Proc. Fla. State Hort. Soc. 118:4-14. 2005.

ROOTSTOCK EFFECTS ON 'HAMLIN' AND 'VALENCIA' ORANGE TREES GROWING AT CENTRAL RIDGE AND FLATWOODS LOCATIONS

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Additional index words. Citrus sinensis, Astatula soil, citrange, citrumelo, mandarin, somatic hybrid, Tavares soil, Valkaria soil

Abstract. **'Hamlin' sweet orange [*Citrus sinensis* (L.) Osb.] field trials were established at the north (Tavares) or south (Lake Placid) ends of the central Ridge region, and two 'Valencia' trials were established in flatwoods sites near St. Cloud or Immokalee between 1987 and 1991 at conventional tree spacings in soils typical for each region. Trees on 17 to 31 rootstocks, including several commercial rootstocks, were planted at each location in formal replicated experiments or in informal non-replicated arrangements. The rootstocks were mostly citranges [*Citrus sinensis* × *Poncirus trifoliata* (L.) Raf.], citrumelos (*Citrus paradisi* Macf. × *Poncirus trifoliata*), mandarins (*Citrus reticulata* Blanco), other sexual hybrids and somatic hybrids. Tree survival among the four field studies was generally above 70% but was less than 50% for some rootstocks because of freeze damage in one Central Ridge study and other unknown causes at one flatwoods study. Trees on sour orange and Bittersweet sour orange rootstocks at all locations eventually succumbed to citrus tristeza virus. Tree heights ranged from about 8 to 15 feet, but the relationships were similar among tree heights in those rootstocks that were common to two or more studies. Among the formal replicated experiments, yield was either measured or estimated annually for about 5 years, and 4 years of juice quality data were collected at the Immokalee site. Yield was generally related directly to tree height. 'Hamlin' and 'Valencia' trees on F80-5 citrumelo, Carrizo, Troyer, and C-32 citranges, × 639 (a Cleopatra mandarin × trifoliate orange hybrid) produced some of the highest cumulative yields and were relatively tall trees. 'Valencia' on 1584 [a trifoliate orange × 'Milam' hybrid (*Citrus jambhiri* Lush.)] was one of the highest yielding combinations. In the Immokalee field trial, juice quality of fruit from trees on Swingle citrumelo did not differ significantly from the juice quality of fruit from trees on most of the other citrange, citrumelo, and mandarin rootstocks. Based on tree survival, growth, and cumulative yield, promising rootstocks were x639, 1584, certain numbered citrumelos, and 'Flying Dragon' trifoliate orange when considered as a rootstock for high density plantings. No differences were observed between trees on Carrizo or Troyer citranges, or between Cleopatra or Sun Chu Sha mandarins.**

The choice of rootstock has been and remains a major factor in citrus grove performance. Improved rootstocks are a perennial concern in Florida and the reasons for this have not changed much in several decades (Castle and Gmitter, 1998; Castle et al., 1993; Grosser et al., 1998; Wutscher and Bowman, 1999). Growers have always sought rootstocks with tolerance to blight and Phytophthora and now that the brown citrus aphid is present, there is more concern about citrus tristeza virus (CTV) tolerance. The Diaprepes root weevil is spreading and virtually no genetic sources of tolerance have been identified (Bowman et al., 2001). There are few new rootstocks available as solutions to these problems.

In addition to conventional horticultural issues, there is new interest in tree architecture and bearing habit as they might be influenced by the scion/rootstock combination and orchard design. This is because of the growing importance and potential of mechanical and robotic harvesting (Roka and Rouse, 2004). Yield is still the primary profit driver for growers of juice fruit when expressed as pounds-solids/acre and juice quality is important for fresh fruit, particularly grapefruit for shipment overseas. Both yield and juice quality are strongly influenced by rootstock.

For the reasons cited above, considerable efforts are being made to create, identify, and evaluate promising rootstocks (Castle et al., 2000; Grosser and Chandler, 2000; Grosser et al., 1998, 2004; Wutscher and Bowman, 1999). The objective of our field studies was to evaluate such new rootstocks with emphasis on yield, juice quality, and tree growth and survival.

Materials and Methods

There were four field studies involving a range of rootstocks listed in Table 1. The two 'Hamlin' field studies were originally planted using extra trees from another trial so some rootstocks occurred in both studies.

Field Study (FS) 1 (Tavares). Trees of 'Hamlin' 1-4-1XE sweet orange on 31 rootstocks were propagated in a commercial nursery using budwood later determined to be infected with a decline strain of citrus tristeza virus (CTV). Six replications of single-tree plots were planted at 10 × 25 ft in March 1987 in N-S rows in a commercial grove near Tavares. The soil is Astatula sand (uncoated Typic Quartzipsamments), a typical deep, excessively drained Entisol of the Central Florida Ridge region. The site was slightly sloping with a lower elevation at the north end. A freeze in 1989 damaged many of these trees which were subsequently replaced in the ensuing years with trees on the same rootstocks commonly referred to as resets. Trees on other rootstocks also were added to the study. Thus, there were three sets of trees: (1) the formal replicated experiment; (2) resets of trees in the formal trial; and (3) trees on various additional rootstocks and their resets that were not part of the replicated experiment (Table 2). No statistical analyses were performed on the latter two sets.

Field Study 2 (Lake Placid). Trees of 'Hamlin' on 20 rootstocks from the same group as those in FS.1 were planted in a commercial grove south of Lake Placid in December 1986 also in Astatula sand soil. There were six replications of single-tree plots plus extra trees on some rootstocks. Trees were spaced 12.5 × 25 ft.; the site was essentially level. These trees were largely unaffected by the 1989 freeze.

We thank John Hey (deceased) of Lake Region Packing Association, Tavares, Gregg Hartt (formerly of Consolidated Tomoka Land Company), Lake Placid, the management of CPI, Immokalee, and Orie Lee, St. Cloud for their generous contributions of land and grove care for our field studies. We appreciate the financial support received from the Florida Citrus Production Research Advisory Council Grant 0110-03I.

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Table 1. Rootstocks in four sweet orange field studies numbered 1 to 4.

Field study				Common name	Abbrev.	Scientific or Common name
			4	1572 PtM	1572	*Poncirus trifoliata* (L.) Raf. × 'Milam' (*Citrus jambhiri* Lush.)
1		3	4	1573-26 PtR	1573	*P. trifoliata* × 'Ridge Pineapple' sweet orange [*C. sinensis* (L.) Osb.]
1				1575-21 RPt	1575	'Ridge Pineapple' × *P. trifoliata*
1		3		1578-173 RPM	1578	'Ridge Pineapple' × 'Milam'
		3	4	1578-201 RPM	1578	'Ridge Pineapple' × 'Milam'
		3		1584 PtM	1584	*P. trifoliata* × 'Milam'
1	2			Benton citrange	Benton	'Ruby' sweet orange × *P. trifoliata*
1				Bittersweet sour orange	BSO	*C. aurantium* (L.)
1		3		C-32 citrange	C-32	Sweet orange × *P. trifoliata*
1	2			C-35 citrange	C-35	'Ruby' sweet orange × *P. trifoliata*
1	2	3		Calamandarin	Cala	probable hybrid of *C. reticulata* (Blanco) and *C. mitis* Blanco
1	2		4	Carrizo citrange	Car	Sweet orange × *P. trifoliata*
1		3	4	Changsha mandarin	Chgsha	*C. reticulata*
1	2			Cleo × Rubidoux	x639	Cleopatra mandarin (*C. reshni* Hort. Ex. Tan) × Rubidoux trifoliate orange
1	2		4	Cleopatra mandarin	Cleo	*C. reshni* Hort. Ex. Tan
1	2			F80-3 citrumelo	80-3	*C. paradisi* Macf. × *P. trifoliata*
		3	4	F80-5 citrumelo	80-5	*C. paradisi* × *P. trifoliata*
1	2	3		F80-8 citrumelo	80-8	*C. paradisi* × *P. trifoliata*
		3	4	F80-9 citrumelo	80-9	*C. paradisi* × *P. trifoliata*
		3	4	F80-14 citrumelo	80-14	*C. paradisi* Macf. × *P. trifoliata*
		3	4	F80-18 citrumelo	80-18	*C. paradisi* × *P. trifoliata*
1	2			'Flying Dragon' trifol. orange	FDT	*P. trifoliata*
1	2	3		Gou Tou	GouT	probable sour orange - pummelo [*C. maxima* (Burm. f.) Merr.] hybrid
1	2			Kinkoji	Kinj	*C. kinkoji* Hort. Ex Tan.
1	2	3	4	Koethen × Rubidoux citrange	K × R	Koethen sweet orange × Rubidoux trifoliate orange
1			4	Morton citrange	Mort	Sweet orange × *P. trifoliata*
		3		Norton citrange	Nort	Sweet orange × *P. trifoliata*
1				Palestine sweet lime	PSL	*C. limettioides* Tan.
1	2			Procimequat	Pquat	[*C. aurantifolia* (Christm.) Swing. × *Fortunella japonica*] × *F. hindsii* (Champ.) Swing.
1	2		4	Rangpur × Troyer	R × T	*C. limonia* Osb. × Troyer citrange
1				Rough lemon	RL	*C. jambhiri*
1	2		4	Rusk citrange	Rusk	'Ruby' sweet orange × *P. trifoliata*
1	2			Shekwasha mandarin	Shek	*C. depressa* Hay.
1				Smooth Flat Seville	SFS	Putative pummelo-sour orange hybrid
1	2			Sour orange	SO	*C. aurantium*
1		3	4	Sun Chu Sha	SCS	*C. reticulata*
1	2			Sunki mandarin	Sunki	*C. reticulata*
1	2			Sweet orange	Swt	'Valencia'
1	2		4	Swingle citrumelo	SwC	*C. paradisi* × *P. trifoliata*
1	2			Troyer citrange	Troy	Sweet orange × *P. trifoliata*
1				Volkamer lemon	Volk	*C. volkameriana* Ten. & Pasq.
		3	4	W-2 citrumelo	W-2	*C. paradisi* × *P. trifoliata*
1				Yuma citrange	Yuma	Sweet orange × *P. trifoliata*
		3		Zhu Luan	Zhu	Probable sour orange - pummelo hybrid
Somatic hybrid rootstocks						
		3		Cleo + Argentine TF	ClAT	Cleopatra mandarin + Argentine trifoliate orange
		3		Cleo + Flying Dragon	ClFD	Cleopatra mandarin + Flying Dragon trifoliate orange
		3		Cleo + Swingle	ClSw	Cleopatra mandarin + Swingle citrumelo
1		3		Hamlin + Flying Dragon TF	Ha + FDT	'Hamlin' sweet orange + trifoliate orange
1		3		Hamlin + *S. disticha*	Ha + Sd	'Hamlin' sweet orange + *Severinia disticha* (Blanco) Swing.
		3		Key lime + Valencia	K + V	*C. aurantifolia* + *C. sinensis*
		3		'Milam' + Sun Chu Sha	M + SCS	'Milam' + Sun Chu Sha mandarin
		3		Sour + Flying Dragon	SoFD	Sour orange + trifoliate orange
		3		Succari + Argentine TF	Suc + ATF	'Succari' sweet orange + trifoliate orange
		3		Succari + *S. buxifolia*	Suc + Sb	*S. buxifolia* (Poir.) Ten.
		3		Valencia + Femminello	V + Fem	'Valencia' sweet orange + Femminello lemon [*C. limon* (L.) Burm. f.]

Field Study 3 (St. Cloud). A Hughes nucellar selection (1-18-31XE) of 'Valencia' sweet orange was propagated on a series of rootstocks including several somatic hybrids provided by Dr. Jude Grosser. These trees were used as single-tree resets among commercial trees spaced 12 × 25 ft in an E-W oriented grove where loss from blight was occurring. The first trees were planted in 1991 with additional trees planted in 1993 and 1995. The site is flat and the soil is Tavares fine sand soil (uncoated Typic Quartzipsamments, an Entisol), a series with a dark grayish brown A horizon of 6 inches underlain by 12 inches of grayish brown fine sand (C horizon) and white sand with mottles at 48 inches. The Tavares soil series is commonly planted with citrus.

Field Study 4 (Immokalee). Trees of the nucellar 'Valencia' selection 1-18-31XE were propagated in a commercial nurs-

Table 2. Hamlin performance among trees on various rootstocks planted in a commercial grove, Tavares. Trees were planted 10 Mar. 1987 at 174 trees/acre (10 × 25 ft).

Rootstock	Tree survival,%[z]	Tree ht., ft.[y]	Yield, boxes/tree					
			1993-94	1994-95	1995-96	1996-97	1997-98	Cum.[x]
Formal trial and resets								
Bittersweet sour orange (12)[w]	67	6.6	1.2	1.0	1.1	1.2	0.6	5.2
C-35 citrange (14)	57	8.9	2.5	2.6	2.7	2.6	2.9	13.2
Calamandarin (7)	71	13.1	3.0	3.3	2.8	3.6	5.0	17.8
Carrizo citrange (7)	57	12.9	3.7	3.5	2.7	4.7	6.7	21.4
Carrizo citrange resets[v] (3)	100	11.9	1.8	2.7	3.5	3.9	5.5	17.4
Cleopatra mandarin (6)	50	13.4	2.5	2.1	1.8	3.2	3.1	12.7
F80-3 citrumelo (7)	57	12.3	3.6	4.1	1.7	3.9	5.2	18.6
F80-8 citrumelo (7)	57	9.0	2.6	2.7	1.8	2.7	2.7	12.5
Flying Dragon trifoliate (4)	100	7.7	1.6	1.4	1.8	2.1	1.0	7.9
Flying Dragon trifoliate[v] (3)	100	8.9	1.0	1.0	0.2	1.6	0.8	4.6
Kinkoji (6)	83	12.6	3.0	1.9	1.6	3.1	4.0	13.6
Procimequat (5)	60	7.3	0.4	0.7	0.5	1.0	0.0	2.6
Rangpur × Troyer (15)	73	9.4	2.3	1.8	1.6	2.9	2.5	11.1
Shekwasha mandarin (3)	67	11.3	2.9	4.5	2.2	3.0	3.0	15.6
Smooth Flat Seville (11)	64	12.0	2.2	2.3	2.7	2.6	3.7	13.6
Sunki mandarin (3)	67	10.9	1.2	3.5	2.0	3.7	3.5	14.0
Swingle citrumelo (5)	60	11.2	3.2	2.7	3.7	4.0	4.0	17.6
Troyer citrange (4)	50	13.0	3.9	3.5	3.5	5.0	6.5	22.4
x639 Cleo × TF (9)	78	12.5	3.6	3.1	2.4	4.0	5.4	18.6
Mean		10.7						14.2
LSD		2.0						5.8
Additional rootstocks								
1573-26 *P. trifoliata* × Ridge Pineapple (3)	33	7.0	2.5	1	1.0	2.5	1.5	8.5
1575-21 Ridge Pineapple × *P. trifoliata* (3)	0	r						
1578-173 Ridge Pineapple × Milam[u] (10)	90	10.3	0.1	0.8	1.2	1.2	2.3	5.6
Benton citrange (3)	33	8.8	3.2	0.0	3.5	4.5	3.0	14.2
Changsha mandarin[t] (9)	89	11.4	1.4	2.2	1.6	2.1	4.1	11.5
Changsha mandarin resets [s] (7)	100	12.1	1.2	1.7	1.5	2.3	3.4	10.1
Goutou[t] (5)	0							
Goutou resets[v] (4)	100	12.1	0.4	1.7	1.6	2.4	3.5	9.7
Hamlin + Flying Dragon[s] (5)	100	6.8	0.3	0.7	0.8	0.8	0.6	3.3
Hamlin + *Severinia disticha*[s] (5)	0		0.1	0.1	0.3	0.3	0.1	0.9
Koethen × Rubidoux citrange (4)	25	10.4	2.2	4.0	3.0	3.0	4.0	16.2
Koethen × Rubidoux citrange resets[u] (19)	79	8.4	0.2	0.8	1.2	1.0	0.9	4.2
Rough lemon[t] (4)	25	13.5	3.0	3.0	3.0	2.0	5.0	16.0
Rusk citrange (7)	14	11.5	1.0	1.0	3.5	3.2	0.5	9.2
Rusk citrange resets[u] (6)	83	9.1	0.5	1.2	1.4	2	2.3	7.3
Sour orange (4)	25	5.4	0.2	0.0	1.0	0.7	0.0	2.0
Sun Chu Sha mandarin[u] (7)	86	10.0	0.1	0.9	1.0	1.0	1.6	4.5
Valencia sweet orange (5)	20	12.0	1.5	1.7	2.5	3.2	2.0	11.0

[z]Tree status as of May 2001.
[y]Measured 25 May 2001.
[x]Cumulative yield (boxes/tree) for 5 seasons (1993-94 to 1997-98).
[w](n) Number of original trees.
[v]Planted July 1990.
[u]Planted Aug. 1991.
[t]Planted 18 Aug. 1988.
[s]Planted 27 June 1989.
[r]Blank spaces indicate missing data

ery on 17 rootstocks. They were planted in December 1991 in N-S rows spaced 12 × 24 ft in a commercial double-row bedded grove near Immokalee. The soil is Valkaria series, a Spodic Psammaquent that is a poorly drained Entisol with a thin, dark grayish brown surface layer underlain by pale brown to yellowish brown fine sand to depths of 80 inches. There were two replications of plots that varied in size from 5 to 10 trees each.

Cultural practices. The trees in FS.1, 2, and 4 were irrigated by microsprinkler and FS.3 by traveling gun. In each study, the trees were fertilized and pests and diseases controlled according to recommended practices and local conditions (Tucker et al., 1995). None of the sites was tested for nematodes nor were any of the cooperators using any practices for nematode control.

Statistical design and data analyses. FS.1, 2, and 4 were planted in a randomized complete-block design and FS.3 was considered a completely randomized design. Yield was measured as volume (1 box = 90 lb oranges; 41 kg) in standard commercial harvest containers. In some cases, yield was estimated by counting fruit, usually by the same experienced person, to an accuracy of 0.5 box and using a conversion factor of 200 to 250 fruit/box depending on their size. Samples of 40 to 50 fruit/plot were harvested for juice quality analysis in a commercial testhouse facility at the CREC, Lake Alfred. Tree height and tree loss were recorded periodically. We did not attempt to determine the cause of tree loss unless it was apparently due to Phytophthora root rot, or blight as confirmed by trunk water uptake. Data suitable for statistical analyses were examined by ANOVA using PROC GLM of the SAS program with mean separation by Least Significance Difference at P < 0.05.

Results and Discussion

Field Study 1 (Tavares)

Trial trees. The number of trees of each rootstock varied from 3 to 15. (Table 2) The data presented are for the trees in the replicated trial, but they were representative for all trees on each rootstock. Tree survival was well below 100% for most rootstocks (Table 2) largely because of the damage from the Dec. 1989 freeze and later decline. Virtually no tree loss from blight was observed. Only three rootstocks, x639, Kinkoji, and 'Flying Dragon' trifoliate orange, had tree survivals that exceeded 75%. Tree height at age 14 years ranged from ca. 8 ft ('Flying Dragon' trifoliate orange and Procimequat) to taller than 12 ft (Calamandarin, Carrizo and Troyer citranges, Cleopatra mandarin, Kinkoji, and x639) (Fig. 1). Annual and cumulative yields were directly related to tree height with some exceptions like the trees on Shekwasha mandarin rootstock had relatively low yields for their size (Fig. 1). During the 5-year period from ages 6 to 10 years, trees on seven rootstocks had cumulative yields over 15 boxes/tree with the highest yielding trees on Troyer and Carrizo citranges (Table 2). Those trees also yielded efficiently, i.e., had good crops for the size of tree. By comparison, trees on C-35 and F80-8 yielded less fruit, but also cropped well for their size.

Resets and trees on additional rootstocks. Only a few reset trees (replacement trees on the same rootstocks) were planted in the formal trial, but in almost every instance they exhibited similar performance as the trees on their matching original rootstocks (Table 2). The 1990 resets on Carrizo citrange (100% survival), and 1990 extra trees on 'Flying Dragon' trifoliate orange, grew and cropped nearly the same as their respective original trees. Such behavior was also exhibited among the trees on the additional rootstocks and their resets.

Among the additional rootstocks, tree survival ranged from none to 100% with variable cropping (Table 2). As with the trial trees, the 1989 freeze damaged some of the trees. There were few losses among the trees on 1578-173, but their yield was relatively low. No trees survived on three rootstocks: 1575-21, Goutou planted in 1988, and a somatic hybrid (Hamlin + *S. disticha*). However, there was 100% survival among a set of trees on Goutou that were planted in 1990, two years after the first trees. These trees planted in 1990 on Goutou, were taller than 12 ft after 8 years and their cumulative yield was ca. 10 boxes. However, Goutou has not become an important rootstock in Florida because of poor juice quality (Castle et al., 1992). Tree losses among those on Changsha mandarin planted in 1988 and 1989 were low, a not surprising result given their excellent cold tolerance (Castle, 1987). All trees on sour orange and Bittersweet sour orange were stunted by tristeza virus and yielded poorly. Those on Benton and K × R citranges made medium-sized trees with relatively good yields for their size (Table 2). The latter rootstock did not fare well in the 1989 freeze, but the trees planted in1991 began to produce about 1 box/tree when 4 years old. The trees on Rusk citrange, which were mostly resets planted in 1991, were taller than expected based on their size in other field trials (Wheaton et al., 1991, 1995). Trees on Sun Chu Sha mandarin in this study grew vigorously like those on Cleopatra mandarin, but the latter appeared to be more productive. 'Valencia' sweet orange as a rootstock resulted in large trees that cropped well but only 20% survived because of losses from Phytophthora damage. The trees on the somatic hybrid, Hamlin + Flying Dragon, all survived the 1989 freeze even though they were planted in the same year. They produced small trees that annually yielded <1 box/tree over the study period (Table 2).

Field Study 2 (Lake Placid)

Tree losses were minimal on all rootstocks except those on F80-8 citrumelo (Table 3). Although difficult to determine the causes, some trees on Carrizo apparently declined from blight. Average tree height was about 11 ft after 11 years. This was a similar tree height as the FS.1 trees when they were 14 years old. Yield was recorded for five seasons, but because yields were estimated, they are presented without statistical analysis. Similar to FS.1, the largest yields were generally associated with the tallest trees, such as those on Cleopatra mandarin, Calamandarin, and Carrizo and Troyer citranges (Table 3; Fig. 1). Overall, the results for tree height and yield were similar among rootstocks in both FS.1 and FS.2, i.e., as tree height decreased, so did cumulative yield. Among the trees on the same six rootstocks at both locations, there were only small differences in cumulative yields over the last 4 years (1994/95-1997/98) of observation except for those on Cleopatra mandarin which cropped exceptionally well at the Lake Placid site (Table 3; Fig. 1).

Field Study 3 (St. Cloud)

This 'Valencia' study included many of the same rootstocks as in the 'Hamlin' studies, but the 'Valencia' study also included somatic hybrids. The management and research-related decisions were different in this study and affected the interpretation of the results. For example, the tree survival values were low, mostly below 50% and in some instances, tree survival was 0% (Table 4). This outcome was unexpected and does not represent the general results obtained in the other field studies presented here nor in other unreported trials of the authors. One partial explanation is that the survival values were the result of a rigorous joint research-cooperator review in 2000 to identify trees in poor condition or that showed little promise. Those trees were removed and the remaining trees were the basis for the tree loss calculations (Table 4). Another possible explanation was that the site had a history of substantial tree loss from blight. We observed only an occasional tree in apparent decline from blight, but other unknown site factors may have contributed to our results. We concluded that the tree survival data were not typical of our field studies (Castle and Baldwin, 1995) and may not be representative of the rootstocks. The tree growth and yield data are useful, however, since they were collected before the tree survival assessment in 2000 took place and were from mostly full complements of trees.

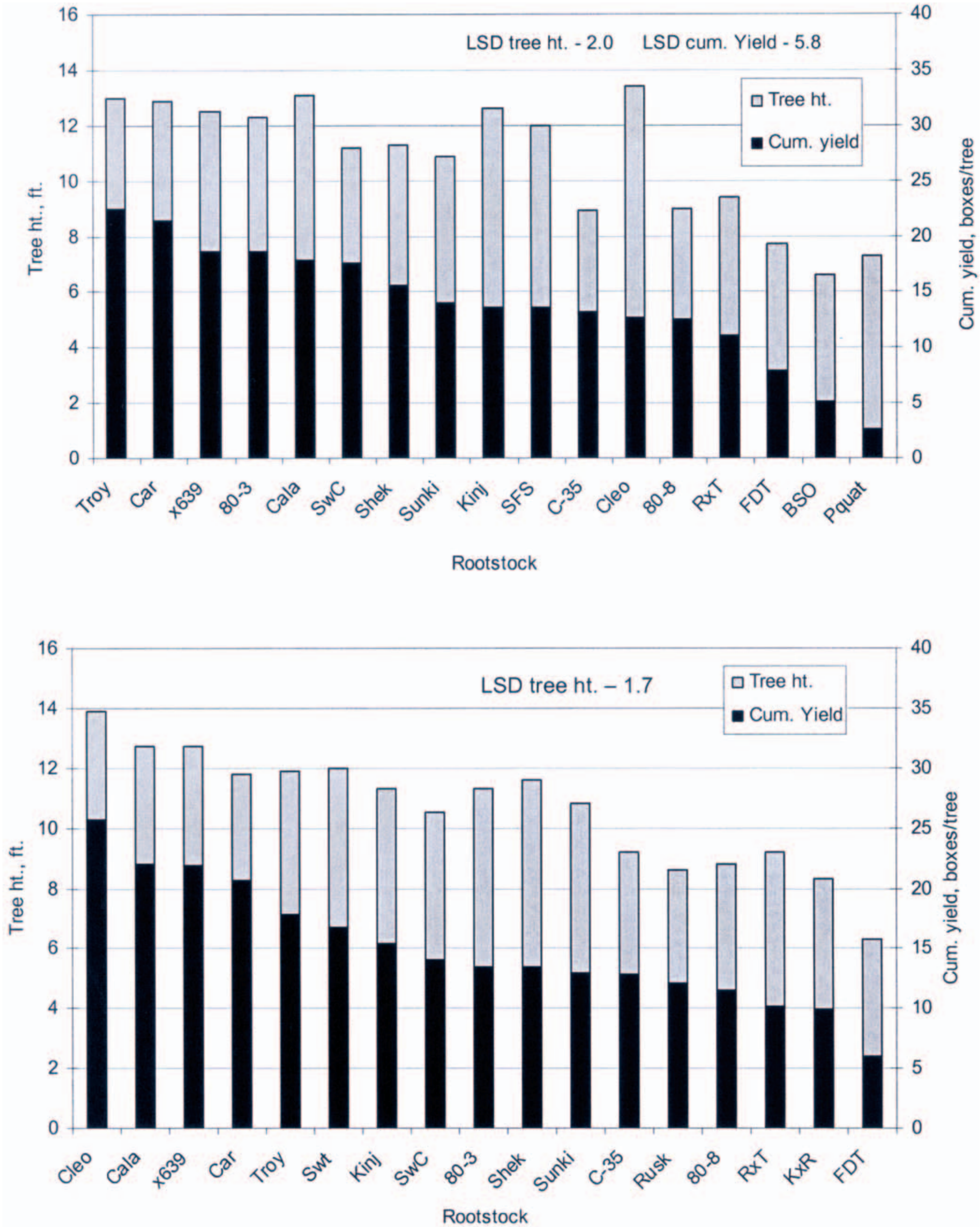

Fig. 1. 'Hamlin' tree heights and cumulative yields of trees on various rootstocks in field studies at Tavares (upper panel) and Lake Placid (lower panel). The data are for only those rootstocks included in statistical analyses. Least Significant Difference (LSD) values are presented except for estimated yields. See Table 1 for rootstock abbreviations.

Table 3. Performance of 'Hamlin' sweet orange trees on various rootstocks planted in a commercial grove, Lake Placid. Trees were planted 15 Dec. 1986 at 12.5 × 25 ft. (145 trees/acre).

Rootstock[y]	Tree survival, %	Tree height, ft.[x]	Estimated annual yield, boxes/tree[z]							Cum. yield
			1989-90	1990-91	1991-92	1994-95	1995-96	1996-97	1997-98	
C-35 citrange (8)[w]	100	9.2	0.6	1.6	1.5	1.0	2.6	2.6	2.9	13
Calamandarin (7)	100	12.7	0.3	0.9	1.1	1.9	5.9	5.4	6.4	22
Carrizo citrange (6)	83	11.8	0.3	1.5	1.7	1.7	5.1	4.8	5.6	21
Cleopatra mandarin (6)	100	13.9	0.1	0.7	1.7	2.6	6.6	6.4	7.6	26
F80-3 citrumelo (8)	87	11.3	0.3	0.5	0.9	1.0	3.3	3.4	4.1	13
F80-8 citrumelo (6)	57	8.8	0.4	1.0	1.1	0.9	2.8	2.4	2.9	11
Flying Dragon TF[v] (4)	100	6.3	0.2	0.5	0.7	0.6	1.5	1.3	1.3	6
Gou Tou[v]	25	9.0	u	0.0	0.0	0.5	1.0	1.0	1.0	4
Kinkoji (5)	80	11.3	0.2	0.6	1.4	0.9	3.9	3.3	5.2	15
Koethen × Rubidoux (4)	75	8.3	0.1	0.5	0.8	0.9	2.2	2.3	3.0	10
Rusk citrange (6)	83	8.6	0.5	1.5	1.3	1.1	2.3	2.5	3.0	12
Rangpur × Troyer (15)	93	9.2	0.3	0.7	1.0	1.2	2.2	1.9	2.7	10
Shekwasha mandarin (4)	100	11.6	0.2	0.1	0.8	1.2	3.6	3.5	4.0	13
Sour orange (4)	25	4.2	0.1	0.0	0.4	0.0	0.0	0.1	0.5	1
Sunki mandarin (3)	100	10.8	0.5	0.4	1.5	0.7	3.0	2.8	4.3	13
Swingle citrumelo (5)	100	10.5	0.2	0.7	1.1	1.2	3.2	3.3	4.5	14
Troyer citrange (4)	100	11.9	0.3	1.0	1.3	1.3	4.3	4.1	5.7	18
Valencia (5)	100	12.0	0.3	1.0	1.3	1.0	3.9	4.2	5.2	17
x639 (Cleo × Trif.) (6)	83	12.7	0.2	1.6	1.6	2.4	5.1	5.0	6.0	22
Mean		10.7								
LSD		1.7								

[z]Yield was estimated based on 200 to 250 fruit/box.
[y]Offset rootstocks were not included in statistical analyses.
[x]Measured Oct. 1997.
[w](n) Number of original trees.
[v]Planted spring 1987.
[u]Blank spaces indicate missing data.

FS.3 was essentially terminated in 2000 when the trees were 9 years old. At that time, few trees on many of the rootstocks were in good condition or had demonstrated sufficient vigor and productivity to be considered commercially promising (Table 4). Among the somatic hybrid rootstocks, only the trees on Cleo + Swingle rootstock had comparatively good survival, grew well, and cropped moderately. The other somatic hybrids, many of which were not planted until 1995, produced slow-growing, low-yielding trees so some had been removed before 2000.

The selections 1573-26, 1578-173, 1578-201, and 1584 were produced by Dr. Harry Ford (CREC, retired) in an attempt to create new burrowing nematode tolerant rootstocks (Ford and Feder, 1969). We have been evaluating these throughout Florida with consistent results that match those in this study. Trees on 1573-26 were nearly dwarfed and did not crop well. The rootstocks 1578-173 and 1578-201 have the same parents. Trees on these rootstocks have had similar, but variable performance in various unreported trials. Their cropping and survival in FS.3 were above normal given that we have observed heavy losses from foot rot in previous trials. Their inconsistent behavior limits their commercial potential.

The average cumulative yield for the rootstocks included in the statistical analysis was 9.5 boxes per tree, but the large Least Significant Difference (LSD) of 3.6 indicated considerable variability (Table 4). The other Harry Ford rootstock, 1584, had the numerical highest yield, but it was not different from that of many of the rootstocks that produced tall trees. 1584 has performed well and yielded efficiently in other unreported trials with grapefruit and sweet orange scions and in a range of soil series.

The numbered citrumelos were essentially identical in growth and yield as reported previously (Castle et al., 1988; Youtsey and Lee, 1995). In a separate study conducted by the cooperator at the same site as FS.3, trees on F80-3 declined relatively quickly from blight after 10 years whereas 70% of those on F80-8 have survived past 20 years. The numbered citrumelos continue to be evaluated in search of citrumelos to possibly replace Swingle (not included in this study). Thus, the lower losses among the trees on F80-14 and F80-18 are encouraging and suggest further evaluations are warranted.

Among the mandarin types, Changsha and calamandarin produced the tallest trees in this field study (Table 4). Trees on Sun Chu Sha were shorter than the trees on Changsha and Calamandarin, but grew to a larger size than the trees on most other rootstocks (Table 4; Fig. 2). The trees on Changsha appeared to be well adapted to the site given their large size but their cumulative yield was low for their size (Fig. 2), and the trees declined markedly in appearance by 2000. Among the citranges, the trees on K × R were medium-sized as in the other field studies with equivalent cumulative yields. The trees on Norton citrange grew and cropped well. This rootstock has not been extensively evaluated in Florida and warrants more trials. Trees on C-32, a sibling to C-35 (Cameron and Soost, 1986), were vigorous and cropped efficiently in this study (Fig. 2) and other unreported trials.

Field Study 4 (Immokalee)

The 'Valencia' trees in this study were planted in two replications of multiple-tree plots with many extra trees planted in adjacent rows. Survival of trees after 13 years was >80% for

Table 4. Performance of 'Valencia' trees on various rootstocks used as scattered resets in a commercial grove, St. Cloud. Trees were planted Aug. 1991 at 116 trees/acre (15 × 25 ft.).

Rootstocks[z]	Tree survival, %	Tree height, ft.[y]	Yield, boxes/tree						
			1994-95	1995-96	1996-97	1997-98	1998-99	1999-00	Cum.[x]
1573-26 (6)[w]	0	5.8	0.4	0.2	0.8	1.0	0.7	0.9	4.0
1578-173 (6)	83	9.3	0.5	0.9	1.7	2.7	2.0	2.7	11.0
1578-201 (6)	67	8.3	0.6	0.6	1.3	2.0	1.3	3.0	9.0
1584 PtM (4)	0	t	0.7	0.8	2.4	3.3	2.2	5.0	14.0
C-32 citrange (6)	0	11.4	0.6	1.0	1.7	2.7	2.2	2.9	11.0
Calamandarin (6)	17	11.9	0.2	0.4	1.4	3.4	1.9	3.7	11.0
Changsha mandarin (6)	0	12.5	0.1	0.2	1.0	2.3	2.0	2.1	8.0
F80-5 citrumelo (9)	33	9.8	0.7	0.9	1.5	2.9	1.6	3.4	11.0
F80-8 citrumelo (11)	36	7.9	0.7	0.8	1.7	2.2	1.5	2.6	9.0
F80-9 citrumelo (8)	12	8.7	0.6	0.8	1.2	2.4	1.8	2.8	9.0
F80-14 citrumelo (12)	50	7.5	0.7	0.7	1.5	2.0	1.8	2.4	9.0
F80-18 citrumelo (7)	57	9.0	0.3	0.5	1.6	2.3	1.7	3.2	9.0
Gou Tou[v] (3)	67	8.2		0.0	0.1	0.1	0.3	1.3	2.0
Koethen × Rubidoux citrange (6)	17	7.0	0.4	0.6	1.1	1.2	1.0	2.0	6.0
Norton citrange (6)	33	10.2	0.4	0.8	1.3	2.3	1.3	2.5	9.0
Sun Chu Sha mandarin (6)	50	10.8	0.1	0.2	1.1	2.4	1.9	3.2	9.0
W-2 citrumelo (4)	25	9.9	0.6	0.6	1.5	2.3	2.1	2.6	10.0
Zhu Luan[v] (4)	75	7.9		0.0	0.1	0.1	0.3	1.6	2.0
Somatic hybrids									
Cleo + Argentine TF (11)	11	7.6	0.0	0.0	0.1	0.3	0.6	1.0	2.0
Cleo + Flying Dragon (6)	0		0.2	0.1	0.6	x[u]	x	x	1.0
Cleo + Swingle (6)	50	7.7	0.5	0.2	0.9	1.3	0.9	1.4	5.0
Hamlin + Flying Dragon TF (6)	0		0.3	0.1	0.5	x	x	x	1.0
Hamlin + *S. disticha* (7)	14	6.7	0.5	0.4	0.9	0.8	0.5	1.2	4.0
Key Lime + Valencia (2)	0		0.1	0.2	0.9	x	x	x	1.0
Milam + Sun Chu Sha[v] (10)	0	4.6		0.0	0.0	0.0	0.2	0.5	1.0
Sour orange + Flying Dragon[v] (10)	0			0.0	0.1	x	x	x	0.1
Succari + Argentine TF (12)	17	6.6	0.0	0.0	0.1	0.5	0.5	0.7	2.0
Succari + *S. disticha*[v] (9)	0	4.7		0.0	0.0	0.0	0.1	0.1	0.2
Valencia + Femminello (2)	0		0.4	0.1	1.5	x	x	x	2.0
Mean		9.2							9.5
LSD		1.5							3.6

[z]Offset rootstocks were not included in statistical analyses.
[y]Measured Sep. 2000.
[x]Cumulative over six seasons: 1994-95 to 1999-00.
[w](n) Number of original trees.
[v]Trees planted in June 1995.
[u]Trees removed.
[t]Blank spaces indicate missing data.

those on most rootstocks with no loss among the trees on Cleopatra mandarin and three citrumelos (Table 5). Decline, apparently from blight (Lee et al., 1984) during the latter part of the observation period, occurred in the trees on Carrizo and Morton citranges and reduced their level of survival. Trees on Rusk citrange in other field trials often looked weak or unthrifty, but continued to crop well (Wheaton et al., 1991, 1995). This behavior was also exhibited in this study, however, many trees eventually became unproductive. No trees survived on 1573-26. They were small and unthrifty trees through most of the observation period. The average tree across rootstocks was 11.3 ft tall ranging in height from 15 ft (Changsha mandarin) down to 7.7 ft (1573-26) (Table 5; Fig. 2). Trees on Rusk and K × R citranges were taller than normally experienced (and similar to Swingle citrumelo in this study) suggesting that the Valkaria soil and site conditions were conducive to good tree growth.

Yields were estimated for 5 years when the trees were 5 to 9 years old (Table 5). Cumulative yields ranged from ~19 boxes/tree (F80-5 citrumelo) to <5 boxes/tree (1573-26). If the Least Significant Difference (LSD) of ~4 from the St. Cloud study is applied to this study, then the performances of the citrumelo rootstocks (except F80-14), the citranges, 1578-201, and 1572 were similar. Among the rootstocks with the lowest cumulative yields were Cleopatra, Sun Chu Sha, and Changsha mandarins. Thus, the trees on the three mandarin rootstocks cropped relatively inefficiently especially Changsha (Fig. 2).

Four years of juice data were variable from year to year because of different sampling dates. There were no differences in juice content among rootstocks for the 2000-01 season (Table 5). In the same season, there were soluble solids and pound solids /box differences among rootstocks, but only the fruit from trees on Rusk citrange had higher soluble solids concentration than fruit from the trees on Swingle citrumelo.

Trees on nine rootstocks were common to the 'Valencia' field studies. Cumulative yields were determined over a 6-year period at St. Cloud when the trees were 3 to 8 years old and

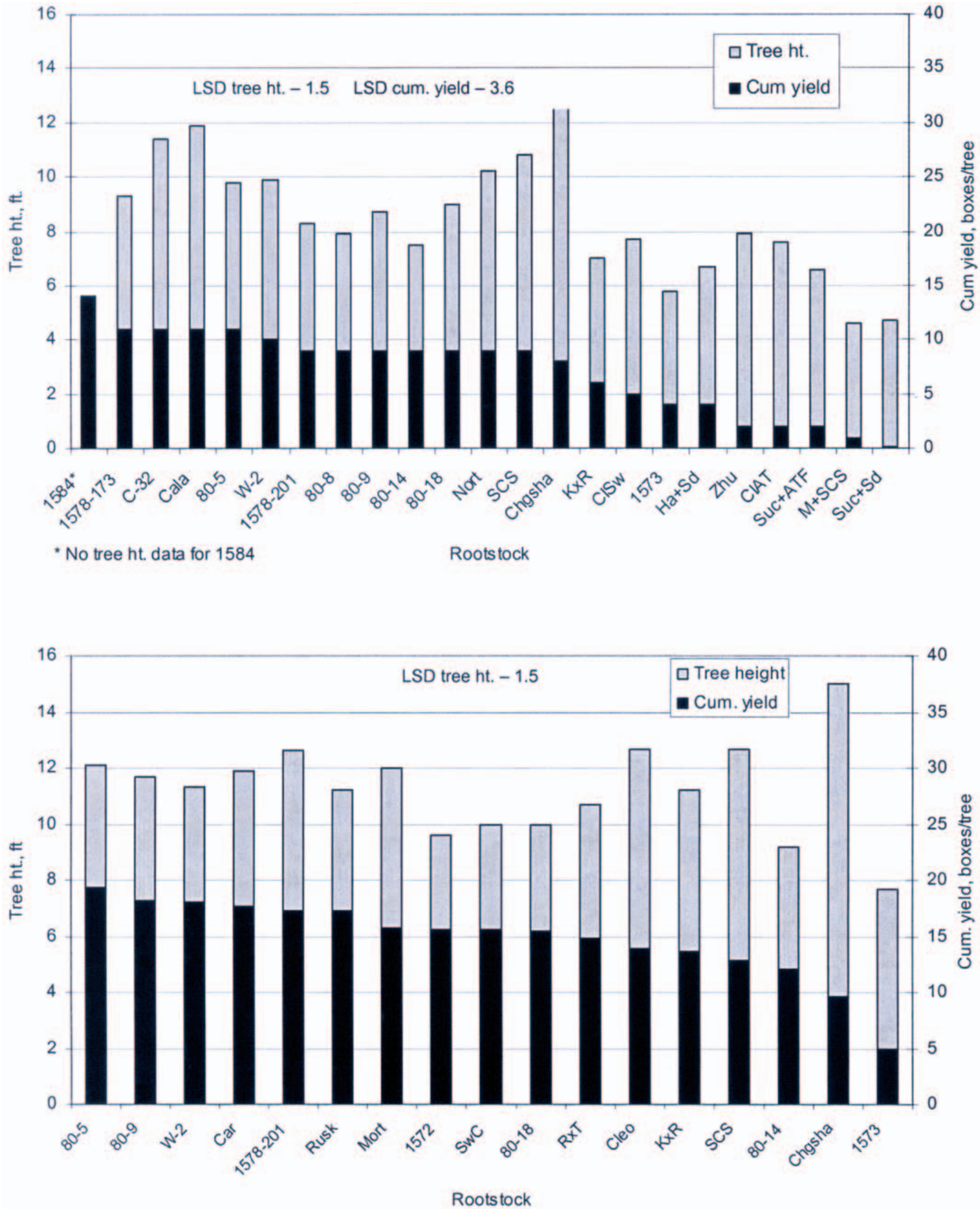

Fig. 2. 'Valencia' tree heights and cumulative yields of trees on various rootstocks in field studies at St. Cloud (upper panel) and Immokalee (lower panel). The data are for only those rootstocks included in statistical analyses. Least Significant Difference (LSD) values are presented except for estimated yields. See Table 1 for rootstock abbreviations.

Table 5. Rootstock effects on the measured fruit quality and estimated yield of 'Valencia' trees, Immokalee. Trees planted Dec. 1991 at 151 trees/acre (12 × 24 ft). Fruit samples collected 14 Apr. 1998, 18 May 1999, 22 Mar. 2000, and 21 Mar. 2001.

Rootstock	Tree survival, %[y]	Tree height, ft.[x]	Yield, boxes/tree[w]		Juice quality[z]			
			Annual	Cum.[v]	% juice	Soluble solids conc.	Ratio	PS/box
1572 PtM (18)[u]	78	9.6	2.4	4.4	54.7	12.5	15.1	6.1
			3.5	7.9	58.8	13.1	20.5	7.0
			4.0	11.9	54.2	12.5	14.2	6.1
			3.7	15.6	54.9	12.2	13.9	6.0
1573-26 PtR (9)	0	7.7	0.6	1.2	57.1	13.3	15.1	6.8
			1.0	2.2	56.4	13.1	20.1	6.6
			1.7	3.9	53.0	13.8	13.6	6.6
			1.0	4.9	54.3	13.1	14.6	6.4
1578-201 RPM (13)	92	12.6	3.0	5.1	57.4	12.1	18.3	6.2
			3.7	8.8	58.3	12.4	18.3	6.5
			4.0	12.8	50.4	11.5	12.3	5.2
			4.5	17.3	55.3	10.7	11.5	5.3
Carrizo citrange (25)	52	11.9	2.9	5.0	58.5	13.0	15.9	6.8
			3.5	8.5	60.1	12.7	18.5	6.9
			5.0	13.5	56.3	12.1	12.6	6.1
			4.2	17.7	56.7	11.3	11.8	5.8
Changsha mandarin (13)	92	15.0	2.2	3.3	58.9	13.4	16.9	7.1
			1.9	5.2	59.1	13.2	16.3	7.0
			2.7	7.9	58.6	11.9	11.0	6.3
			1.7	9.6	56.2	11.5	10.1	5.8
Cleopatra mandarin (30)	100	12.7	2.4	4.2	59.5	12.7	16.9	6.8
			2.2	6.4	59.1	12.7	17.8	6.7
			4.0	10.4	57.0	11.7	11.9	6.0
			3.5	13.9	54.5	10.7	11.0	5.2
F80-5 citrumelo (13)	77	12.1	3.2	5.5	61.3	12.8	17.5	7.1
			3.7	9.2	59.6	13.1	20.4	7.0
			4.7	13.9	58.1	12.0	13.7	6.3
			5.5	19.4	56.7	11.7	14.4	6.0
F80-9 citrumelo (7)	100	11.7	3.1	4.8	61.3	17.1	17.0	7.4
			3.7	8.5	59.0	13.2	19.4	7.0
			5.0	13.5	58.0	11.9	12.6	6.2
			4.7	18.2	57.5	11.8	14.0	6.1
F80-14 citrumelo (19)	100	9.2	1.4	3.2	54.6	14.7	14.7	5.4
			2.7	5.9	55.8	12.0	17.6	6.0
			3.5	9.4	56.8	11.6	13.5	5.9
			2.7	12.1	54.6	11.5	13.9	5.7
F80-18 citrumelo (19)	100	10.0	2.1	4.0	56.3	12.5	17.2	6.3
			3.2	7.2	59.0	12.6	18.8	6.7
			4.2	11.4	54.1	11.5	13.3	5.6
			4.0	15.4	54.7	11.2	13.9	5.5
Koethen × Rubidoux (30)	83	11.2	1.6	3.2	59.9	13.1	18.0	7.1
			2.9	6.1	56.3	12.9	19.6	6.5
			4.0	10.1	59.3	12.1	13.9	6.4
			3.5	13.6	56.0	11.5	14.0	5.8
Morton citrange (9)	56	12.0	3.8	5.7	59.9	12.7	16.7	6.8
			2.2	7.9	62.5	12.1	17.2	6.8
			3.8	11.7	54.0	11.6	12.1	5.6
			4.0	15.7	55.8	10.9	12.4	5.5
Rangpur × Troyer (29)	62	10.7	2.2	4.1	59.6	12.4	18.5	6.7
			3.0	7.1	60.6	13.1	19.8	7.2

[z]Means of two replications.
[y]As of 2004.
[x]Measured 21 Mar. 2001.
[w]Yield was estimated based on 200 to 250 fruit/box.
[v]Cumulative over five seasons.
[u](n) Number of original trees.

Table 5. (Continued) Rootstock effects on the measured fruit quality and estimated yield of 'Valencia' trees, Immokalee. Trees planted Dec. 1991 at 151 trees/acre (12 × 24 ft). Fruit samples collected 14 Apr. 1998, 18 May 1999, 22 Mar. 2000, and 21 Mar. 2001.

			Yield, boxes/tree[w]		Juice quality[z]			
Rootstock	Tree survival, %[y]	Tree height, ft.[x]	Annual	Cum.[v]	% juice	Soluble solids conc.	Ratio	PS/box
			3.5	10.6	56.4	11.6	13.2	5.9
			4.2	14.8	57.4	11.3	13.0	5.9
Rusk citrange (13)	38	11.2	3.3	5.9	59.5	13.8	17.1	7.4
			3.5	9.4	57.8	13.4	19.1	6.9
			4.2	13.6	57.8	12.5	12.6	6.4
			3.7	17.3	54.6	12.1	13.0	5.9
Sun Chu Sha (114)	96	12.7	2.5	4.1	58.4	13.2	18.6	7.0
			2.3	6.4	57.2	12.9	17.4	6.6
			3.5	9.9	57.3	11.8	12.3	6.1
			3.0	12.9	56.5	11.8	11.9	6.0
Swingle citrumelo (20)	90	10.0	2.7	4.6	57.2	12.8	17.4	6.6
			3.1	7.7	60.1	13.1	20.5	7.1
			3.7	11.4	55.3	12.2	13.8	6.1
			4.2	15.6	54.4	11.3	13.8	5.5
W-2 citrumelo (18)	72	11.3	3.0	5.0	58.1	12.3	17.9	6.4
			3.5	8.5	59.0	12.7	18.3	6.7
			4.5	13.0	55.5	11.9	14.0	5.9
			5.0	18.0	56.9	11.8	13.3	6.0
Mean 2000-01		11.3			55.7	11.6	13.0	5.8
LSD		1.5			n.s.	0.7	1.9	0.6

[z]Means of two replications.
[y]As of 2004.
[x]Measured 21 Mar. 2001.
[w]Yield was estimated based on 200 to 250 fruit/box.
[v]Cumulative over five seasons.
[u](n) Number of original trees.

during a 5-year period at Immokalee when the trees were 5 to 9 years old. Tree survival and growth data were obtained when tree age was less than one year apart between the sites. Among the trees on these nine rootstocks, cumulative yield was generally lower at St. Cloud as were survival values and tree heights (Tables 4, 5; Fig. 2). Trees on the citrumelos F80-5 and W-2 along with 1578-201 were some of the top performers at both locations. Trees on Sun Chu Sha mandarin grew well but had lower yield perhaps because 'Valencia' trees on mandarin rootstocks are not known to crop well until they are 10-15 years old (Castle et al., 1993). Changsha mandarin appeared to be an even worse example of this late cropping habit because the trees on this rootstock were the tallest at both locations with low yields (Fig. 2).

Conclusions

In order for a new rootstock to continue through the evaluation process and eventually reach commercial acceptance, it should exceed some or all of certain horticultural and pest and disease resistance standards dictated by prevailing local conditions. Trees must also behave consistently in the nursery and survive in the field. During field evaluation, it is also important to include existing commercial rootstocks for comparison. This was a deficiency in several of the field studies reported here. Thus, comprehensive sets of criteria were not used to evaluate the rootstocks in our field studies. However, on the combined basis of survival, growth, cumulative yield, and bearing efficiency, the commercial rootstocks that were included seemed to perform according to their established reputations (Castle and Tucker, 1998). This enabled us to make reasonable conclusions about the other rootstocks for 'Hamlin' and 'Valencia' sweet orange scions as follows:

- x639—Trees were vigorous and cropped well with 'Hamlin.' Juice quality in other field trials of the authors has been typical for mandarin rootstocks. Other reports also indicate promise for this rootstock (Castle et al., 2000; Stover et al., 2004).
- 1584—It was included in only one study, but its performance in FS. 3 and in other trials has been consistently above average with medium-sized trees that often exceeded the yield and juice quality of trees on Swingle citrumelo.
- Numbered citrumelos—We have had these rootstocks in several trials scattered throughout Florida and with different scions. Their performance has not been as consistent as desired, and their behavior reported here was virtually the same as trees on Swingle. A major advance with a new citrumelo would be one that is adapted to the high pH soils of the Indian River region. Unfortunately, in other reports about grapefruit trees growing on a range of these rootstocks including Swingle, most trees did not survive after 10 years in Riviera sand soil (Bauer et al., 2004; Castle et al., 2002, 2004).
- 'Flying Dragon' trifoliate orange—This rootstock has attracted little attention in Florida even though the trees

survive well and crop efficiently with excellent quality fruit that can exceed that of trees on sour orange (Castle, 1987). Trees on 'Flying Dragon' are also consistently small and are more appropriate for high density plantings.

- Carrizo vs. Troyer citrange—As we have experienced in other trials, there were no differences between these two rootstocks.

- Cleopatra vs. Sun Chu Sha mandarin—The trees on these two rootstocks were not strictly comparable in the Tavares study because those on Sun Chu Sha were planted 4 years after those on Cleopatra mandarin. Nevertheless, both rootstocks were productive with 'Hamlin' and were largely indistinguishable from each other with 'Valencia' in the Immokalee study.

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