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EVALUATION OF NEW CITRUS ROOTSTOCKS FOR 'TAHITI' LIME PRODUCTION IN SOUTHERN FLORIDA

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Abstract. **Two 'Tahiti' lime (*Citrus latifolia* Tan.) trials were planted in Miami-Dade County to evaluate the performance of new rootstocks specifically selected for their potential on the highly calcareous limerock soils common to the area. The first trial consisted of two replications of 10-tree plots planted in 1997 with a grower-cooperator. There were 20 rootstocks including various sexual and somatic hybrids plus Rangpur (*C. limonia* Osb.) for comparison. Yield was measured three times over 2 years and the cumulative results ranged from <20 to nearly 160 lb of fruit per tree. The highest yielding trees were those on Volkamer lemon, Rangpur, *C. ambylcarpa*, US-801, and US-897. This trial was terminated and removed because of citrus canker. The second trial of 52 sexual and somatic hybrid rootstocks was planted in 2001 at the USDA, Subtropical Horticulture Research Station, Miami, with six replications of three-tree plots. Yield and tree size were measured once in 2004 before further data collection was suspended by the appearance of citrus canker. Most trees were about 6 to 7 ft tall and produced from <1 to about 11 lb of fruit per tree. Among the higher yielding trees were those on the commercial standard for comparison, *C. macrophylla*, some selections of *C. limonia* (including Rangpur), several somatic hybrids, and Volkamer lemon. Tree condition and appearance (canopy greenness) were rated as a single variable to express apparent differences in nutritional adaptation to the soil. Trees on macrophylla, US-801, US-812, US-897, several somatic hybrids, the *C. limonia* selections, Rangpur, rough lemon, and Volkamer lemon were among those with the best ratings.**

Trifoliate orange [*Poncirus trifoliata* (L.) Raf.] is an important citrus relative for breeding new rootstocks. It is a source of tolerance to citrus tristeza virus, citrus nematodes, cold weather events, and *Phytophthora nicotianae* Breda de Hoan. Trees grown with trifoliate orange and its hybrids (e.g., citranges and citrumelos) as the rootstock are well known for their relatively high fruit quality (Castle, 1987). Unfortunately, trifoliate orange is generally a source of intolerance to calcareous soil conditions. Lime-induced chlorosis is a common consequence of using these rootstocks in soils with high available $CaCO_3$. In the worst situations, trees on sensitive rootstocks will not grow. Attempts to grow trees on such rootstocks in calcareous conditions have often resulted in a grove being removed well before it has produced an economic return to the owner.

Calcareous conditions are problematic in many Southern Flatwoods areas of Florida because limestone, seashells, marl, and other forms of $CaCO_3$ are present in the soil. Therefore, the two most popular commercial rootstocks, Swingle citrumelo and Carrizo citrange, are not normally recommended for 'Tahiti' lime (Campbell, 1991; Castle and Tucker, 1998). Furthermore, most of the remaining rootstock options are also less than satisfactory for reasons related to yield, fruit quality, and tolerance to soils and diseases (Campbell, 1991). Several field evaluations have demonstrated the difficulty in developing suitable rootstocks for Florida's most challenging calcareous environment: the 'Tahiti' lime industry located on the limerock soils in Miami-Dade County (Campbell, 1972; Campbell, 1974; Campbell and Lincoln, 1962).

The economic limitations imposed on the Florida citrus industry by calcareous soils are serious enough to justify plant breeding and evaluation efforts. Thus, our objective was to assess a broad range of new sexual and somatic hybrid rootstocks in field trials in the harsh calcareous soil conditions of Miami-Dade County.

Materials and Methods

Two field experiments were planted. Experiment 1 (E.1) was established in two blocks on the property of a commercial cooperator located near the UF Tropical Research and Education Center in NW Homestead. 'Tahiti' lime trees, clone SPB-7-X (shoot-tip grafted 24-18-XE), were produced in a commercial nursery on various rootstocks (Table 1) and planted in August 1997 in plots of 10 trees in two replicate randomized complete blocks at a spacing of 15 × 22 ft. Some trees were planted 1 year later. The north block (block 4) was previously planted with avocado trees and the south block (block 5) with lime trees. Local growers claim that avocado

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Table 1. Rootstocks in two southern Florida 'Tahiti' lime field trials.

Trial	Common name	Abbrev.	Scientific name
E.1	Amblycarpa	Amb	*Citrus amblycarpa* (Hassk.) Ochse
E.2	Changsha + 50-7 TF	ChTF	Changsha mandarin + trifoliate orange [*Poncirus trifoliata* (L.) Raf.] 50-7
E.1	Changsha mandarin	Chgsha	*C. reticulata* Blanco
E.2	Cleo + Flying Dragon	ClFD	Cleopatra mandarin + Flying Dragon trifoliate orange
E.1	Cleo + RL 8166	CL + 8166	Cleopatra mandarin + rough lemon (*C. jambhiri* Lush.) selection 8166
E.2	Cleo + Swingle	ClSw	Cleopatra mandarin + Swingle citrumelo (*C. paradisi* Macf. × *P. trifoliata*)
E.2	Cleo + Volk	ClVk	Cleopatra mandarin + Volkamer lemon (*C. volkameriana* Ten. & Pasq.
E.2	Cleo × TF PLN 1578	ClT8	Cleopatra mandarin × trifoliate orange (obtained from J. Forner, Spain)
E.2	Cleo × TF PLN 1579	ClT9	Cleopatra mandarin × trifoliate orange (obtained from J. Forner, Spain)
E.2	Cleo × TF PLN 1580	ClT0	Cleopatra mandarin × trifoliate orange (obtained from J. Forner, Spain)
E.2	Cleo + Argentine TF	ClAT	Cleopatra mandarin + Argentine trifoliate orange
E.2	Cleopatra mandarin	Cleo	*C. reshni* Hort. ex. Tan.
E.2	Cleo × Rubidoux	x639	Cleopatra mandarin × Rubidoux trifoliate orange
E.1 E.2	Gou Tou	GouT	Probable sour orange (*C. aurantium* (L.)-pummelo [*C. maxima* (Burm. f.) Merr.] hybrid
E.1	Hamlin + Rangpur	Ha+Rg	Hamlin sweet orange [*C. sinensis* (L.) Osb.] + Rangpur lime (*C. limonia* Osb.)
E.2	Hamlin + Rough lemon	Ha+RL	Hamlin sweet orange + rough lemon (*C. jambhiri* Lush.)
E.1 E.2	Kinkoji	Kinj	*C. obovoidea* Hort ex. Tan.
E.2	LT 01 Cleo × Flying Dragon	CFD1	Cleopatra mandarin × trifoliate orange Flying Dragon
E.2	LT 02 Tu Nin Mon(a)	TNMa	*C. limonia*
E.2	LT 03 Hong Nin Mon(a)	HNMa	*C. limonia*
E.2	LT 04 Cleo × Swingle	CxSw	Cleopatra mandarin × Swingle citrumelo
E.2	LT 05 PSL × Cia	Psia	Palestine sweet lime (*C. limettioides* Tan.) × *C. ichangensis* Swing.
E.2	LT 06 PSL × Cib	Psib	Palestine sweet lime × *C. ichangensis*
E.2	LT 07 Hong Nin Mon(b)	HNMb	*C. limonia*
E.2	LT 08 Pimpled mandarin	Pimm	*C. reticulata*
E.2	LT 09 Cleo × Flying Dragon	CFD9	Cleopatra mandarin × trifoliate orange Flying Dragon
E.2	LT 10 AP 65-56	6556	(Pummelo × sour orange) × Orlando tangelo (*C. paradisi* × *C.reticulata*)
E.2	LT 11 Cleo × Flying Dragon	CF11	Cleopatra mandarin × trifoliate orange Flying Dragon
E.2	LT 12 Hong Nin Mon(c)	HNMc	*C. limonia*
E.2	LT 13 Tu Nin Mon(b)	TNMb	*C. limonia*
E.2	Macrophylla	Mac	*C. macrophylla* Wester
E.2	Milam + Kinkoji	MiKi	Milam (*C. jambhiri*) + Kinkoji
E.2	Nova + CI	NoIg	Nova tangelo + *C. ichangensis*
E.2	Nova + HB pummelo	NoPm	Nova tangelo × Hirado Buntan pummelo
E.2	PLN 1579 Cleo × TF	ClT9	Cleopatra mandarin × trifoliate orange
E.1 E.2	Rangpur lime	Rg	*C. limonia*
E.2	Rough lemon	RL	*C. jambhiri*
E.1	Shekwasha	Shek	*C. depressa* Hay.
E.1 E.2	Smooth Flat Seville	SFS	Probable sour orange-pummelo hybrid
E.2	Sour + 50-7 TF	SoTF	Sour orange + trioliate orange 50-7
E.2	Sour + Carrizo	SoCa	Sour orange + Carrizo citrange (*C. sinensis* × *P. trifoliata*)
E.2	Sour + Flying Dragon	SoFD	Sour orange + trioliate orange
E.2	Sour + PSL	SO + PSL	Sour orange + Palestine Sweet Lime
E.2	Sour orange	SO	*C. aurantium*
E.1	Sour orange + Rangpur	SO + Rg	Sour orange + Rangpur lime
E.1 E.2	Sun Chu Sha	SCS	*C. reticulata*
E.1 E.2	US 801	US 801	Changsha × English Small trifoliate orange
E.2	US 802	US 802	Pummelo × trifoliate orange
E.1 E.2	US 809	US 809	Changsha mandarin × English Large trifoliate orange
E.1 E.2	US 812	US 812	Sunki mandarin × Benecke trifoliate orange
E.1 E.2	US 827	US 827	Rangpur lime × trifoliate orange
E.2	US 852	US 852	Changsha mandarin × English Large trifoliate orange
E.1 E.2	US 896	US 896	Cleopatra mandarin × Rubidoux trifoliate orange
E.1 E.2	US 897	US 897	Cleopatra mandarin × Flying Dragon trifoliate orange
E.2	US 942	US 942	Sunki mandarin × Flying Dragon trifoliate orange
E.2	US 952	US 952	Pearl tangelo × trifoliate orange Flying Dragon trifoliate orange
E.2	Valencia + Fem. lemon	Vfem	Valencia sweet orange + Femminello lemon [*C. limon* (L.)]
E.1 E.2	Volkamer lemon	Volk	*C. volkameriana*
E.1 E.2	Zhu luan	Zhu	Probable sour orange-pummelo hybrid

leaf litter tends to enrich the soil such that when limes follow avocados, the lime trees often perform better than when lime trees follow lime trees.

The soil is classified as Udorthents, limestone substratum-urban land complex (USDA/NRCS, 1996). It is similar to Krome very gravelly loam, a carbonatic, hyperthermic Lithic

Udorthent. These soils are very shallow and moderately well drained with limerock close to the surface. Soil preparation prior to planting included rock plowing (scarification) to a 4-8 in. depth and trenching in tree rows to ca. an 18-in. depth.

Irrigation was provided by microsprinkler. Weed, pest, and disease control were achieved through standard commercial practices. The trees were fertilized regularly with a series of N-P-K formulations and foliar or ground applications of micronutrients using various compounds including Sequestrene 138 to supply chelated Fe, and foliar applications of $MgNO_3$. Tree height was measured in July 2000. In Sept. 1999, all commercially mature fruit were harvested from the entire plot and weighed; in March and July 2000, a subset of about 2-4 representative trees was harvested in each plot. The quantity of fruit per unit of tree height was calculated as an indication of tree efficiency.

Experiment 2 (E.2) was planted in May 2001 at the USDA Subtropical Horticulture Research Station, near Cutler Ridge, south Miami. These trees were propagated commercially with the same scion clone as E.1 and planted in Krome very gravelly loam soil at 10 × 20 ft in a randomized complete-block design of six replications with three-tree plots. There were not enough trees for six reps of every rootstock, so extra trees of some rootstocks were planted in available spaces (Table 3). Each tree was set into a 3-ft diameter by 1.5-ft deep hole made with an auger and then backfilled. Irrigation was via a drip system operated every other day for 4 h. Agri-Mek (Syngenta Corp., Greensboro, N.C.) was used for pest control. The trees were fertilized the first year with 6N-6P-6K; thereafter, CitriBlen 16N-5P-16K (The Scotts Co., Marysville, Ohio), a slow release formulation, was applied annually. Foliar micronutrients were routinely applied; Fe was applied as Sequestrene 138 to the soil under the tree canopy. Tree appearance and condition were rated in both trials within a few years after planting.

Statistical analyses were performed using ANOVA (SAS, Cary, N.C.) with mean separation by Least Significant Difference. Simple correlation coefficients were calculated among tree height and yield data.

Both experiments were prematurely terminated by citrus canker (*Xanthomonas axonopodis* pv. *citri*) infection when the trees were ca. 3 years old (E.1 in 2000; E.2 in 2003). The trees were subsequently destroyed. In the absence of the opportunity for long-term observation, tree growth, appearance and initial cropping became the primary means of evaluating tree performance and rootstock potential.

Results and Discussion

Experiment 1. Tree survival, with a few exceptions, was 80-100% at the time the trial was terminated (Table 2). Where survival was <80%, it appeared that trees on those rootstocks had been planted in areas of the trial site where trees generally struggled to grow most likely because of soil problems. Overall tree size and appearance were judged to be excellent for their age by the cooperator's standards and experience. In our September 1999 ratings (data not given), the trees on all rootstocks had excellent canopy color. Virtually no micronutrient deficiencies were evident except for mild Fe and Mn symptoms among the trees on Changsha and Sun Chu Sha mandarins, and US 809.

After 3 years, the E.1 trees were ~7 ft tall across both replications (Table 2). Trees on Rangpur were among the tallest along with those on US 801, US 812, US 827, and Volkamer lemon. The smaller trees were ca. 6 to 7 ft tall and were either those of a given rootstock, e.g., US 812, growing in block 5 versus block 4, or those on Changsha mandarin that were virtually the smallest trees in both blocks. The trees in block 4 were significantly taller than the trees in block 5 (Table 2). This size difference is consistent with local grower observations about the benefits of growing lime trees in blocks previously planted to avocado. We did not measure soil organic matter content, but the surface of block 4 soil was visibly darker. In some instances, this tree size difference between blocks was relatively large as with the trees on rootstocks like Gou Tou, US 812, Smooth Flat Seville, and Sun Chu Sha mandarin suggesting that some rootstocks may have benefited more from the additional organic matter apparently present.

Although the trees on some rootstocks in block 4 were taller than those in block 5, there were no differences in cumulative yield per tree between blocks or among rootstocks (Table 2; Fig. 1). Yield ranged from more than 130 lb per tree (Volkamer lemon, US 801, Rangpur, *C. amblycarpa*, and US 897) to less than 90 lb per tree (Sun Chu Sha, Shekwasha, and Changsha mandarins, and Smooth Flat Seville). We attempted to determine if yield differences were simply due to tree size differences by calculating yield efficiency in lb fruit per unit of tree height. The most efficient trees were those with the highest cumulative yields, but the differences were not statistically significant indicating that yield was directly related to tree size (Table 2).

Experiment 2. Tree survival on most rootstocks exceeded 80% in E.2 as in E.1 (Table 3). The trees on the mandarin selections Tu Nin Mon and Pimpled mandarin, US 852, and Cleo × Swingle citrumelo had relatively low survival probably because many of the trees were very small at planting. The average tree was 6.2 ft tall after 3 years, and height among the rootstocks ranged from ca. 5 to 7.5 ft (Fig. 2). The tallest trees were those *C. macrophylla.* Many of the smaller trees were those on the somatic hybrid rootstocks.

We were only able to harvest one crop before the E.2 trial was terminated. The crops were small, but there were highly significant differences among rootstocks with yield ranging from 11 lb per tree to none (Table 3; Fig. 2). The average yield was 4.1 lb per tree. A full range of possible relationships between tree height and yield were expressed. Trees of the commercial standard, *C. macrophylla,* had the largest crop and were the largest trees. Trees on other rootstocks like US 812 and CFD1 were equally large, but had small crops. Other trees were not as tall but had a good crop as observed on SO + PSL and Milam + Kinkoji. The trees on some rootstocks were of average height but had no fruit (US 852 and Cleo × Swingle). The trees on several somatic hybrid and other rootstocks were the same height or smaller and yielded better than those on Rangpur (Fig. 2). As a result, these rootstocks generally had the highest yield efficiencies (Table 3).

In addition to rootstock effects on tree growth and cropping, there were marked differences in tree appearance as recorded in our ratings (Table 3). The trees with a "1" rating stood out from all other trees by virtue of their excellent green leaf color and the general consistency of this observation among all the trees on these rootstocks. The trees on *C. macrophylla,* rough and Volkamer lemons, many USDA hybrids, a few somatic hybrids, some mandarins including Sun Chu Sha, and some sexual hybrids received a "1" rating. The trees on Gou Tou, Zhu Luan, US 852, and Rangpur were

Table 2. 'Tahiti' lime rootstock trial, Brooks Tropicals, Homestead. Trees planted in August 1997 at 15 × 22 ft (132 trees/acre). Block 4 had previously been planted to avocado and block 5 to lime trees.

Rootstock	Year	Tree survival, %		Tree height[z]		Annual yield, lb fruit/tree		Cumulative yield, lb fruit/tree		Total cumulative yield	Lb fruit/ft of height
		Block 4	Block 5	Block 4	Block 5	Block 4	Block 5	Block 4	Block 5		
C. amblycarpa	98-99[y]					22.5	9.0				
	99-00[x]					6.0	4.7				
	99-00[w]	100	100	7.7	7.2	31.9	63.4	60.4	77.1	137.6	9.3
Cleo + RL8166[v]	98-99					—	—				
	99-00					4.5	6.4				
	99-00	100	60	5.6	4.1	9.1	1.5	13.6	7.9	21.5	2.2
Changsha mandarin	98-99					16.2	4.5				
	99-00					5.8	3.5				
	99-00	100	100	6.6	6.6	21.7	27.5	43.7	35.5	79.2	6.0
Gou Tou	98-99					11.7	7.2				
	99-00					5.5	4.7				
	99-00	100	100	8.0	6.2	36.3	22.1	53.5	34.0	87.5	6.1
Kinkoji	98-99					14.4	6.3				
	99-00					4.8	4.8				
	99-00	100	100	7.2	6.5	34.1	31.5	53.3	42.6	95.9	7.0
Hamlin + Rangpur[u]	98-99					17.0	—				
	99-00					4.6	—				
	99-00	90	—	7.1	—	21.2	—	42.8	—	42.8	6.0
Rangpur	98-99					10.8	9.0				
	99-00					5.6	4.7				
	99-00	100	100	8.7	7.4	27.5	80.9	43.9	94.6	138.5	8.9
Shekwasha mand.	98-99					9.0	5.4				
	99-00					5.0	4.4				
	99-00	90	100	7.6	6.8	39.1	21.5	53.1	31.3	84.4	5.8
Smooth Flat Seville	98-99					15.3	7.2				
	99-00					4.5	4.6				
	99-00	100	100	7.8	6.2	28.0	22.0	47.8	33.8	81.6	5.8
Sour org. + Rang.	98-99					13.5	6.4				
	99-00					3.9	5.5				
	99-00	100	70	7.7	4.4	24.7	10.9	42.1	22.8	64.9	5.3
Sour org. + PSL[v]	98-99					—	—				
	99-00					3.6	3.6				
	99-00	100	100	4.6	3.4	5.1	2.3	8.7	5.9	14.6	1.8
Sun Chu Sha mand.	98-99					7.2	4.5				
	99-00					4.1	4.0				
	99-00	100	100	7.8	6.3	46.9	21.7	58.2	30.2	88.4	6.1
US 801 Changsha ×	98-99					15.3	8.1				
Eng. Sm. TF	99-00					5.4	5.2				
	99-00	100	100	8.7	7.6	23.9	82.6	44.6	95.9	140.5	8.9
US 809 Changsha ×	98-99					12.6	4.5				
Eng. Lg. TF	99-00					5.1	4.1				
	99-00	100	100	6.8	6.7	36.7	29.4	54.4	38.0	92.4	6.8
US 812 Sunki ×	98-99					12.6	9.0				
Benecke TF	99-00					5.7	4.9				
	99-00	90	100	9.2	6.9	36.6	34.2	54.9	48.1	103.0	6.5
US 827 Rangpur × TF	98-99					13.5	6.3				
	99-00					7.3	4.7				
	99-00	70	100	8.0	8.7	31.5	38.8	52.3	49.8	102.1	6.1
US 896 Cleo ×	98-99					15.3	9.0				
Rubidoux TF	99-00					5.6	5.1				
	99-00	100	100	7.8	6.3	36.5	23.8	57.4	37.9	95.3	6.7
US 897 Cleo ×	98-99					30.6	10.8				
Flying Dragon TF	99-00					5.0	5.1				
	99-00	100	100	7.2	7.1	55.5	26.6	91.1	42.5	133.6	9.3
Volkamer lemon	98-99					18.9	7.2				
	99-00					6.3	4.1				
	99-00	100	100	8.8	7.5	86.4	33.9	111.6	45.2	156.8	9.3

[z]Trees measured 18 July 2000.
[y]Yield measured 17 September 1999.
[x]Yield measured 22 March 2000.
[w]Yield measured 18 July 2000.
[v]Trees planted approximately one year later. Not included in the data analyses.
[u]No Hamlin + Rangpur plot was planted in block 5.
[t]Least Significant Difference.

Table 2. (Continued) 'Tahiti' lime rootstock trial, Brooks Tropicals, Homestead. Trees planted in August 1997 at 15 × 22 ft (132 trees/acre). Block 4 had previously been planted to avocado and block 5 to lime trees.

Rootstock	Year	Tree survival, %		Tree height[z]		Annual yield, lb fruit/tree		Cumulative yield, lb fruit/tree		Total cumulative yield	Lb fruit/ft of height
		Block 4	Block 5	Block 4	Block 5	Block 4	Block 5	Block 4	Block 5		
Zhu luan	98-99					14.0	4.5				
	99-00					6.1	4.4				
	99-00	80	100	7.7	6.4	31.2	31.1	51.3	40.0	91.3	6.4
Replication mean				7.5	6.4			51.9	42.8		
p-value				<0.0001				0.1466			
Rootstock mean				7.0				47.5			6.5
p-value; LSD[t]				0.0003; 1.4				0.1308			0.3001

[z]Trees measured 18 July 2000.
[y]Yield measured 17 September 1999.
[x]Yield measured 22 March 2000.
[w]Yield measured 18 July 2000.
[v]Trees planted approximately one year later. Not included in the data analyses.
[u]No Hamlin + Rangpur plot was planted in block 5.
[t]Least Significant Difference.

among those rated "3," i.e., with a fair appearance and some chlorosis.

The primary intent of E.1 and E.2 was to conduct long-term trials to identify rootstocks adapted to calcareous soil conditions. Our results would complement other horticultural information (Bowman et al., 1999; Campbell, 1972; Campbell and Lincoln, 1962; Castle et al., 1992; Wutscher and Bowman, 1999; Wutscher and Olsen, 1970). Unfortunately, the occurrence of citrus canker in both experiments effectively converted them into preliminary screening trials with limited data. To interpret our data, we grouped the rootstocks into several categories and have compared our results with those of Campbell (1991) who distinguished well-adapted rootstocks from those that gave variable results in field trials, or were poorly adapted to the calcareous soils of Miami-Dade County (Campbell, 1972, 1974, 1991; Campbell and Lincoln, 1962; Colburn et al., 1963). The criteria for grouping were tree growth and appearance, and yield; also, the rootstocks are grouped for comparison within types, e.g., mandarins.

Most promising rootstocks. The best performing rootstocks were selected primarily on the basis of yield but they also produced trees with good growth and appearance. These were *C. macrophylla*, Volkamer and rough lemon, Rangpur, SO + TF50-7, HNMa, HNMb, TNMb, HA+RL, *C. amblycarpa*, US 801, US 812, US 897, US 942, and CIT0, a hybrid developed in Spain by J. Forner (2000). Among these rootstocks, several like Rangpur were included in both trials, but performed inconsistently as noted by Campbell (1991); however, the trees on Volkamer lemon grew and yielded well in both trials. This coincides with Campbell's (1991) observations and ranking of this rootstock along with *C. macrophylla* as the best performing rootstocks and explains the commercial popularity of the latter. In the E.2 trial, the trees on *C. macrophylla* had the highest numerical yield, but there were no significant yield differences among macrophylla and the other rootstocks mentioned above. Trees on the E.2 somatic hybrid rootstocks, SO + PS, V + FEM, CL + FD, SOFD, yielded well and produced relatively small trees, but had lower ratings for appearance.

Rootstocks that merit further evaluation. Based on yield, this group includes US 827 to Ha+Rg in E.1, and sour orange to US 801 in E.2 (Figs. 1 and 2). Among these rootstocks, trees on SO + Carrizo, US 896, Sun Chu Sha mandarin, US 897, LT 11 Cleo × Flying Dragon, and US 812 were rated high for appearance. The US series of rootstocks were generally vigorous in both trials. US 812, a Sunki mandarin × Benecke trifoliate orange hybrid, has been screened and field-tested in Florida and elsewhere usually with good horticultural performance and tolerance to calcareous soils (Sagee et al., 1992; Wutscher and Bowman, 1999). Also included in this group were two

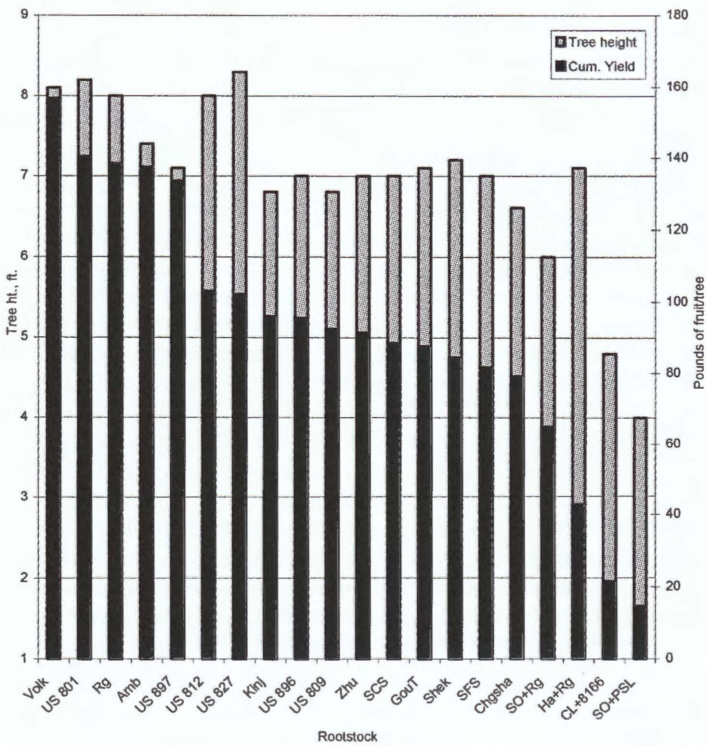

Fig. 1. Cumulative yields and heights of 3-year-old 'Tahiti' lime trees grown on various rootstocks in a Miami-Dade County, Florida, cooperative experiment. The trees were planted in August 1997 at 15 × 22 ft (132 trees/acre). See Table 1 for full rootstock names.

Table 3. UF/USDA 'Tahiti' lime rootstock trial, SHRS, Miami. Trees planted in May 2001 at 10 × 20 ft (218 trees/acre).

Rootstock	Tree survival, %	Tree ht, ft[x]	Yield, lb of fruit/tree[y]	Yield/ft tree ht	Existing tree cond. rating[z]
C. macrophylla (18)[w]	89	8.3	11.0	1.3	1
Cleopatra mandarin (14)	93	5.4	0.3	0.0	2
Changsha + 50-7 TF (18)	94	6.2	4.4	0.6	2
Cleopatra + Argentine TF (18)	100	6.2	2.8	0.4	2
Cleopatra + Flying Dragon TF (18)	100	5.6	8.8	1.6	2
Cleopatra + Swingle citrumelo (18)	100	4.7	1.6	0.3	3
Cleopatra + Volkamer lemon (18)	89	5.6	3.1	0.4	2
Gou Tou (18)	83	4.6	0.5	0.2	3
Hamlin + Rough lemon (20)	90	7.3	10.0	1.3	1
Kinkoji (*C. obovoidea*) (19)	100	5.6	0.8	0.1	2
LT 01 Cleo × FDT (18)	83	7.2	0.9	0.1	1
LT 02 Tu Nin Mon(a) (15)	73	4.7	1.1	0.2	2
LT 03 Hong Nin Mon(a) (18)	89	7.7	8.0	1.0	1
LT 04 Cleo × Swingle citrumelo (18)	61	5.1	0.0	0.0	2
LT 05 PSL × *C. ichangensis* (16)	87	6.0	5.4	0.8	2
LT 06 PSL × *C. ichangensis* (18)	100	6.5	3.1	0.4	2
LT 07 Hong Nin Mon(b) (18)	94	7.7	10.0	1.3	1
LT 08 Pimpled mandarin (18)	78	5.6	1.4	0.2	2
LT 09 Cleo × FDT (17)	94	6.5	0.6	0.1	2
LT 10 AP 65-56 (20)	100	6.3	2.1	0.2	2
LT 11 Cleo × FDT (11)	82	6.2	2.2	0.3	1
LT 12 Hong Nin Mong (c) (18)	89	7.1	6.2	0.8	2
LT 13 Tu Nin Mon(b) (12)	75	6.7	8.9	1.3	1
Milam + Kinkoji (16)	81	5.0	7.4	1.4	2
Nova + *C. ichangensis* (20)	100	4.7	0.4	0.1	3
Nova + HB pummelo (20)	95	5.9	4.9	0.7	2
PLN 1578 Cleopatra × TF (20)	75	5.5	4.1	0.8	2
PLN 1579 Cleopatra × TF (18)	100	6.7	2.3	0.3	2
PLN 1580 Cleopatra × TF (18)	94	7.2	6.7	0.9	1
Rangpur (18)	83	5.6	4.1	0.7	3
Rough lemon (18)	94	7.6	6.2	0.8	1
Smooth Flat Seville (18)	83	6.2	0.7	0.1	2
Sour orange (18)	78	6.0	5.9	0.9	2
Sour orange + 50-7 TF (18)	100	6.2	10.2	1.6	1
Sour orange + Carrizo citrange (20)	100	6.2	5.8	0.9	1
Sour orange + FDT (18)	94	5.2	8.1	1.5	2
Sour orange + PSL (20)	80	5.2	9.2	1.7	2
Sun Chu Sha mandarin (17)	88	6.7	3.4	0.5	1
US 801 Changsha × Eng. Sm. TF (20)	100	6.2	1.1	0.1	2
US 802 Pummelo × TF (20)	100	7.5	0.9	0.1	1
US 809 Changsha × Eng. Lrg. TF (18)	89	5.9	1.0	0.2	2
US 812 Sunki × Benecke TF (20)	95	7.6	1.8	0.2	1
US 827 Rangpur × TF (20)	100	6.2	0.7	0.1	2
US 852 Changsha × Eng. Lrg. TF (16)	75	4.8	0.0	0.0	3
US 896 Cleo × Rubidoux TF (20)	95	6.9	3.4	0.5	1
US 897 Cleo × FDT (21)	90	7.5	2.8	0.4	1
US 942 Sunki × FDT (18)	83	7.7	6.5	0.8	1
US 952 Pearl × FDT (18)	94	6.2	1.7	0.2	2
Valencia + Femminello lemon (19)	89	5.9	8.8	1.5	2
Volkamer lemon (18)	94	7.5	7.2	1.0	1
x639 Cleopatra × TF (18)	94	6.3	3.4	0.5	2
Zhu luan (17)	88	4.6	0.0	0.0	3
Experiment mean	—	6.2	4.1	0.6	2
LSD[v]	—	1.4	5.1	0.8	1

[z]Tree condition rating recorded 3 February 2004:
1 = Excellent—good size and leaf color—dark green
2 = Good—good size and leaf color—green/light green and/or chlorosis
3 = Fair—moderate canopy size and leaf color green/light green and/or chlorosis
4 = Poor—small canopy size and major leaf deficiency symptoms

[y]Data were collected between November and December 2003.

[x]Trees measured 6 February 2004.

[w]Indicates the number of original trees planted.

[v]Least Significant Difference.

top performers particularly SO + TF 50-7. The fourth hybrid, SO + Carrizo, was at the top end of the middle group in E.2 and produced relatively tall trees while those on the other sour orange-hybrid rootstocks were among the smallest in the trial.

Disappointing rootstocks. The trees on three somatic hybrid rootstocks had low yield in E.1 probably because they were planted a year after the main trial and, thus, did not have sufficient time to express their potential. One of these rootstocks, SO + PSL, was among the leaders in E.2. Trees on Gou Tou, Zhu Luan, Smooth Flat Seville, Kinkoji, US 852 (Bowman et al., 1999), and others also performed poorly in E.2 and had intermediate performance in E.1. Of these, the first four have attracted some commercial interest in the Indian River region as rootstocks to use in areas previously planted with sour orange (Castle et al., 1992). Little is known from field experience about their tolerance to calcareous soils, but in screening tests, they often perform similar to mandarins (Castle and Manthey, 1998; Sagee et al., 1992; Sudahono et al., 1994). Many of these rootstocks were rated poor for appearance and general condition (Table 3) indicating relatively high levels of chlorosis in the tree canopies.

Conclusions

In rootstock evaluations, overall behavior and the consistency of those behaviors are critical in the final assessment. The short length of our trials and the inclusion of most rootstocks in only one trial mean that our conclusions can only be considered as preliminary. Nevertheless, these first time results for most of the rootstocks are encouraging given our harsh test conditions. We initiated the evaluation of a variety of rootstock selections and somatic and sexual hybrids primarily with Cleopatra and Sunki mandarins, sour orange, and Palestine sweet lime. No trees on other rootstocks had numerically higher yields than those on *C. macrophylla* or Volkamer lemon, but in many instances, the trees on the previously untested rootstocks were statistically equivalent in yield and their tree sizes were smaller suggesting their possible suitability for plantings of closely spaced trees.

As to previously tested rootstocks included in our trials, our results agree with those of Campbell (1991) who rated *C. macrophylla*, sour orange, and Volkamer lemon as well adapted rootstocks for 'Tahiti' lime, rough lemon, Rangpur, and Shekwasha mandarin as questionable, and Cleopatra mandarin as not recommended.

The Florida 'Tahiti' lime industry has been seriously reduced because of Hurricane Andrew and citrus canker. If the industry were to increase again, consideration should be given to those rootstocks named in the "*Most promising rootstocks*" section above. They appear to be adapted to calcareous soils and have other favorable horticultural traits demonstrated in this and other field studies.

Literature Cited

Bowman, K. D., H. K. Wutscher, D. T. Kaplan, and J. X. Chaparro. 1999. A new hybrid citrus rootstock for Florida: US-852. Proc. Fla. State Hort. Soc. 112:54-55.

Campbell, C. W. 1972. Rootstock effects on tree size and yield of 'Tahiti' lime (*Citrus latifolia* Tanaka). Proc. Fla. State Hort. Soc. 85:332-334.

Campbell, C. W. 1974. Tahiti lime rootstocks for Southern Florida. Univ. Fla. Homestead AREC Res. Rpt. SB74-1.

Campbell, C. W. 1991. Rootstocks for 'Tahiti' lime. Proc. Fla. State Hort. Soc. 104:28-30.

Campbell, C. W. and F. B. Lincoln. 1962. A comparison of rootstocks for Tahiti lime on Rockdale soils in Florida. Proc. Fla. State Hort. Soc. 75:61-63.

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

Castle, W. S. and J. A. Manthey. 1998. Screening citrus rootstocks for iron-deficiency tolerance. Fruits 53(6):375-381.

Castle, W. S. and D. P. H. Tucker. 1998. Florida citrus rootstock selection guide. Fla. Coop. Ext. Serv. Pub. SP-248.

Castle, W. S., R. R. Pelosi, C. O. Youtsey, F. G. Gmitter, Jr., R. F. Lee, C. A. Powell, and X. Hu. 1992. Rootstocks similar to sour orange for Florida citrus trees. Proc. Fla. State Hort. Soc. 105:56-60.

Chapman, H. 1968. The mineral nutrition of citrus, p. 127-289. In Reuther, Batchelor, and Webber (eds.). The citrus industry, Vol. 2. Univ. of Calif.

Colburn, B., F. E. Gardner, and G. E. Horanic. 1963. A rootstock trial for Tahiti limes in Dade County, Florida. Proc. Fla. State Hort. Soc. 76:24-29.

Cooper, W. C. and A. Peynado. 1954. Screening citrus rootstock seedlings for tolerance to calcareous soils. J. Rio Grande Valley Hort. Soc. 8:100-105.

Forner, J. B., M. A. Forner, A. Alcaide, S. Verdejo-Lucas, and F. J. Sorribas. 2000. New hybrid citrus rootstocks released in Spain. Proc. Int'l Soc. Citriculture 1:58-61.

Grosser, J. W. 2004. What's new in citrus rootstock improvement? Citrus Industry 85(2):22-24.

Grosser, J. W. and F. G. Gmitter, Jr. 1990. Protoplast fusion and citrus improvement. Plant Breeding Rev. 8:339-374.

Grosser, J. W., J. Jiang, E. S. Louzada, J. L. Chandler, and F. G. Gmitter, Jr. 1998. Somatic hybridization, an integral component of citrus cultivar improvement: II. rootstock improvement. HortScience 33:1060-1061.

Hamze, M., J. Ryan, and N. Zaabout. 1986. Screening citrus rootstocks for lime-induced chlorosis tolerance. J. Plant Nutr. 9:459-469.

Medina-Urrutia, V., K. F. Lopez Madera, P. Serrano, G. Ananthakrishnan, and J. W. Grosser. 2004. New intergeneric somatic hybrids combining amblycarpa mandarin with six trifoliate/trifoliate hybrid selections for lime rootstock improvement. HortScience 39:355-360.

Sagee, O., D. Hasdai, M. Hamou, and A. Shaked. 1992. Screenhouse evaluation of new citrus rootstocks for tolerance to adverse soil conditions. Proc. Intl. Soc. Citriculture 1:299-303.

Stover, E., R. Pelosi, M. Burton, S. Ciliento, and M. Ritenour. 2004. Performance of 'Oroblanco' and 'Melogold' pummelo ∞ grapefruit hybrids on nine rootstocks on a calcareous, poorly drained soil. HortScience 39:28-32.

Sudahono, D. H. Byrne, and R. E. Rouse. 1994. Greenhouse screening of citrus rootstocks for tolerance to bicarbonate-induced iron chlorosis. HortScience 29:113-116.

United States Dept. Agric., Natural Resources Conserv. Serv. 1996. Soil survey of Dade County area, FL.

Wutscher, H. K. and K. D. Bowman. 1999. Performance of 'Valencia' orange on 21 rootstocks. HortScience 34:622-624.

Wutscher, H. K. and E. O. Olsen. 1970. Leaf nutrient levels, chlorosis, and growth of young grapefruit trees on 16 rootstocks grown on calcareous soil. J. Amer. Soc. Hort. Sci. 95:259-261.