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Rootstocks Affect the 17-Year Survival and Performance of 'Valencia' Trees Grown in Immokalee

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Abstract. A non-replicated planting of 'Valencia' orange [*Citrus sinensis* (L.) Osb.] trees on 19 rootstocks was established near Immokalee in 1991 to evaluate tree performance on a scale approximating commercial conditions. Trees on various standard or new rootstocks ranging from citranges [*C. sinensis* x *Poncirus trifoliata* (L.) Raf.] and citrumelos (*C. paradisi* Macf. x *P. trifoliata*) to Cleopatra, Sun Chu Sha, and Changsha mandarins (*C. reticulata* Blanco) were grown in a commercial nursery. Individual beds of 98 trees on one rootstock were planted at 14 × 22 ft (4.3 × 6.7 m; 141 trees/acre (348 trees/ha) in a commercial grove. The soil is mainly Malabar fine sand. Soil pH values were above 8 in places near the edges of the site where calcareous soil from nearby ditches was used to form beds; elsewhere in the site, soil pH averaged 7.8. Tree survival was above 90% except for those on rough lemon (*C. jambhiri* Lush.) and Cleopatra mandarin that lost 20% to 30% of the trees to blight and the complete loss of trees on sour orange (*C. aurantium* L.) to tristeza virus. Trees on most rootstocks were about 12 to 13 ft (3.8 m) tall at age 9 years; those on Cleopatra mandarin and F80-5 citrumelo were the tallest at 14.5 ft (4.4 m) and those on Swingle citrumelo were 10.7 ft (3.3 m). The highest cumulative yields across six seasons came from trees on Carrizo and Benton citranges (14 to 15 [90 lb = 41 kg] boxes/tree); the lowest yield came from trees on Cleopatra mandarin (9.5 boxes). From juice quality data obtained in five seasons, the highest pound-solids/box values were from trees on Carrizo, Benton, and Rusk citranges. Thus, 'Valencia' trees on several new rootstocks, F80-14, Benton, several numbered citrumelos and on Sun Chu Sha, have the potential to exceed the performance of those on standard commercial rootstocks.

'Hamlin' and 'Valencia' are the two principal sweet oranges used for processed products in the Florida citrus industry. 'Valencia' is essentially the more important cultivar because the fruit have higher juice quality, but it normally is less productive than 'Hamlin'. For that reason, the search for rootstocks and orchard systems that improve the productivity of 'Valencia' has been a long-term endeavor in Florida. Thus, we tested the hypothesis that 'Valencia' trees on a range of new rootstocks that had been evaluated in field trials during the past 15 years (Castle, 1987; Castle and Baldwin, 2005; Castle and Bauer, 2005) would exhibit better yield and tree survival in larger-scale commercial conditions compared with the standard commercial rootstocks.

Materials and Methods

'Valencia' trees on 19 rootstocks (Table 1) were propagated in a commercial nursery and planted 14 × 22 ft (4.3 × 6.7 m) on double-row beds in 1991 in a commercial grove southeast of Immokalee. Each bed had 49 tree spaces/row and was planted with trees on one rootstock. The intent was to establish one large group of trees on each rootstock similar to a commercial setting rather than a formal trial with randomized replications of smaller sets of trees.

The soil at the site is Malabar-high-fine sand (loamy, siliceous, hyperthermic, Grossarenic Ochraqualf), a soil found on low ridges along flats (formerly sloughs), a different landscape position than usual for this soil series (Bauer et al., 2007). Soils of the Malabar series are Alfisols with an argillic layer starting about 15 inches (38 cm) deep. At the site, the soil is a dark gray at the surface and yellow-colored sand to depths up to 4 ft (1.2 m) or more. In 1995 (4 years after planting), trees on $CaCO_3$-sensitive rootstocks, like the citranges, displayed foliar micronutrient deficiency symptoms. To investigate the relationship of $CaCO_3$ to tree growth and appearance, 80 soil samples were collected in a grid pattern. Eight cores, 1 × 8 inches (2.5 × 20 cm), were taken under every sixth tree along every fourth row beginning with row 1. The cores from each tree were composited, screened, and pH was measured in 2:1 (water:soil) dilutions of air-dried samples along with the $CaCO_3$ concentration using an acetic acid procedure (Loeppert et al., 1984). In addition, one plot of 10 adjacent trees was selected in a row among those on Benton and Carrizo citranges and Swingle and W-2 citrumelos (Fig. 1). Tree canopies in these 10-tree transects visibly changed from normal healthy green to ones with mild to moderate micronutrient deficiency. Each tree was rated for appearance using the scale: 0 = healthy and no visible micronutrient deficiency; 1 = <25% visible symptoms; 2 = 25% to 50% symptoms; 3 = >50% visible symptoms. Soil samples as described for the grid protocol were collected from each tree in the 10-tree plots and analyzed for pH and $CaCO_3$ concentration. The trees were irrigated with microsprinklers and managed according to recommended cultural practices (Obreza and Morgan, 2008). All trees were hedged annually, but not topped.

The height of about 12 representative trees/bed was measured in 2000; tree survival was recorded at age 4 and 17 years. Yield was measured in six seasons during commercial harvest by recording the volume of fruit in 90-lb (41 kg) boxes removed from each bed. Samples of 40–50 fruit/bed were also taken from 20 representative trees/bed between late March and early May for five seasons. The juice was extracted and analyzed in an official

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Table 1. Performance of 'Valencia' trees on various in a planting at Immokalee. Trees planted in Apr. 1991 at 141 trees /acre (14 × 22 ft).

Rootstock	Tree survival, % 4 yr	Tree survival, % 17 yr	Tree ht, ft[z]	Yield, boxes/tree[y] Season	Yield, boxes/tree[y] Annual	Yield, boxes/tree[y] Cum.	Juice quality[x] % Juice	Juice quality[x] SSC	Juice quality[x] Ratio	Juice quality[x] PS/box
1572 *P. trifoliata* (L.) Raf.	98	90		94-95	0.5		60.1	10.0	13.2	5.4
x Milam(*Citrus jambhiri* Lush. Hybrid			10.5	99–00			59.5	12.0	14.5	6.4
				00-01			55.6	11.7	16.5	5.9
				01-02	2.8					
				02-03	3.4	12.9	62.9	12.0	14.7	6.8
1573-26 *P. trifoliata*	100	91		94-95	0.5		55.9	11.1	11.8	5.6
x *Citrus sinensis* (L.) Osb. 'Ridge Pineapple'			9.0	99-00			64.6	12.3	13.5	7.1
				00-01			54.7	11.5	15.5	5.6
				01-02	0.9					
				02-03	1.3	4.7	66.3	12.2	14.2	7.3
1578-173 'Ridge Pineapple' x Milam[w]	50	48		94-95	0.3		58.2	10.0	12.7	5.3
			11.5	99-00						
				00-01			56.7	11.8	16.9	6.0
1578-201 'Ridge Pineapple' x Milam[w]	48	45		94-95	0.2		60.2	10.1	13.3	5.5
			11.5	99-00			62.9	11.7	12.9	6.6
				00-01			57.7	11.5	16.7	6.0
Benton citrange (*C. sinensis* x *P. trifoliata*)	99	90		94-95	1.3					
			12.0	99-00			61.4	12.5	15.0	6.9
				00-01			58.4	12.6	17.7	6.6
				01-02	3.3					
				02-03	3.1	14.8	63.4	12.5	18.1	7.1
Carrizo citrange	100	81		94-95	1.2					
			11.5	99-00			65.0	12.4	13.7	7.2
				00-01			61.0	12.2	20.7	6.7
				01-02	4.4					
				02-03	2.8	15.7	60.5	11.9	18.9	6.5
Changsha mandarin (*C. reticulata* Blanco)	99	98		94-95	0.3		60.1	10.0	13.2	5.4
			12.7	99-00			55.2	12.3	17.6	6.1
				00-01			60.6	11.6	16.1	6.3
				01-02	3.2					
				02-03	2.7	11.5	61.4	11.8	15.3	6.5
Cleopatra mandarin	88	67		94-95	0		60.9	9.6	11.9	5.3
			14.2	99-00			58.6	10.6	12.2	5.6
				00-01			59.7	11.2	14.6	6.0
				01-02	2.4					
				02-03	4.5	9.5	58.8	10.5	13.3	5.5
F80-5 citrumelo	99	88		94-95	0.4		59.7	10.0	13.0	5.4
(*C. paradisi* Macf. x *P. trifoliata*)			14.5	99-00			60.0	12	14.8	6.5
				00-01			59.3	12	14.6	6.4
				01-02	3.3					
				02-03	2.8	12.1	60.7	11.4	13.2	6.2
F80-8 citrumelo	100	97		94-95	0.6		58.9	9.9	12.8	5.2
			12.5	99-00			57.9	12	15.0	6.3
				00-01			63.3	11.9	16.6	6.8
				01-02	3.9					
				02-03	3.2	14.4	62.0	11.5	14.2	6.4
F80-9 citrumelo	100	93		94-95	0.3		57.8	10.8	11.3	5.6
			13.5	99-00			60.6	12.5	16.0	6.8
				00-01			57.6	10.7	16.0	5.6
				01-02	3.8					
				02-03	2.9	12.7	60.5	12.2	16.2	6.6
F80-14 citrumelo	100	88		94-95	0.7		59.5	9.6	13.1	5.1
			9.7	99-00			58.8	12.1	14.9	6.4
				00-01			56.6	11.9	16.7	6.0
				01-02	3.4					
				02-03	3.1	14.4	61.2	11.5	15.4	6.3

Table 1 continued on next page.

Table 1. Continued from previous page.

Rootstock	Tree survival, %		Tree	Yield, boxes/tree[y]			Juice quality[x]			
	4 yr	17 yr	ht ft[z]	Season	Annual	Cum.	% Juice	SSC	Ratio	PS/box
F80-18 citrumelo	100	95		94-95	0.7		58.0	10.0	10.6	5.2
			13.0	99-00			58.0	11.7	13.3	6.1
				00-01			57.2	11.9	14.1	6.1
				01-02	2.9					
				02-03	3.5	13.4	59.3	11.5	13.3	6.2
Rusk citrange	99	96		94-95	1.1		60.5	10.1	11.7	5.5
			12.2	99-00			60.1	12.8	15.8	6.9
				00-01			63.2	12.9	17.7	7.4
				01-02	3.1					
				02-03	2.8	14.6	61.9	12.4	16.4	6.9
Schaub rough lemon (*C. jambhiri*)[w]	99	80		94-95	0.3		53.0	9.9	13.4	4.7
			13.5	99-00			56.1	10.5	13.3	5.3
				00-01			56.1	12.3	16.2	6.2
				01-02	4.9	12.5				
				02-03			58.1	10.5	12.7	5.5
Sour orange (*C. aurantium* L.)[w]	99	0		94-95	0.1		57.5	10.1	10.9	5.2
			13.0	99-00			59.2	10.9	13.0	5.8
				00-01			54.4	11.5	14.6	5.6
				01-02						
				02-03			57.2	11.2	17.5	5.8
Sun Chu Sha mandarin	99	96		94-95	0.2		59.7	10.0	13.9	5.4
			13.0	99-00	59.9	11.9	12.3	6.4		
				00-01			60.1	11.7	13.6	6.3
				02-03	4.9	14.5	60.8	11.2	12.8	6.1
Swingle citrumelo	99	93		94-95	0.8		62.2	9.4	13.7	5.3
			10.7	99-00			57.9	12.7	15.8	6.6
				00-01			61.0	12.3	17.4	6.8
				01-02	3.4					
				02-03	3.1	12.5	61.5	11.5	14.2	6.4
W-2 citrumelo	100	97		94-95	0.4		59.4	9.7	12.7	5.2
		14.2		99-00			59.0	12.1	12.3	6.4
				00-01			59.1	12.1	13.0	6.4
				01-02	4.4					
				02-03	3.2	14.3	64.4	11.1	12.6	6.4

[z]Trees measured 12 Oct. 2000 at 9 years old (1 ft = 0.305 m).
[y]Yield (in 90 lb = 41 kg boxes) data were collected in the 1994–95, 1996–97, 1997–98, 1998–99, 2001–02, and 2002–03 seasons. Annual data not presented for the 1996 through 1999 seasons. Blank spaces indicate where no data were collected.
[x]Fruit samples collected 28 Feb. 1995, 6 May 1998, 22 Mar 2000, 12 Apr 2001 and 12 Mar 2003. Blank spaces indicate that no data were collected.
[w]Data collection was halted prematurely because of excessive tree loss.

test house facility at the CREC, Lake Alfred. As this "planting" was without replication, no statistical analyses were performed on the horticultural data. Relationships between soil data and tree appearance ratings were determined by correlation analysis.

Results and Discussion

When the trees were 4 years old, there were virtually no losses among the trees on all rootstocks except those on the 'Ridge Pineapple' X Milam hybrids located on the two western-most beds of the project (Table 1). Tree loss among those two rootstocks was nearly 50% because of termite damage and phytophthora foot rot losses that followed. Enough trees survived, however, to allow the subsequent collection of fruit samples and measurements of tree growth. When the trees were 17 years old, losses on some rootstocks were relatively high because of their known and confirmed susceptibilities to blight (rough lemon and Cleopatra mandarin) and citrus tristeza virus (sour orange) (Castle, 1987); however, losses were generally <12% among the trees on the citrumelo or citrange rootstocks even though they were growing in a part of the site with the highest soil pH (Fig. 1).

The tallest trees at age 9 years were >14 ft (4.3 m) in height (Cleopatra mandarin, W-2, and F80-5 citrumelos); trees on other rootstocks such as Swingle and F80-14 were 3 ft shorter. At that time, the trees on most rootstocks had closed canopies within the row and only small changes in height occurred thereafter.

Yield was measured in six seasons between 1994 and 2003. In the first year of cropping, yield was generally <0.5 boxes/tree, but was >1.0 box/tree for those on Benton, Carrizo, or Rusk citranges (Table 1; only the data of 3 years and cumulative yield are presented). As the trees aged, yield increased to 3 to 5 boxes/tree for those on many rootstocks; cumulative yields ranged from <10 boxes on some rootstocks because of the diseases explained above, to >14 boxes (Benton, Carrizo, and Rusk citranges, F80-8,

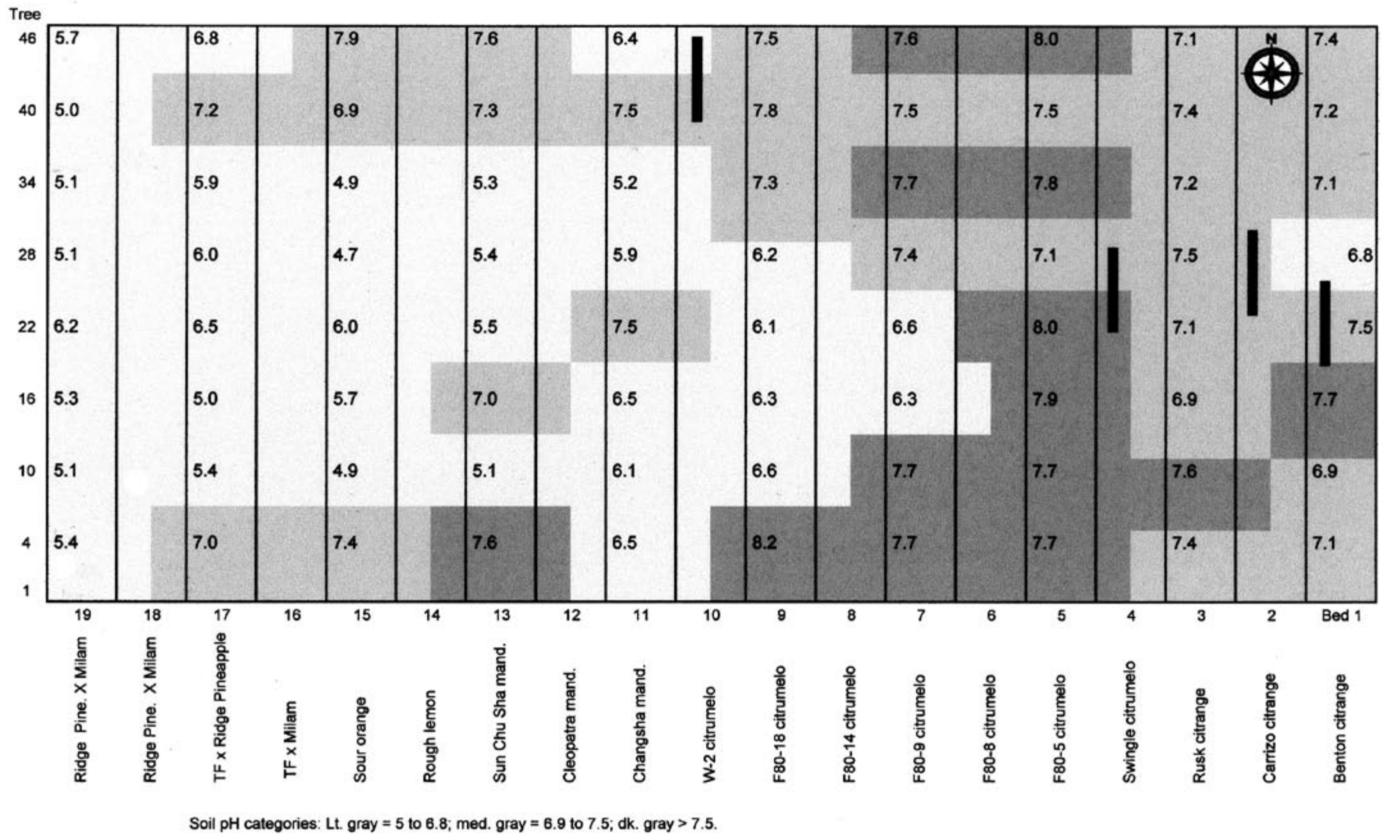

Fig. 1. Soil pH values, 0–8 inches (20 cm). The thick black lines are the 10-tree transect locations.

F80-14, and W-2 citrumelos, and Sun Shu Sha mandarin). Juice quality was measured in six seasons, but samples were collected in conjunction with commercial harvest so the sampling time varied between late February and early May. Thus, the data from year to year are not strictly comparable within and between rootstocks. There were no important differences among the majority of the rootstocks largely because many of them are hybrids of trifoliate orange, rootstocks known to produce relatively high quality juice (Castle, 1987; Castle et al., 2006) (Table 1). Nevertheless, fruit from trees on Benton, Carrizo, and Rusk citranges often had the highest juice quality. The trees on Swingle citrumelo were representative in that they produced fruit with >6 pound-solids/box.

Certain aspects of tree performance were unexpected given the apparent site conditions. Small pieces of shell and limestone (highly calcareous materials) littered the surface of the eastern portion of the site, suggesting that the beds located there would have been unsuitable for trees on rootstocks that were trifoliate orange hybrids like citranges and citrumelos (Castle et al., 1993, 2006). Site measurements showed that soil pH varied from about 5.0 to 8.0 across the site (Fig. 1). The western half of the site generally had pH values in the desired range of about 5.5 to 6.5 for citrus; the values in the eastern part of the site were mostly 7.0 and higher. Some of the highest values were along the edges because of materials excavated from the adjacent drainage canals and incorporated during bed formation.

Why did the trees on the citrange and citrumelo rootstocks in beds 1–7 perform so well? The answer is related to the soil profile and probably root system expansion. We had selected 10-tree transects down a row of trees on four rootstocks in which the trees displayed a range of leaf micronutrient deficiency symptoms (Fig. 1). Soil pH beneath the transect trees was significantly correlated with $CaCO_3$ concentration, but the canopy ratings were variable and not correlated with either soil measurement (Table 2). Data from additional soil sampling below 8 inches (20 cm) showed that the pH was <6.5 and that extractable Ca values were <150 ppm by the Mehlich 1 soil test. We conclude from those data, and the fact that micronutrient deficiency symptoms disappeared in virtually all trees as they matured, that root growth into more favorable subsoil horizons had occurred, allowing the trees to maintain an adequate mineral nutrient status.

Conclusions

The results support our hypothesis that 'Valencia' trees on new rootstocks have the potential to exceed the performance of those on standard commercial rootstocks. The planting demonstrated that 'Valencia' trees were capable of producing 500 boxes/acre when grown in flatwoods soils of the Malabar series on rootstocks such as Benton and Carrizo citranges and several numbered citrumelos. The trees on Sun Chu Sha mandarin were also very productive with essentially no tree loss, in contrast with those on Cleopatra mandarin that experienced heavy tree loss to blight and exhibited the well-known low-yielding tendency with nucellar clones of 'Valencia' (Castle, 1987; Castle et al., 1993, 2006). Overall, the most promising rootstock was F80-14. It was one of the better-yielding rootstocks in a trial with 'Hamlin' and 'Marsh' scions (Castle and Bauer, 2005; Youtsey and Lee, 1995).

Table 2. Canopy ratings (R) and soil data from 10-tree transects among trees on four rootstocks growing in Malabar soil.

	Benton citrange			Carrizo citrange			Swingle citrumelo			W-2 citrumelo		
Tree	Rating[z]	Soil pH	$CaCO_3$, %	Rating	Soil pH	$CaCO_3$, %	Rating	Soil pH	$CaCO_3$, %	Rating	Soil pH	$CaCO_3$, %
1	1.9	7.47	0.26	1.2	7.40	0.36	1.4	7.77	0.33	1.8	7.51	0.26
2	2.3	7.61	0.30	1.5	7.45	0.32	1.5	7.96	0.39	2.2	7.90	0.31
3	2.6	7.90	0.44	2.3	7.55	0.29	1.5	7.95	0.41	2.1	7.92	0.36
4	2.5	8.08	0.69	1.9	7.74	0.33	2.1	7.89	0.37	2.8	7.97	0.39
5	1.8	8.14	0.77	1.9	7.57	0.28	1.6	7.92	0.55	1.9	8.23	0.46
6	1.9	8.13	0.74	1.2	7.84	0.36	1.7	7.87	0.38	2.9	8.24	0.61
7	2.0	8.10	0.83	1.2	7.82	0.41	2.4	7.85	0.38	2.5	8.09	0.51
8	1.0	7.84	0.93	2.4	8.01	0.43	2.6	8.10	0.44	2.2	8.19	1.00
9	1.2	8.01	0.58	1.8	7.94	0.43	2.0	8.10	0.72	1.9	8.12	0.64
10	2.4	8.02	0.67	2.4	7.93	0.49	2.7	8.19	0.47	1.9	8.21	0.76
Mean	*2.0*	*7.9*	*0.6*	*1.8*	*7.7*	*0.4*	*2.0*	*8.0*	*0.4*	*2.2*	*8.0*	*0.5*
Simple correlation coefficients[y]												
	0.01	0.75	–0.40	0.36	0.76	0.19	0.62	0.59	0.14	0.26	0.70	0.01
	R-pH	pH-Ca	R-Ca	R-pH	pH-Ca	R-Ca	R-pH	pH-Ca	R-Ca	R-pH	pH-Ca	R-Ca

[z]Tree canopy appearance: 0=no visible micronutrient deficiency symptoms; 1= <25% of the canopy with symptoms; 2= 25% to 50% of the canopy with visible symptoms; 3= >50% of the canopy has deficiency symptoms.

[y]For linear correlation, significance at the 5% level with 8 degrees of freedom is 0.63.

In our planting, the trees on F80-14 were among the smallest yet most productive.

The planting also demonstrated that any field trial or planting has variability that can be useful. In our planting, the transect data helped interpret the main results by providing information to explain the relatively good performance of the trees on citranges and citrumelos growing in calcareous parts of the site.

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