That factor was added to the trial because a grove adjacent to the trial was infested with burrowing nematodes (*Radopholus similis* Cobb). The subplot treatments were 12 rootstocks (Table 1) planted at 4.6 × 6.1 m (358 trees/ha) in six-tree plots (two adjacent rows with three trees in each row). The Indiantown trial was planted in a randomized complete-block design with 10 replications of six-tree plots (like at Avon Park) at 5.1 × 7.6 m (252 trees/ha). In addition, two perimeter rows and one in the middle of the trial were planted with six replications of three-tree, in-row plots of rootstock seedlings and rooted cuttings of the scion. Those plants were included to observe their behavior regarding blight along with the budded trial trees.

Each trial was managed according to recommended nutritional, irrigation (micro-sprinkler), and pest control programs to produce fruit for processing. The annual nitrogen fertilization rate was ≈220 to 250 kg·ha⁻¹. The Avon Park trees were mechanically hedged generally on an annual cycle; hedging was also done in the Indiantown trial but began later because of the wider spacing at that site. The trees in neither trial were topped in the life of the trials. Several serious freezes occurred during the trial period. The trees were protected with water applied through the irrigation system and did not sustain any damage that required a change in cultural practices or appeared to affect data validity. At Indiantown, trees lost to *Phytophthora* foot or root rot or citrus blight were replaced annually on

the same rootstocks; at Avon Park, trees were also replaced on the same rootstock, but only for ≈10 years on an irregular basis and, thereafter, on other rootstocks.

Data. Tree trunk diameter 15 cm above the bud union of two trees/plot was measured at planting and annually thereafter. Annual measurement of tree canopy height was added when the trees were ≈4 years old. Trees with blight were recorded in all replicates with diagnosis confirmed by trunk water uptake (Lee et al., 1984). Other annually collected data included yield and juice quality measurement of 60-fruit samples taken from each of six to eight plots. The fruit samples were usually collected in mid to late-March at Avon Park and early May at Indiantown. Juice was extracted and analyzed in an industry standard commercial facility at the University of Florida Citrus Research and Education Center (CREC), Lake Alfred. Yield was measured during commercial harvest by recording volume in standard containers that held ≈400 kg of fruit. Normally, all six trees in a plot were harvested and any diseased or declining trees with salvageable crops were included. When the number of unacceptable trees exceeded three/plot, a substitute plot was selected, or if none was available, then the number of replicates was reduced and the data were analyzed using a missing plot procedure, a situation that arose with only four rootstocks and only required substitutions for one or two plots at both locations.

At Indiantown, the soil was typically more variable than at Avon Park (Bauer et al., 2007) as reflected in plot to plot yield data. Thus, a local USDA-National Resource and Conservation Service soil scientist surveyed the Indiantown location to identify the soils. Soil (0 to 20 cm deep) and leaf samples were collected from within certain plots according to soil series and rootstocks to study any relationship between tree performance and soil traits. The soil samples were air-dried, extracted with a Mehlich I solution, and analyzed for phosphorus, calcium, and magnesium by atomic absorption spectrometry; pH was measured in water (2:1 water:soil). Samples of 60 spring flush leaves/plot were collected, washed, dried at 70 °C, and ground for nutrient analysis by atomic absorption; nitrogen was determined by the Kjeldahl method.

A study of the impact of rootstock on juice flavor was conducted over two consecutive seasons when the trees were 16 and 17 years old. Samples of 400 kg of fruit were differentially harvested in March by combining fruit from four replicates of trees on Carrizo citrange, Cleopatra mandarin, rough lemon, sour orange, or Swingle citrumelo. Normal fruit samples were collected periodically in advance to track soluble solids:acid ratio. The juice was extracted and analyzed as described previously. Harvest dates were selected when Brix:acid ratios of the fruit from each rootstock were projected to be near 15. The 400-kg samples were washed, sized, and run through a commercial extractor at CREC, Lake Alfred. The juice was passed

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Table 1. Height and survival of 'Valencia' orange trees on 12 rootstocks grown at Avon Park (AP; n = 8) or Indiantown (I; n = 6), FL.

Rootstock	Tree ht (m) at				Survival (%) ^z	
	5 yr		11 yr		AP	I
	AP	I	AP	I		
Carrizo citrange <i>Citrus sinensis</i> (L.) Osb. × <i>Poncirus trifoliata</i> L. (Raf.)	3.1	3.0	4.5	4.1	69	45
Cleopatra mandarin <i>C. reticulata</i> Blanco	2.9	3.1	4.5	4.4	65	27
Macrophylla <i>C. macrophylla</i> Wester	2.6	3.0	3.8	3.7	77	68
Orlando tangelo <i>C. paradisi</i> Macf. × <i>C. reticulata</i>	2.6	3.3	4.4	4.6	83	35
Palestine sweet lime <i>C. limettioides</i> Tan.	2.9	3.1	4.2	3.7	63	13
Rangpur <i>C. limonia</i> Osb.	2.8	3.0	4.3	4.1	60	27
Rough lemon <i>C. jambhiri</i> Lush.	2.9	3.4	4.3	4.6	46	20
Sour orange <i>C. aurantium</i> L.	2.8	2.9	4.4	4.3	96	95
Sweet orange <i>C. sinensis</i>	2.2	2.9	4.0	4.1	90	83
Swingle citrumelo <i>C. paradisi</i> × <i>P. trifoliata</i>	2.3	2.6	3.6	3.6	98	63
Trifoliolate orange <i>P. trifoliata</i>	2.4	2.9	3.5	3.7	75	53
Volkamer lemon <i>C. volkameriana</i> . Ten. & Pasq.	3.1	3.5	4.7	4.7	44	23
Valencia sweet orange cuttings ^y				3.8		84
Mean	2.7	3.1	4.2	4.1	72	46
Least significant difference	0.2	0.2	0.2	0.3		

^zAfter 24 years at Avon Park and 27 years at Indiantown.

^yExcluded from statistical analysis.

through a finisher, pasteurized, filled into 177-mL tin cans, and then stored frozen until use. Samples were removed from storage, brought to 15.5 °C, and presented to ≈15 to 18 experienced panelists familiar with tasting citrus juices. The juices were rated on a hedonic scale of 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely (Kramer, 1960).

Statistical analyses. Statistical comparisons were not made between locations. Data were analyzed within a location according to the trial design using PROC GLM (SAS Institute, Cary, NC) with mean separation by the least significant difference (LSD) method. Yield data at both locations were analyzed each year. The Indiantown yield data were also examined using a repeated-measures analysis to determine yield trends. Citrus fruit yield has two components: tree growth over time and the associated increase in yield, and annual yield variation resulting from environmental factors (weather). Data plots indicated yield with tree age could be represented by a quadratic curve, but the quadratic effect on yield in relation to tree age was not statistically significant. The measurable yield trend with time was linear and interacted ($P < 0.0001$) with rootstock. The slopes of the yield regressions were calculated and compared by the LSD method. Mean flavor data were compared using rank sums for multiple comparisons (Kramer, 1960).

Economic interpretation. Data analyses were conducted using prevailing industry costs and returns during the 1980s when the trial was conducted (all financial assumptions and cost and return numbers are available

from R.P. Muraro). Annual yields, tree losses with annual replacement of trees on the same rootstocks (virtually all tree losses were from citrus blight), and juice quality data from both trials were used to calculate annual net operating income and annual and cumulative cash flows for trees on the seven commercial rootstocks among the 12 rootstocks in the trials. The calculation assumed that replacement trees grew and yielded the same as the original trees. That assumption is based on observation, occasional measurement of tree height, and yield estimates at both locations. To address the time value of money, a discount rate (because \$1 today is worth more than \$1 received in future years) of 15% was used for the cash flow calculations and estimated internal rates of return. The outcomes are based on hypothetical 1-ha groves in three scenarios with trees planted at their respective trial spacing: 1) no tree loss; 2) actual tree loss with no replacement; and 3) actual tree loss with replacement (Muraro and Castle, 1996); and certain other hypothetical tree spacing situations deemed reasonable from observations of tree development and final canopy size during the course of the trials. The financial outcomes included ending grove value.

Results and Discussion

Tree growth and survival. After 5 years, the trees at both locations on all rootstocks were nearly the same height, ≈3 m; however, some significant differences were beginning to appear among rootstocks (Table 1). The shortest trees at both locations were those on

Swingle citrumelo (≈2.5 m) and the tallest ones were those on Volkamer lemon (≈3.3 m). After 11 years, mean tree heights had increased to ≈4 m, but again with little difference between locations. The shortest trees at both locations (≈3.5 m) were those on Swingle citrumelo, trifoliolate orange, and macrophylla; the tallest trees at 4.7 m were those on Volkamer lemon. Changes in trunk cross-sectional area essentially showed the same relationships among rootstocks and locations (Fig. 1). At Avon Park, the trees growing in the portion of the trial site that received preplant fumigation were significantly larger in the first year than those that received no fumigation; however, the fumigation main effect was small and disappeared within the next 2 years. Fumigation was not a significant factor in tree survival, fruit yield, or juice quality and is not considered here. The 'Valencia' (scion) cuttings were among the smaller plants at the Indiantown location.

Most tree losses were from citrus blight, a disorder of unknown cause in which a tree loses xylem function and declines (Derrick and Timmer, 2000). In the first 2 years, 11 of the trees on sweet orange rootstock (18%) were lost to *Phytophthora* and less than 10% each among the trees on rough lemon or Volkamer lemon. Thereafter, all tree losses were from blight. Tree survival was strongly affected by rootstock and the pattern of tree losses was different between locations (Table 1; Fig. 2). After ≈25 years, the survival at both locations ranged from less than 46% among trees on Volkamer lemon and rough lemon to greater than 80% among those on sweet and sour oranges. Blight was more severe at Indiantown where after 27 years, only 40% or less of the original trees survived on six rootstocks, whereas at Avon Park, tree survival was greater than 60% on all but two rootstocks.

Tree decline from blight was first observed at Indiantown when the trees were 5 to 6 years old and preceded any decline at Avon Park by 2 years. At Indiantown, the trees on Volkamer lemon were among the first to show blight symptoms. Tree loss thereafter occurred at a relatively steep largely linear rate for more than 18 years before appearing to halt for a few years. That pattern was similar at Avon Park where tree loss was lower (Fig. 2). Tree loss on Cleopatra mandarin at both locations was low for ≈12 years and then accelerated at different rates between locations leading to a higher survival at Avon Park. The trees on Swingle citrumelo also had low rates of loss that extended to more than 20 years; however, there was a clear location effect. Tree loss at Avon Park remained low and 98% of the trees survived, whereas at Indiantown, tree loss increased over time and only 63% of the original 60 trees survived. The pattern of tree loss was also highly variable within a location and rootstock. There were six-tree plots at both locations that survived completely intact for years beyond when blight appeared in other plots on the same rootstocks. There were also plots in which all the trees became

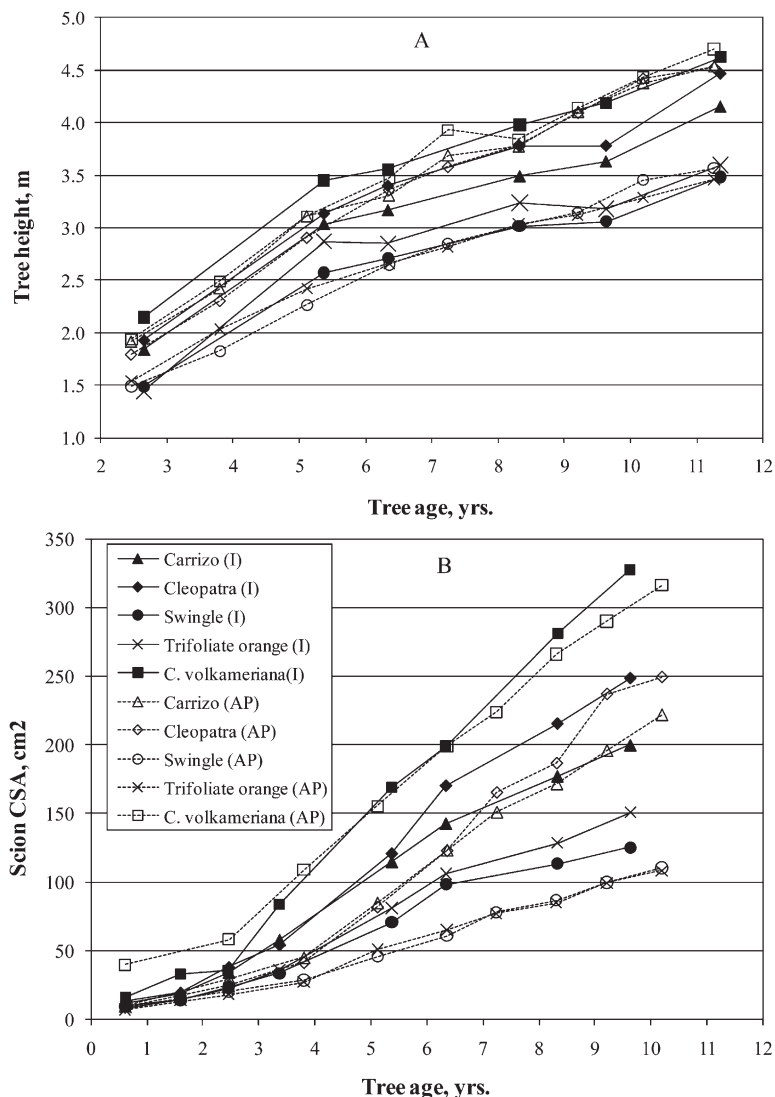


Fig. 1. Tree height (A) and trunk cross-sectional area (B) growth among 'Valencia' orange trees on five of 12 rootstocks in two field trials planted at 358 trees/ha at Avon Park (AP) or 252 trees/ha at Indiantown (I), FL.

blighted before any were affected in other plots indicating the nonrandom development of blight, which has been previously reported but remains unexplained (Derrick and Timmer, 2000). Replanting in a space where a tree was removed because of blight did not seem to accelerate decline. The incidence of blight among replacement trees was very similar to the pattern experienced with the original trees. Replacement trees on Volkamer lemon and rough lemon began to decline \approx 8 years after planting and those on Cleopatra mandarin started to decline from blight after 12 years.

Cuttings of the 'Valencia' scion were only included at Indiantown. Much like the trees budded on sweet orange rootstock, the cuttings survived many years with virtually no loss to blight; however, some cuttings declined later and their survival was only 64% as compared with 84% for the trees budded on sweet orange rootstock. The cuttings were mostly planted along the perimeter of the trial where the spoil from adjacent ditches may have influenced their survival, but their

growth and yield appeared to be no more variable than among the budded trees.

Yield and juice quality. All trees began to produce measureable crops within 2 years after planting (Table 2). In Year 2, yield was generally higher at Avon Park where the trees on macrophylla, Palestine sweet lime, Rangpur, rough lemon, and Volkamer lemon produced \approx 40 kg/tree and most other trees at both locations produced less than 10 kg/tree. The relationships among rootstocks were established early and the trend was largely unchanged after 14 years. There were significant differences within location and among rootstocks in each of the years that yield was measured. The highest cumulative yields (one young tree yield was missed at Avon Park) were 2176 and 2573 kg for trees on Volkamer lemon at Avon Park and Indiantown, respectively. Yield generally increased with tree age, but fluctuated annually after the trees were \approx 8 years old, which is normal for Valencia in Florida (Castle and Baldwin, 1995; Castle et al., 1993; Florida Agricultural Statistics

Service, 2009). The highest peak yields were among the trees on Volkamer lemon, which exceeded 300 kg/tree. Other trees at both locations with relatively high cumulative and annual yields were those on rough lemon followed by Rangpur, Palestine sweet lime, macrophylla, and Carrizo citrange (range, 1800 to 2528 kg/tree). Those trees commonly produced between 200 and 300 kg/tree annually after they were \approx 7 years old. The trees on other rootstocks such as trifoliolate orange, Swingle citrumelo, and sour orange generally yielded 50 to 100 kg less/tree annually leading to cumulative yields at both locations that were between \approx 1100 and 1500 kg/tree. The yield of the cuttings was often similar to or lower than yield of the budded trees.

Yield trends over time have rarely been statistically examined in citrus rootstock trials (Bevington and Cullis, 1990). Repeated-measures analysis among the Indiantown trees showed yield increased over time at significantly different rates among trees on 12 rootstocks as indicated by the slopes of the regression lines (Table 3). The trend over time was linear meaning that yield continued to increase as the trees increased in size regardless of rootstock. Trees on those rootstocks with the most vigor like rough lemon and Volkamer lemon had the largest annual increase in yield; trees on Swingle citrumelo and trifoliolate orange had the smallest increase.

The juice quality data are presented in 2-year means for young (Years 5 to 6), middle-aged (Years 9 to 10), and mature (Years 13 to 14) trees and for years unaffected by freezes (Table 4). Using 2-year means helped reduce year-to-year seasonal and sampling variability. Typical juice contents among rootstocks were \approx 56% to 61% with significant differences among rootstocks, but only small differences between locations at any tree age. Juice content increased as the trees matured, especially at Indiantown where the mean value increased from 56.4% to 63.3%. Fruit soluble solids concentrations among trees on Volkamer lemon, rough lemon, macrophylla, and Palestine sweet lime constituted a group with relatively lower values; the highest values were for the trees on trifoliolate orange and the 'Valencia' cuttings (11.6% to 13.8%). Soluble solids concentration tended to be higher among the Indiantown trees than those at Avon Park and increased with tree age at Avon Park but was less consistent at Indiantown. The difference is largely the result of the later annual sampling time (May versus March) at Indiantown and not location. The fruit from trees on rootstocks with low soluble solids also had lower acid values and the fruit from those trees on those rootstocks with high soluble solids, like sour orange and trifoliolate orange, had significantly higher acid values. Soluble solids-acid ratio is a measure of fruit maturity. Fruit with lower ratios mature later than those with higher ratios. There were significant differences in each age group within locations. High soluble solids fruit such as those from trees on sour orange and trifoliolate orange had higher acidity and lower ratios.

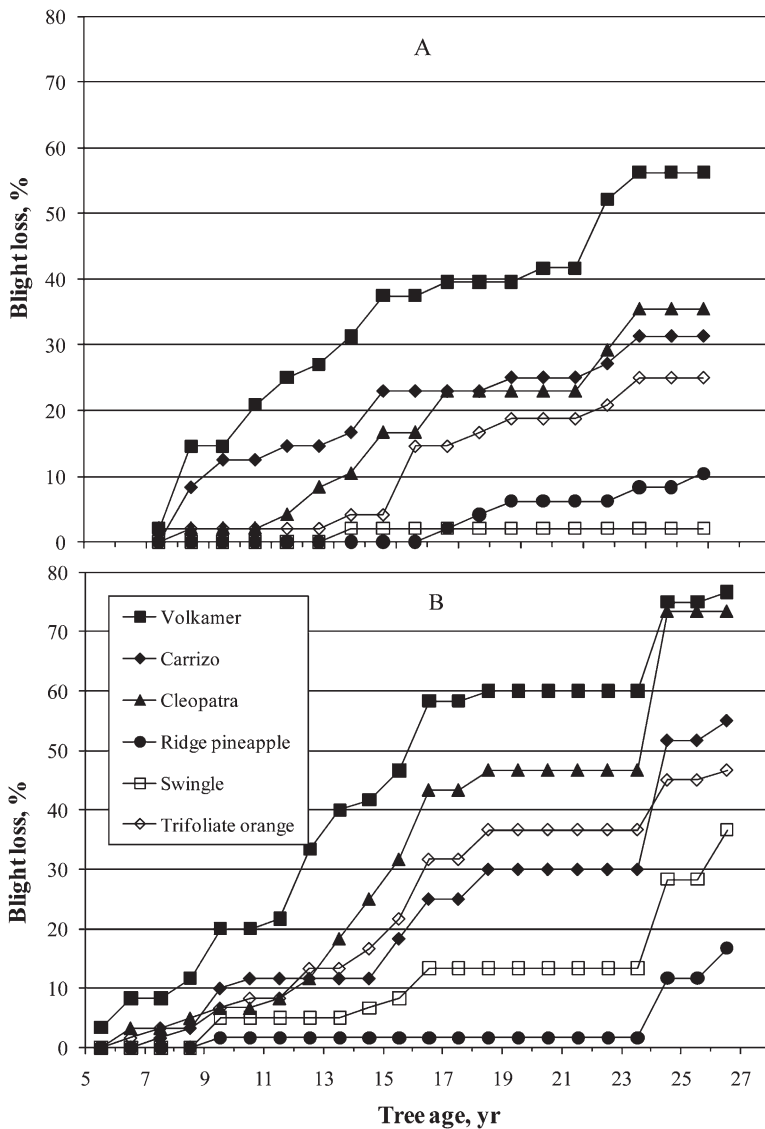


Fig. 2. Cumulative blight loss among 'Valencia' orange trees on five of 12 rootstocks in two field trials planted at Indiantown (A) or Avon Park (B), FL.

The main differences among rootstocks largely carried through when all the juice factors were combined into the soluble solids/ha calculations (Table 4). That variable is important to growers of fruit for juice because it is the basis for payment by the processor and, thus, determines income. The highest producers of soluble solids/ha were the trees on those rootstocks (Volkamer lemon, and so on) that produced fruit with relatively low-quality juice, but had the highest fruit yields. The high soluble solids concentrations in fruit from trees on rootstocks like sour orange did not compensate for their lower productivity. Trees on Volkamer lemon yielded 6000 to 7000 kg of soluble solids/ha in Year 13 to 14 at Indiantown and Avon Park, respectively, whereas those on trifoliolate orange produced less than 4600 kg at either location. However, the quantities of soluble solids produced at Avon Park were higher than at Indiantown because of the difference in tree planting density, which was higher at Avon Park. The cuttings

had among the best juice quality values, but their lower yields resulted in the lowest soluble solids production/ha.

Juice flavor. The experienced panelists were not able to distinguish differences over two seasons among pasteurized 'Valencia' juices produced from trees on different rootstocks and normalized by soluble solids:acid ratio. The hedonic scores indicated that all juices had acceptable flavor, although the juices from the trees on rough lemon had typically low soluble solids and those on sour orange had one of the highest values (Table 5). These results contradict the conventional view that trees on rough lemon produce low-quality juice as compared with those on sour orange. Seasonal sampling data show that the soluble solids difference between the two rootstocks would occur almost all season-long, but changes in acid do not occur at the same rate; thus, there are times when ratios are similar and taste differences apparently become difficult to separate. Flavor of orange juice products is important in Florida where a 100-point

scoring system is used commercially and 40 points are assigned to flavor for Grade A products (Fellers, 1990). The implication of our results is that growers producing fruit for juice with trees on different rootstocks harvested according to ratio might benefit with better returns; likewise, processors might have blending options with such fruit.

Yield variability among replications. In comparing high- and low-yielding individual replicates within trees on four commercial rootstocks in the trial at Indiantown, tree height of the low-yielding replicates tended to be smaller after 14 years, but cumulative yield was 30% to 200% larger in the more productive replicates (Table 6). The yield differences between replicates within rootstocks were meaningful and, in all cases, were established when the trees were young and generally continued for their recorded lifetimes (Fig. 3). Furthermore, 'Valencia' typically alternate bears in Florida (Florida Agricultural Statistics Service, 2009), but that tendency seemed to be reduced among the low-yielding replicates.

The differences within rootstocks suggest that soil factors were affecting tree nutrition and yield but not tree growth. A professional assessment of the soil variability and series present at the site reinforces the relationship of rootstock performance to certain soil features such as the presence of, and depth to, an argillic (clay) horizon, presence of calcareous materials, soil organic matter content, and texture (Mann et al., 2009). Tree performance was adversely affected when one or more of these soil traits were present like in all the low-yielding replicates, which had an argillic horizon of sandy clay or sandy clay loam texture present at ≈ 40 to 70 cm. The high-yielding replicates were all growing in Pineda soils, which are considered among the best for citrus in the coastal flatwoods areas of Florida. Pineda soils also have an argillic horizon, but it occurred at the trial location at depths greater than 80 cm. The coated sand grains in Pineda soils have been shown to have a positive influence on tree yield (Mann et al., 2009). Excessive amounts of phosphorus (particularly in the 0- to 15-cm sample) and calcium were found in the soil samples. The calcium contents are well above the level considered adequate probably because of the strong extractant used in processing the soil samples (Obreza and Morgan, 2008); however, in most instances, the quantities reported at both sample depths in the low-yielding replicates exceeded those at both depths in the high-yielding replicates. The high soil phosphorus and calcium levels were reflected in the high leaf nutrient concentration data for phosphorus and calcium combined over 2 consecutive years of sampling (Table 4). Other leaf nutrient concentrations were optimum or near optimum except for zinc. Severe leaf zinc deficiency was observed for many years among the trees growing in the poorer performing replicates and less so in the other replicates. Chronic zinc deficiency can reduce yield (Obreza and Morgan, 2008).

Table 2. Yield (kg/tree) of 'Valencia' orange trees on 12 rootstocks at Avon Park (AP; n = 8) and Indiantown (I; n = 6), FL.

Rootstock	Tree age (yrs)												Cumulative	
	2	3	4	5	6	7	8	9	10	11	12	13		14
Carrizo citrange														
AP	10	51	0 ^z	76	120	80	230	122	245	188	231	295	267	1912 ^z
I	7	12	35	70	90	122	187	161	187	161	255	255	216	1759
Cleopatra mandarin														
AP	1	32	0	38	73	71	167	167	193	209	115	278	198	1540
I	1	4	26	40	68	108	177	161	162	122	246	225	190	1531
Citrus macrophylla														
AP	41	55	0	48	104	59	237	169	235	164	233	228	228	1800
I	8	22	49	60	129	145	210	172	201	189	228	247	213	1872
Orlando tangelo														
AP	2	33	0	37	51	45	151	131	201	186	130	228	167	1361
I	5	3	34	54	90	119	197	177	197	145	268	255	209	1753
Palestine sweet lime														
AP	38	74	0	97	132	38	281	112	270	191	269	226	281	2010
I	6	22	58	100	129	154	202	153	198	163	270	228	288	1971
Rangpur														
AP	37	69	0	74	110	91	232	168	243	207	213	272	232	1946
I	6	21	46	103	116	166	215	189	219	196	281	293	245	2097
Rough lemon														
AP	29	61	0	41	123	57	253	181	273	214	236	259	239	1964
I	7	19	66	101	152	176	232	269	250	250	293	391	325	2528
Sour orange														
AP	8	46	0	59	76	62	189	127	207	194	155	248	208	1581
I	3	8	22	41	74	100	154	104	169	139	221	253	187	1475
Swingle citrumelo														
AP	10	40	0	55	65	69	133	109	166	159	153	164	160	1281
I	3	11	20	40	66	91	145	96	123	104	188	182	123	1191
Sweet orange														
AP	8	25	0	21	41	44	138	126	193	189	131	230	203	1349
I	5	7	25	38	91	107	181	142	185	131	227	243	225	1606
Trifoliolate orange														
AP	12	42	0	67	71	101	140	133	153	160	167	148	164	1357
I	5	9	21	32	85	98	126	128	143	121	182	206	177	1332
Volkamer lemon														
AP	41	77	0	96	149	55	283	185	258	208	224	334	265	2176
I	8	24	59	121	150	184	251	235	225	242	356	364	355	2573
Valencia cuttings^y														
				43	74		108	156	112	223	182	158		1057
Least significant difference														
AP	5	11		25	18	23	27	27	30	29	30	45	55	
I	4	6	13	19	28	25	29	31	52	30	39	56	58	

^zYield was not measured at AP this year; thus, the cumulative yield is minus 1 year of data.

^yExcluded from statistical analysis.

A recent, comprehensive study showed that Florida citrus yield can be significantly related through several statistical methods to various soil properties (Mann et al., 2009). In our study at Indiantown, the magnitude and consistency of the yield differences within rootstocks revealed and confirmed site-specific soil factors that would be useful in selecting sites for particular rootstocks. The best examples are Carrizo citrange and Swingle citrumelo. They are hybrids of trifoliolate orange, a rootstock well known for intolerance to high levels of soil calcium that can result in calcium-induced iron chlorosis and nutrient imbalances and deficiencies that affect tree growth and cropping (Castle, 1987; Castle et al., 2009; Obreza and Morgan, 2008). Calcareous materials and high pH contributed to the differential performance among the high- and low-yielding plots of trees on those rootstocks.

A further consideration is whether the differences among replicates compromised the statistical validity of the Indiantown trial. Site variability is normally accounted for by blocking when establishing a field trial. The estimates of variability for blocks were not

excessive or statistically significant in most years at either location. Blocking as a statistical tool is not a perfect technique, especially in a situation like the highly variable soils of the Florida flatwoods and when good measures of site variability are not available in advance. It is for those reasons that we designed our trial with large plot sizes and number of replicates.

Financial interpretation. Our primary objective was to develop an improved means for selecting a rootstock for a citrus grove producing fruit for juice processing. We showed through financial analysis that income generated over 15 years could be used for that purpose regardless of location within Florida; furthermore, we demonstrated that yield was the primary determinate of profitability despite significant differences among rootstocks in their reaction to citrus blight and in 'Valencia' orange juice quality.

At the end of the 15-year financial analysis, cash flow among trees on seven of the 12 rootstocks for the "no blight" scenario at each location ranged from \$15,331/ha (Volkamer lemon) to -\$106 (Swingle citrumelo) at Indiantown and at Avon Park from \$22,366

Table 3. A repeated-measures analysis of yield trends over 10 years among 'Valencia' trees planted on 12 rootstocks (n = 6) in 1976 at Indiantown, FL.

Rootstock	Slope of regression	
	line ^z	R ²
Carrizo citrange	19.9 bc ^y	0.77
<i>Citrus macrophylla</i>	18.2 cd	0.70
Cleopatra mandarin	15.8 cd	0.72
Orlando tangelo	18.4 cd	0.70
Palestine sweet lime	17.5 cd	0.76
Rangpur lime	19.5 c	0.78
Rough lemon	27.0 a	0.85
Sour orange	19.8 bc	0.74
Swingle citrumelo	12.5 d	0.59
Sweet orange	26.6 ab	0.70
Trifoliolate orange	15.7 cd	0.82
Volkamer lemon	27.9 a	0.88

^zY = a + bX where X = tree age (years).

^yMean separation by least significant difference method; LSD = 6.9.

(Carrizo citrange) to \$9,868 (Ridge Pineapple sweet orange) (Table 7). Cash flows decreased substantially in the second scenario of blight losses in the trials with no tree replacement, except among the trees on those rootstocks with little or no blight loss, e.g., sour orange and Swingle citrumelo; however, at Indiantown, the cash flow for the trees on Swingle citrumelo changed from a positive to negative value and the returns would probably have improved further if the trees had been planted on more suitable soil (Table 6).

By replacing lost trees with another tree on the same rootstock, cash flow at Indiantown increased by comparison with the no replacement scenario, particularly among those rootstocks like Volkamer lemon that had the highest losses; at Avon Park, there was little change. The trees on Swingle citrumelo at Indiantown had a negative cash flow even when trees lost to blight were replaced. Negative cash flows mean that incomes did not exceed the 15% profit level we selected for the financial calculations. When the planting density at Indiantown for the trees on Swingle citrumelo was adjusted to the same as at Avon Park (358 trees/ha), cash flow improved to greater than \$5000/ha.

Internal rates of return (IRR) tracked the cash flows and ranged from 14% to 29%. During the period of the trials, there were no particularly high production or harvesting costs, but juice prices paid by processors were historically high; thus, the IRRs were above normal for agricultural investments (Bierman and Smidt, 2006).

Financial interpretation, rootstock selection, and planting density. Rootstock evaluation normally relies on common measures of horticultural performance like tree growth, productivity, and fruit and juice quality. Rootstock selection decisions based just on those traits do not take into account differences in the relative value or contribution of each rootstock attribute. Financial evaluation of horticultural performance integrates all biological and economic factors affecting the outcomes of an orchard on a particular rootstock and, thus, is a better means of assessment. We showed, e.g., that

Table 4. Juice quality of fruit harvested from ‘Valencia’ orange trees on 12 rootstocks (n = 6) grown at Avon Park (AP) and Indiantown (I), FL.

Rootstock	Tree age (yrs) ^z	Juice content (%)		Soluble solids concn (%)		Acid (%)		SS/A ratio		Soluble solids (kg·ha ⁻¹) ^y	
		AP	I	AP	I	AP	I	AP	I	AP	I
Carrizo citrange	5–6	58.1	56.7	11.4	12.2	0.96	0.72	12.0	17.8	2317	1347
	9–10	58.9	61.3	11.8	13.5	0.93	0.84	12.8	16.3	4555	3645
	13–14	59.1	63.7	12.9	12.2	0.91	0.75	14.3	16.4	7647	4933
Cleopatra mandarin	5–6	59.0	59.9	11.1	11.9	0.97	0.74	11.5	16.5	1299	949
	9–10	60.8	61.7	11.5	13.1	0.93	0.88	12.4	14.9	4499	3072
<i>C. macrophylla</i>	13–14	60.1	64.3	12.6	11.7	0.93	0.76	13.7	15.6	6417	3897
	5–6	53.7	47.1	9.8	10.3	0.85	0.62	11.7	18.0	1418	1181
	9–10	57.2	60.1	10.9	11.7	0.89	0.74	12.3	15.9	4504	3250
Orlando tangelo	13–14	59.2	62.7	13.1	11.6	0.93	0.70	14.4	16.6	6328	4227
	5–6	57.8	60.3	11.1	12.2	0.98	0.77	11.4	16.3	1012	1360
	9–10	59.9	62.3	11.5	12.9	0.89	0.86	13.0	15.1	4097	3869
Palestine sweet lime	13–14	59.8	63.6	12.5	11.8	0.94	0.78	13.5	15.3	5294	4385
	5–6	54.8	57.5	9.9	11.8	0.86	0.75	11.6	16.1	2225	1971
Rangpur	9–10	57.5	60.4	10.6	12.4	0.89	0.79	12.0	15.8	4185	3378
	13–14	59.9	63.4	12.4	11.6	0.88	0.73	14.2	15.9	6737	4922
	5–6	56.7	56.0	10.2	10.9	0.88	0.66	11.7	17.2	1892	1703
Rough lemon	9–10	58.9	61.0	11.0	12.0	0.88	0.77	12.6	15.6	4785	3837
	13–14	61.3	62.6	12.5	11.0	0.83	0.67	15.2	16.5	6897	4729
	5–6	54.9	53.0	10.0	10.8	0.85	0.67	11.8	17.0	1605	1754
Sour orange	9–10	58.3	60.3	11.2	12.1	0.91	0.79	12.3	15.3	5307	4754
	13–14	59.7	61.1	12.5	10.8	0.91	0.69	13.9	15.8	6664	6011
	5–6	59.6	59.9	11.4	12.3	1.02	0.77	11.2	16.7	1640	1102
Sweet orange	9–10	60.6	60.8	11.7	13.3	0.94	0.94	12.6	14.3	4248	2842
	13–14	59.9	64.2	12.8	12.1	0.99	0.79	13.1	15.3	6272	4539
	5–6	56.7	57.9	10.7	11.3	0.92	0.66	11.7	18.4	673	1093
Swingle citrumelo	9–10	59.4	61.1	11.7	13.1	0.89	0.91	13.3	14.6	3964	3300
	13–14	59.1	64.7	12.7	11.8	0.89	0.76	14.4	15.6	5803	4721
	5–6	59.0	58.7	11.5	11.9	0.97	0.72	12.0	16.4	1454	909
Trifoliolate orange	9–10	59.5	59.6	12.2	13.2	0.88	0.85	13.9	15.7	3568	2078
	13–14	60.6	64.5	13.6	11.9	0.87	0.72	15.7	16.5	4771	3052
	5–6	58.5	58.3	11.8	12.2	0.99	0.73	12.0	17.2	1693	1074
Volkamer lemon	9–10	59.3	60.1	12.9	13.7	0.94	0.87	13.8	15.8	3891	2931
	13–14	59.8	63.1	13.8	12.1	0.89	0.73	15.5	16.9	4589	3748
	5–6	55.7	51.0	10.1	10.8	0.86	0.65	11.9	17.7	2472	1904
Cuttings	9–10	57.8	60.3	10.7	12.0	0.86	0.75	12.4	16.0	4900	4628
	13–14	57.5	61.4	11.6	11.1	0.85	0.72	13.8	15.5	7187	6248
	5–6	56.7	63.5	12.4	12.4	0.89	0.89	14.0	14.0	858	858
Mean	9–10	62.0	62.0	12.8	12.8	0.83	0.83	15.5	15.5	2638	2638
	13–14	63.0	63.0	11.6	11.6	0.75	0.75	15.7	15.7	3120	3120
	5–6	57.0	56.4	10.7	11.5	0.92	0.71	11.7	17.1	1642	1362
Least significant difference	9–10	59.0	60.8	11.5	12.7	0.90	0.83	12.8	15.4	4375	3465
	13–14	59.7	63.3	12.7	11.6	0.90	0.73	14.3	16.0	6217	4618
	6	1.8	1.2	0.3	0.5	0.04	0.04	0.4	0.6	403	594
	9	1.4	NS	0.4	0.7	NS	0.08	0.9	0.9	666	753
	14	1.7	2.4	0.7	0.7	0.10	0.04	1.1	1.0	2073	1036

^zData are means of a 2-year period, e.g., Years 5 and 6.

^yCalculated by multiplying the yield from Table 2 for the given year × % juice × % soluble solids × no. tree/ha. NS = nonsignificant.

trees on Volkamer lemon were precocious in bearing and relatively high-yielding thereafter; but, the ‘Valencia’ trees on that rootstock produced low juice-quality fruit and had high losses to blight. That combination of attributes presented in a rootstock selection guide (Castle et al., 2006) might discourage use of Volkamer lemon; however, the financial analysis showed that at both locations, although ≈50% of the trees were replaced after 15 years, the trees on that rootstock had one of the highest cash flows and internal rates of

return (Table 7). Volkamer lemon was the most profitable rootstock at Indiantown and one of the most profitable at Avon Park.

Our results confirmed our hypothesis and the commonly known importance of yield as a factor in selecting citrus rootstocks like with apple planting systems (Robinson et al., 2007). However, the financial analysis quantified its importance with citrus and also showed that the importance of yield lies in the ability of that trait to compensate to a large degree for other comparative weaknesses

within a citrus rootstock. If those deficiencies are reduced or absent, the evidence from our trials suggested that even a moderately productive rootstock combined with tolerance to blight, high juice quality, and the proper matching of tree vigor with planting density would outperform trees on a rootstock like Volkamer lemon. That point is illustrated by comparing the “blight with resets” results of the ‘Valencia’ trees on Carrizo citrange with those on Volkamer lemon at each location and between the two locations (Table 6). Blight loss was ≈50% less for the trees on Carrizo citrange than on Volkamer lemon regardless of location; juice quality was similar for each rootstock at each location so those factors are not considered in the comparison. At Indiantown, the 32% higher cumulative yield/tree of the trees on Volkamer lemon (Table 2) was sufficient to offset their lower juice quality and greater blight losses resulting in a larger cash flow than for the trees on Carrizo citrange. At Avon Park, the difference in cumulative yield/tree between the two rootstocks was only 12% and there were 42% more trees than at Indiantown. Thus, the increased planting density at Avon Park coupled with similar yields/tree between the two rootstocks (Table 2) led to a cash flow result for the trees on Carrizo citrange that was the best overall financial performance between both locations. The effect of planting density explains the generally higher cash flows and IRRs for the trees at Avon Park versus Indiantown, but the relative financial outcomes remained largely unchanged among rootstocks. Higher planting density has the potential to improve grower returns and function as a buffer to a certain extent against changes in economic factors such as fruit or juice prices (Robinson et al., 2007).

Planting density had a positive influence on rootstock financial outcomes when comparisons were made between locations for a particular rootstock. Another aspect of tree spacing is whether trees on certain rootstocks with lower vigor and smaller tree size were better suited for higher density and on that basis, outperformed those less suited for the 358 trees/ha planting density at Avon Park. The trees on trifoliolate orange are the best example because of all rootstocks, those trees were the smallest and produced good yields of fruit with excellent juice quality. Nevertheless, their performance was still far below the yields (Table 2) and soluble solids production (Table 4) of the trees on Volkamer lemon. Even if the spacing at Avon Park for the trees on trifoliolate orange was adjusted to 538 trees/ha, total yield would have been 7% below that of the trees on Volkamer lemon at the original density of 358 trees/ha. That comparison supports the contention that when selecting rootstocks for a citrus grove of juice oranges and properly matching planting density with tree size and site factors, yield can dominate performance.

The effect of spacing was obvious with the trees on Swingle citrumelo. At a planting density of 252 trees/ha in Indiantown, they

Table 5. Rootstock effects on pasteurized 'Valencia' orange juice flavor and quality.^z

Rootstock	1991–1992 season				1992–1993 season			
	SSC ^y	Acid ^y	Ratio ^y	Flavor ^x	SSC	Acid	Ratio	Flavor
Carrizo citrange	11.8	0.83	14.2	7.2	12.3	0.87	14.1	7.3
Cleopatra mandarin	11.8	0.82	14.3	7.2	12.1	0.75	16.1	7.1
Rough lemon	10.7	0.78	13.7	6.9	10.5	0.71	14.9	7.4
Sour orange	12.7	0.88	14.4	7.4	12.3	0.78	15.7	6.7
Swingle citrumelo	11.5	0.81	14.1	7.0	12.6	0.79	15.3	7.3

^zData are for one 400-kg sample/rootstock normalized for ratio and harvested at Indiantown from four replicates when the trees were 16 and 17 years old.

^ySSC is soluble solids concentration; Acid is % acid; Ratio is SCC/acid.

^xFlavor judged by an experienced taste panel using an Hedonic scale: 1 = dislike extremely; 5 = neither like nor dislike; 9 = like extremely. There were no significant differences among rootstocks in either season.

had a positive cash flow only under the “no blight” scenario; when adjusted to 358 trees/ha, the cash flow improved to a relatively low, but positive value that exceeded the Cleopatra mandarin cash flow. Trees on other rootstocks like sour orange or sweet orange had relatively good cash flows, but not the highest ones although the trees on sweet orange and sour orange produced good to excellent quality fruit, respectively, and virtually none were lost to blight. It was slowness to bearing (Table 2) that resulted in the lower cash flow of the trees on sour orange at Indiantown, but essentially the same bearing behavior at Avon Park at the higher planting density resulted in an excellent cash flow. ‘Valencia’ trees on Cleopatra mandarin in Florida are vigorous and well-known to be slow-bearing (Castle, 1987; Wutscher, 1979) as occurred at both locations. Those attributes resulted in the lowest cash flow at Indiantown (except for Swingle citrumelo) where substantial cropping only began when the trees were ≈10 years old, the same age at which substantial blight losses also began to occur.

Robustness of financial interpretation. If financial interpretation is a useful tool, how broadly can it be applied and when in the life of a field trial are the basic conclusions about rootstocks determined? Horticulturally, our rootstock results were classic for Florida and are very representative in general for ‘Valencia’, likewise for rootstock responses to blight (Castle and Baldwin, 1995; Castle and Phillips, 1980; Castle et al., 1993; Wutscher and Bowman, 1999). Rootstock effects on yield and juice quality were apparent within the first few cropping years; by the time the trees had cropped four to six times and additional juice quality data were gathered, the differences among rootstocks were well established and changed little thereafter. After 6 cropping years, the trees were ≈10 years old and the same relative financial differences were apparent then as at the end of the trial. The trees on many of the trial rootstocks at that time had produced 40% to 50% of their total yield. If using horticultural plus financial interpretation is validated in further studies, the impact on the time of the plant improvement process of creation to release would be meaningfully reduced.

Biological factors that could influence our financial outcomes are rootstock traits, inherent fruit quality of the scion, and site conditions that could change rootstock performance or the relationship among rootstocks under

evaluation; economic factors include whether the fruit is being grown for the fresh or juice market, tree losses and replacement costs, and planting density. Our results showed that financial analysis has value when there are rootstock differences. Rootstocks with similar or offsetting traits resulting in similar horticultural outcomes were not distinguished by financial analysis. Nevertheless, financial analysis would distinguish among rootstocks, e.g., with similar long-term productivity, but different cropping patterns. Trees on a rootstock that was precocious would likely be more profitable than on a rootstock less quick to bear under otherwise similar circumstances.

The role of the scion variety in rootstock evaluation and financial interpretation poses an interesting question, i.e., will the results vary if the scion is a high- or low-quality orange? A high-quality juice orange like ‘Valencia’ might not be very much affected by citrus rootstocks or it might be ideally suited because it would allow the fullest expression of rootstock effects. The ‘Valencia’ trees in our trials responded to the rootstocks that exhibited a range of attributes and effects on tree vigor, juice quality, yield, and blight tolerance resulting in useful financial separations. The same question can be applied to a low-quality juice orange like ‘Hamlin’, i.e., are rootstock differences relatively diminished or magnified? The evidence from our ‘Valencia’ trials and another unpublished 13-year ‘Hamlin’ trial with some of the same rootstocks indicates that rootstocks sufficiently affect all aspects of horticultural performance regardless of scion and that financial interpretations are possible and worthwhile. However, it remains to be demonstrated if this approach can be applied to field research with fresh fruit cultivars. Also, in an apple study, financial analysis showed that the planting systems had differential sensitivity to fruit price (Robinson et al., 2007), something we did not determine in our study.

We found that financial outcomes were not exceptionally sensitive to tree losses that occurred before the trees began to crop. The initial tree losses from Phytophthora infections had little impact on the cash flows after 15 years. Afterward, as trees age, their annual yields increase and represent an increasingly larger proportion of their total productivity over a given period. Thus, a tree lost at age 12 years could have more impact on grove

performance than one lost at age 4 years, but that impact is also a function of planting density. The impact is diminished as planting density increases as clearly seen with the trees on Cleopatra mandarin at Avon Park versus Indiantown under the “blight with resets” scenario (Table 6).

Rootstock effects on inherent scion fruit quality. Ancillary to the issue of scion-rootstock interactions and their effects on financial outcomes is the question of whether a rootstock can improve fruit soluble solids, the basis for sale of fruit to processors in Florida. The answer appears to be no because at Indiantown, the soluble solids concentration of the fruit from the ‘Valencia’ cuttings was higher than in the fruit from virtually all of the budded trees with only a few exceptions. Those exceptions probably resulted from differences in mean fruit size with smaller fruit having higher soluble solids concentrations like produced by the trees on trifoliolate orange at both locations (Barry et al., 2004). Thus, it can be concluded again that yield is perhaps the key element in profitability.

Soil variability and rootstock performance. The soils at the two locations are representative of the major citrus-growing areas of Florida. Horticultural variability among replicates was relatively low among rootstocks at Avon Park, ≈10% to 20% difference between high- and low-yielding replicates (data not given) as compared with that at Indiantown where the site/soil was highly variable. We showed, e.g., that trees on one rootstock, Swingle citrumelo were limited in their performance at the Indiantown location for two reasons: they were spaced too far apart and the soil at certain sites was not well suited primarily because of its calcareous nature. By adjusting their spacing in the hypothetical analysis, their performance was improved and even more so when a financial interpretation was applied to only the data from the higher-performing replicates growing in more favorable soil (Table 6; Fig. 3).

Conclusions

We conclude that a new model involving horticultural and financial evaluation should be used in citrus rootstock trials. The model is sufficiently flexible to accommodate a range of trial variables, including scion cultivar, tree spacing, and soil and site factors. Financial analysis integrates horticultural (including harvesting), pest, and disease rootstock data to provide a more complete understanding of all factors involved in interpreting rootstock performance. The model has certain limitations: 1) at present, the application of the model to fresh fruit cultivars has not been demonstrated; 2) a minimum time is required to collect an appropriate data set for the model to be valid; thus, it would not be useful in preliminary screening-type field trials with the objective to identify the most promising rootstocks; and 3) although the model is appropriate for a number of research situations,

Table 6. Variability in plot characteristics among 'Valencia' orange trees on four rootstocks in a replicated field trial, Indianatown, FL.

Rootstock	Plot yield ^a	Mature tree ht. (m)	Cumulative yield (kg/tree)	No. of trees lost to blight	Soil data		Leaf concn ^w												
					Soil sample depth (cm)	General soil traits ^b	pH	Phosphorus (mg·kg ⁻¹)	Calcium (mg·kg ⁻¹)	O.M. (%)	Nitrogen (D)2.04 a	Phosphorus (H)0.23 a	Potassium (O)1.30 a	Calcium (H)5.43 a	Magnesium (O)0.46 a	Manganese (H)143 a	Zinc (D)13 a	Iron (O)65 a	
Carrizo citrange	Low (1)	4.1	1489	2	Lokosee	0-15	Alfisol: 0-10 cm dark sand A horizon; 10-50 cm light gray to white sand E horizon; sandy clay loam layer at 40 cm	7.4	(VH)93	3920	2.1	(D)2.04 a	(H)0.23 a	(O)1.30 a	(H)5.43 a	(O)0.46 a	(H)143 a	(D)13 a	(O)65 a
	High (9)	4.1	2260	4	Pineda	0-15	Alfisol: 0-30 cm gray to grayish brown sand A horizon; iron-coated yellowish sand grains above the sandy clay loam argillitic B horizon, which occurs at depths 50 to 100 cm	7.0	(VH)84	1440	1.8	(L)2.32 b	(H)0.26 a	(O)1.28 a	(O)4.95 a	(O)0.45 a	(H)164 a	(D)12 a	(O)59 a
Cleopatra mandarin	Low (2)	3.9	1040	0	Malabar	0-15	Alfisol: 0-35 cm light to dark gray sand A horizon; 35-75 cm brownish yellow iron-coated sand B horizon; 75-150 cm sandy clay loam B horizon	7.8	(VH)138	2640	1.9	(O)2.70 b	(H)0.26	(O)1.29 b	(H)5.20 a	(O)0.48 a	(H)126 a	(D)16 a	(L)51 a
	High (9)	4.6	2166	6	Pineda	0-15	See above	7.8	(VH)111	2800	1.7	(L)2.24 a	(H)0.24 a	(O)1.18 a	(H)5.41 a	(O)0.48 a	(H)160 a	(D)15 a	(L)51 a
Swingle citrumelo	Low (1)	3.2	824	1	Lokosee	0-15	See above	6.6	(VH)63	1840	1.2	(O)2.68 a	(H)0.28 a	(O)1.34 a	(H)5.31 a	(O)0.42 a	(H)146 b	(L)19 a	(O)61 a
	High (9)	3.7	1710	0	Pineda	0-15	See above	6.7	(VL)9	276	0.1	(H)2.84 b	(H)0.26 a	(O)1.41 b	(H)5.23 a	(O)0.39 a	(H)116 a	(L)18 a	(O)59 a
Volkamer lemon	Low (1)	4.9	2313	5	Pople	0-15	Alfisol: profile is essentially the same as for Pineda except there is a calcareous layer beginning at ≈65 cm	8.2	(VH)85	4960	2.0	(O)2.56 a	(H)0.27 a	(O)1.55 b	(O)4.94 a	(O)0.44 a	(H)135 a	(D)17 a	(O)60 a
	High (8)	5.0	3023	6	Pineda	0-15	See above	7.4	(H)61	2000	2.2	(H)2.79 b	(H)0.27 a	(O)1.40 a	(H)5.05 a	(O)0.46 a	(H)218 b	(D)17 a	(O)67 a
						15-30		8.0	(M)16	6200	1.5								

^aAmong 10 replicates of six-tree plots of one rootstock, low = the plot or one of the plots with the lowest cumulative yield; high = high cumulative yield; the number in parenthesis is the plot illustrated in Figure 3.

^bA description of the main characteristics that distinguish the soil series from each other and their features as determined by the on-site study.

^cMehlich 1 extraction. P values are: (VL) very low, (L) low, (M) medium, (H) high, or (VH) very high. All calcium values are excessive.

^wCombined data of 2-year sampling. Mean separation at $P \leq 0.05$ within rootstocks. By Florida standards for spring flush leaves collected from nonfruiting shoots, the values are (D) deficient, (L) low, (O) optimum, or (H) high.

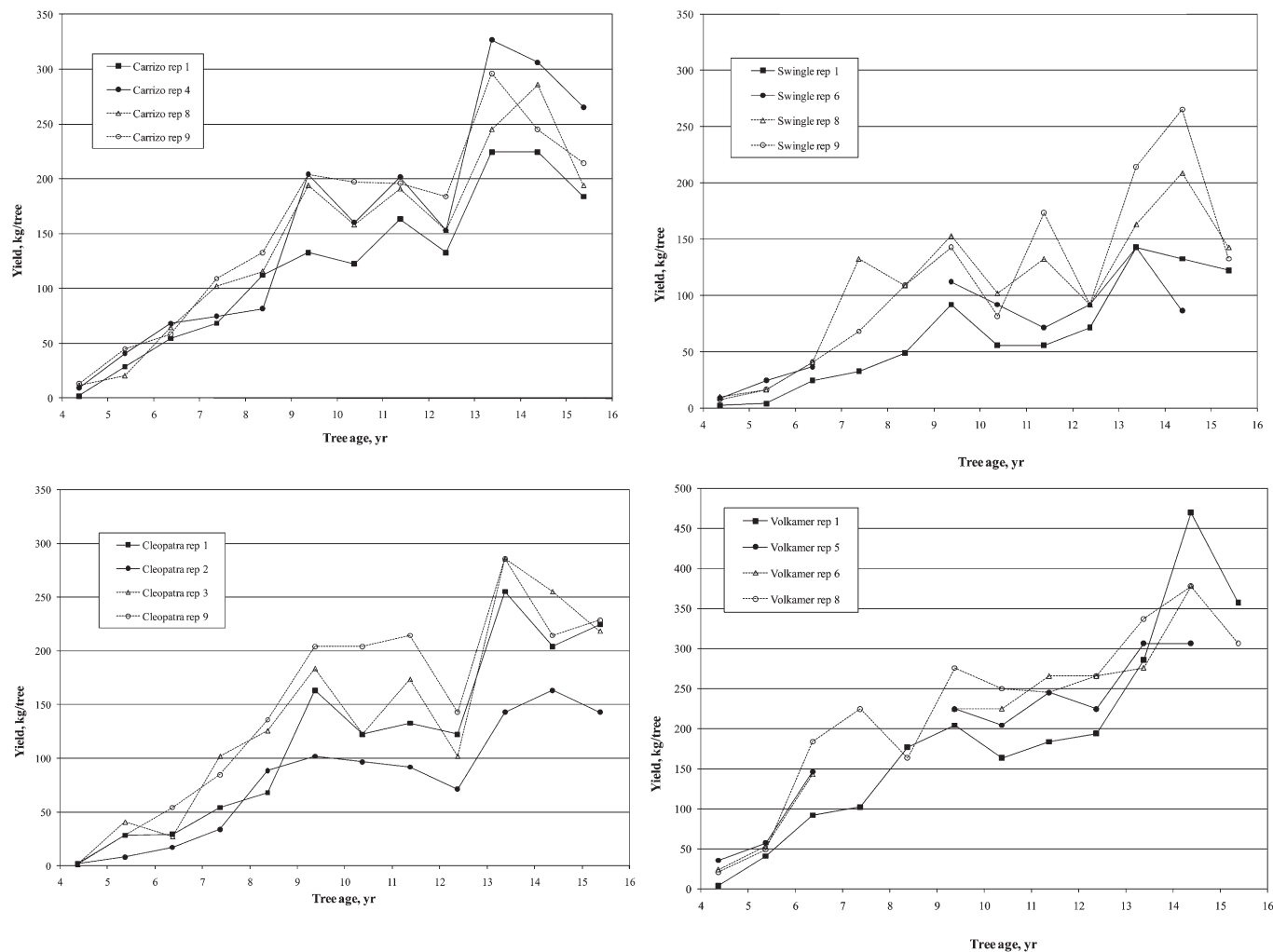


Fig. 3. Productivity among the highest- and lowest-yielding replicates of 'Valencia' orange on four of 12 rootstocks in a field trial planted at 252 trees/ha at Indiantown, FL.

Table 7. Discounted annual cash flows (US dollars/ha) and internal rates of return (IRR) based on 15-year (1980–1995) historical data for a hypothetical 1-ha grove of 'Valencia' trees on selected rootstocks planted at Indiantown (252 trees/ha) or Avon Park (358 trees/ha), FL.²

Rootstock	Discounted cash flow with ending orchard value, 15% rate						Tree loss (%)		IRR with capital investment and ending orchard value (%)					
	No blight		Blight with no resets		Blight with resets		No blight		Blight with no resets			Blight with resets		
	AP	I	AP	I	AP	I	AP	I	AP	I	AP	I	AP	I
Rough lemon	18,431	13,039	8,452	4,762	8,396	5,928	62	47	28	24	23	20	23	20
Volkamer lemon	19,476	15,331	12,333	6,239	13,464	7,338	44	50	29	25	26	21	27	21
Sour orange	15,457	5,330	15,457	5,330	15,457	5,330	0	2	26	19	26	19	26	19
Cleopatra mandarin	13,345	4,821	10,903	2,302	10,742	2,272	20	23	25	19	24	17	24	17
Carrizo citrange	22,366	9,144	16,438	6,674	16,826	6,928	23	25	29	22	27	21	28	21
Swingle citrumelo	10,883	106	10,656	-526	10,628	-529	6	7	24	15	24	14	24	14
Pineapple swt. org.	9,868	7,487	9,868	7,193	9,868	7,200	0	2	22	21	22	21	22	21
Swingle citrumelo (358)		6,289		5,387		5,385				20		20		20

²Tree loss is at the end of the financial analysis period when the trees were ≈15 years old.

financial outcomes may be deemed relatively unimportant by citrus growers when choosing rootstocks based on perceived risk. Those risks associated with individual horticultural traits can result in different decisions than those supported by financial interpretations. Swingle citrumelo is the principal commercial rootstock in Florida, not Volkamer lemon (Florida Citrus Budwood Program, 2008). The results of our study would suggest the opposite choice, but trees on Swingle citrumelo are reasonably productive, yield fruit

with very good juice quality and size, and have excellent survival history. The sum of those traits explains its popularity and success. Furthermore, our results support the general recognition of the excellent horticultural attributes of trees on Carrizo citrange as now amended with financial analysis.

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