

# Tree Size, Yield, Fruit Quality, and Leaf Mineral Nutrient Concentration of 'Fairchild' Mandarin on Six Rootstock

Esmaeil Fallahi<sup>1</sup> and D. Ross Rodney<sup>2</sup>

Yuma Agricultural Center, University of Arizona, Route 1 Box 40-M, Somerton, AZ 85350

Additional index words. citrus

**Abstract.** The influence of six rootstock on growth, yield, fruit quality, and leaf mineral nutrient concentration of 'Fairchild' mandarin ['Clementine' mandarin (*Citrus reticulata* Blanco) × 'Orlando' tangelo (*C. paradisi* Macf. × *C. reticulata*)] is reported for the arid climate of southwestern Arizona. Trees on macrophylla (Alemow) (*C. macrophylla* Wester) were precocious and produced high yield 4 years after planting. Six-year cumulative yields of trees on Volkamer lemon (*C. limon* Burro f.), Carrizo citrange [*C. sinensis* (L.) Osbeck × *Poncirus trifoliata* (L.) Raf.], Taiwanica (*C. taiwanica* Tan. & shin.), and rough lemon (*C. jambhiri* Lush.) were similar and higher than those of trees on macrophylla and Batangas mandarin (*C. reticulata*). 'Fairchild' mandarin tree canopies were large with Volkamer lemon and Taiwanica; intermediate with Carrizo citrange, rough lemon, and Batangas mandarin; and small with macrophylla rootstock. Fruit from trees on Carrizo citrange had the highest soluble solids concentration (SSC), while those on Volkamer lemon and rough lemon had the lowest SSC and total acids. 'Fairchild' trees on macrophylla had higher levels of leaf N, Mn, and Fe but lower Ca, while trees on Batangas mandarin and Carrizo citrange had higher leaf K than those on the other rootstock. Trees on Volkamer lemon had higher leaf Zn than those on Carrizo citrange, Taiwanica, rough lemon, and Batangas mandarin rootstock. Considering yield, growth, fruit quality, and/or leaf nutrient concentration, Volkamer lemon, Carrizo citrange, Taiwanica, and rough lemon are suitable for 'Fairchild' mandarin in the arid regions of southwestern Arizona. Trees on macrophylla could be advantageous for short-term planting, but would not be satisfactory for long-term planting because of gradual decline in growth and yields. Batangas mandarin is not recommended for 'Fairchild' mandarin due to poor production.

Mandarin and mandarin hybrid cultivars are treated as specialty fruit and are only a small part of the citrus acreage in the United States. Nevertheless, the demand for mandarin fruit, particularly 'Fairchild' grown in Arizona, is increasing (Arizona Agricultural Statistics Service, 1988).

Mandarin fruit are relatively small with a tender peel and do not store or ship well. Trees tend to over-bear, which contributes to biennial bearing. Rootstock can favorably influence tree yield, bearing habit, fruit quality, and leaf mineral nutrient concentration, and these effects have been reported for commercially important citrus cultivars (Castle, 1980, 1987; Castle and Phillips, 1977; Cooper and Lime, 1950; Fallahi et al., 1989; Gardner and Horanic, 1966; Hilgeman et al., 1966; Hutchison and Hearn, 1977; Krezdorn and Phillips, 1970; Rouse and Maxwell, 1979; Wutscher, 1977, 1979; Wutscher and Dube, 1977; Wutscher and Shun, 1972, 1973, 1975).

The common commercial rootstock for mandarin cultivars are sour orange (*Citrus aurantium* L.) and Cleopatra mandarin. They have generally been satisfactory and, thus, there are few rootstock studies involving mandarin scions (Castle and Krezdorn, 1975; Fallahi et al., 1991; Krezdorn, 1977; Iyengar et al., 1982; Sharples and Hilgeman, 1972; Smith, 1975; Wutscher and Shun, 1976); also, there is only limited information concerning rootstock effects on 'Fairchild' mandarin performance (Wutscher et al., 1976). The arid climate and high pH of soils of southwestern Arizona limit the selection of rootstock for mandarins. In selecting a rootstock, adaptability to the prevail-

ing soil conditions and horticultural characteristics of the scion cultivar, such as tree growth, yield, fruit quality, and leaf mineral concentration are considered. Therefore, the objective of this study was to assess tree growth, yield, fruit quality, and leaf mineral nutrient concentration of 'Fairchild' mandarin grown on six rootstock in southwestern Arizona. When the experiment reported herein was initiated, there was no information available, to our knowledge, on the performance of any citrus cultivar on Volkamer lemon, Taiwanica, and Batangas mandarin under desert conditions. Volkamer lemon was generally known as a vigorous rootstock and Taiwanica as a rootstock resistant to tristeza, exocortis, and *Phytophthora* spp. Macrophylla was a popular rootstock and believed to be suitable for use in high-density plantings. Rough lemon was the most common rootstock in the Arizona citrus industry. Therefore, these six rootstock, which encompass lemon types (Volkamer lemon, macrophylla, and rough lemon), a mandarin (Batangas), a citrange (Carrizo), and a sour orange type (Taiwanica) were chosen.

## Materials and Methods

'Fairchild' mandarin trees budded on Volkamer lemon, Carrizo citrange, Taiwanica, rough lemon, Batangas mandarin, and macrophylla were grown in a greenhouse and planted in the field in Mar. 1970. The budwood sources and budded trees were indexed and free of viruses and viroids at the time of planting. Tree spacing was 7.0 × 7.0 m. The soil, Superstition sand (Typic Calciorthid, 80% sand), was deep and well-drained with silt present in the top 20 cm. Soil pH was ≈ 8.0 because of a high Na and Ca content. 'Orlando' tangelo was planted around the experiment block as the pollinizer.

Equal amounts of ammonium nitrate were applied in October, December, February, and April every year at an annual rate of

Received for publication 10 June 1991. Accepted for publication 10 Sept. 1991. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

<sup>1</sup>Tree Fruit Physiologist, to whom reprint requests should be addressed. Present address: Univ. of Idaho, SW Idaho Research and Extension Center, 29603 U of I Lane, Parma, ID 83660.

<sup>2</sup>Emeritus Professor of Horticulture.

Abbreviations: SSC, soluble solids concentration; TA, total acids; TCSA, trunk cross-sectional area.

0.5 to 1.5 kg N/tree as tree age increased. Trees were flood-irrigated biweekly between April and September and monthly between October and March and received an annual foliar micronutrient application until 1985. Pesticide was applied twice annually for thrips control, and the orchard was disked when needed for weed control. Tree spacing and cultural practices in the experiment block were similar to those in commercial groves.

The experiment design was a randomized complete block with four replications of two-tree plots. Fruit from each tree was harvested, and yield was recorded in 1974 (4 years after planting) for precocity evaluation and then annually from 1983 through 1988. Trunk diameter was measured annually  $\approx 13$  cm above the bud union, and trunk cross-sectional area (TCSA) was calculated in 1974 and 1988 (4 and 18 years after planting, respectively). Tree volume was calculated in 1988 using measurements of tree height and width:  $V = 0.524 \times \text{height} \times \text{width}^2$  (Turrell, 1946).

Fifteen fruit per tree (30 fruit/plot) were collected randomly at commercial harvest time in early November of each year. Fruit quality was evaluated annually from 1987 through 1989. Fruit were weighed, cut in half, and rind thickness was measured with a caliper. Juice was extracted by an electric juicer and strained. Juice volume per fruit was measured. A 500-ml aliquot of the combined juice from all fruit of each sample was weighed and percent juice content (by weight) of each fruit was calculated. Total SSC was measured with a temperature-compensated refractometer (Atago NI; Cole-Parmer Co., Chicago). Total acids (TA) concentration was determined by titration with 0.39 N NaOH to a pH of 8.0 using an automated Fisher Titrator (Model 41; Fisher Scientific Co., Pittsburgh). Thirty leaves per tree were sampled randomly in mid-Aug. 1987 and 1988 from the middle of the 6-month-old, nonbearing shoots. Leaves were washed in a mild Liqui-nox detergent and rinsed with distilled water and dried in a forced-air oven at 70C to a constant weight. Leaves were analyzed for N by a Kjeldahl method (Schuman et al., 1973) and for K, Ca, Mg, Fe, Zn, Mn, and Cu by dry ashing and atomic absorption spectrophotometry (Video 11; Allied, Waltham, Mass.). Analyses of variance for yield in each individual year and for cumulative yield over 6 years, TCSA for 1974 and 1988, tree canopy volume for 1988, and analyses of variance for 3-year means for each quality factor and 2-year means for leaf minerals are reported. Means were separated with Duncan's multiple range test when a significant F value existed.

## Results and Discussion

**Tree growth and yield.** 'Fairchild' trees on macrophylla grew faster initially, had a significantly larger TCSA, and produced a higher yield in 1974 (4 years after planting) than trees on Carrizo citrange, Taiwanica, or Batangas mandarin (Table 1). In other studies, 'Redblush' grapefruit and 'Orlando' tangelo trees on macrophylla were also precocious (Fallahi et al., 1989, 1991). Yields of trees on macrophylla, however, were lower than those on Volkamer lemon, Carrizo citrange, Taiwanica, and rough lemon starting in 1984 (Table 1). Trees on macrophylla, in spite of having a large TCSA in 1974, had a significantly smaller TCSA and canopy volume in 1988, as compared to those on the other rootstock (Table 1). The decline in growth and productivity of trees on macrophylla was due to sieve tube necrosis, as judged by the visual symptoms (Fallahi et al., 1990). A similar growth decline was observed in 'Orlando' tangelo trees on macrophylla rootstock (Fallahi et al., 1991).

'Fairchild' mandarin trees on Carrizo citrange and rough lemon had similar cumulative yields and canopy volumes (Table 1),

as did 'Orlando' tangelo trees grown at the same experiment site (Fallahi et al., 1991); however, in a different study, the canopy volumes of 'Otani Iyo' mandarin trees on rough lemon were significantly larger than those of trees on Carrizo citrange, while the latter trees had higher yields (Kawase et al., 1987). Trees on Volkamer lemon and Taiwanica had significantly larger canopies than those on Carrizo citrange, although the cumulative yields of trees on these three rootstock were similar (Table 1). Trees on Volkamer lemon and Taiwanica occupied most of their allotted space by 1988, but the trees on Carrizo were smaller and, therefore, could probably be planted at a spacing closer than 7.0 x 7.0 m. TCSA and canopy volumes of trees on Batangas mandarin were similar to those of trees on Carrizo citrange and rough lemon, but they were always less productive (Table 1), suggesting that Batangas mandarin would be a less desirable, rootstock for 'Fairchild' mandarin. In previous reports, Cleopatra mandarin was also among the low-yielding rootstock for 'Orlando' tangelo (Krezdorn, 1977) and 'Bower' mandarin (Wutscher et al., 1976).

Severity of biennial bearing, calculated as the percentage of yield differences between two consecutive years, was greater in the trees on macrophylla than in trees on the other rootstock between 1984 and 1986 and between 1987 and 1988 (data not shown). Trees on Carrizo and Taiwanica showed the least tendency to biennial bearing during these years. The 'Fairchild'/'Orlando' planting arrangement did not affect 'Fairchild' yield in any discernible pattern.

**Fruit characteristics.** Weights and total juice contents of fruit from trees on Taiwanica were higher than those of fruit from trees on other rootstock, except Volkamer lemon and Batangas mandarin (Table 2). Since both yield and fruit weight of trees on Volkamer lemon and Taiwanica were high, these rootstock are excellent choices for 'Fairchild' under the climatic conditions of this experiment. The percentage of juice in the fruit from trees on Batangas mandarin was significantly lower than that from other rootstock, and no significant differences were found among the percentage of juice contents in the fruit from trees on other rootstock (Table 2).

'Fairchild' fruit rind was  $\approx 2$  to 4 mm thick and did not vary with rootstock (data not shown). 'Orlando' tangelo fruit from trees on macrophylla and rough lemon had significantly thicker rind than fruit from trees on Carrizo citrange (Fallahi et al., 1991).

'Fairchild' fruit from trees on Carrizo citrange had a significantly higher SSC than those from trees on rough lemon and Volkamer lemon, which also produced a lower TA than Carrizo (Table 2). Previous reports indicate that 'Orlando' tangelo fruit from trees on Carrizo citrange also had a higher SSC and TA than those on rough lemon or Volkamer lemon (Fallahi et al., 1991; Hutchison and Hearn, 1977; Krezdorn, 1977; Krezdorn and Phillips, 1970). The SSC : TA ratios in the fruit from trees on Carrizo citrange, rough lemon, and Volkamer lemon were similar but significantly higher than those on Batangas mandarin (Table 2); thus, fruit would reach an earlier maturity on these rootstock. This result differs from studies by Krezdorn and Phillips (1970) and Krezdorn (1977), who reported a higher SSC : TA ratio in 'Orlando' tangelo fruit from trees on rough lemon than on Carrizo citrange. 'Fairchild' fruit from trees on Volkamer lemon had a significantly higher SSC : TA ratio than those from trees on Taiwanica and macrophylla, which is in agreement with the results from an experiment with 'Orlando' tangelo conducted at the same site (Fallahi et al., 1991).

**Leaf mineral nutrient concentration.** Leaves of trees on all rootstock, except those on Volkamer lemon and macrophylla,

Table 1. Yield and growth of 'Fairchild' mandarin trees on six rootstocks.<sup>1</sup>

Rootstock <sup>y</sup>	TCSA (cm <sup>2</sup> )		1988 Canopy vol (m <sup>3</sup> )	Yield/tree (kg)							Cumulative yield, 1983-88 (kg/tree)
	1974	1988		Year							
	1974	1988	1974	1983	1984	1985	1986	1987	1988		
VOL	35 ab	309 a	64 a	31 ab*	67 a	81 a	116 a	111 a	77 b	141 a	593 a
CAR	20 c	296 a	42 b	22 b	42 b	87 a	107 ab	94 ab	116 a	104 b	550 a
TAI	25 bc	347 a	64 a	16 b	41 b	84 a	94 ab	102 a	91 b	81 b	493 a
RLE	36 ab	296 a	49 ab	31 ab	64 a	90 a	93 ab	86 ab	51 c	90 b	474 a
BAT	16 c	320 a	45 b	7 b	26 b	65 ab	80 bc	67 b	45 cd	50 c	333 b
MAC	45 a	152 b	14 c	52 a	37 b	35 b	62 c	26 c	24 d	43 c	227 b

<sup>1</sup>Each value is the mean of four two-tree replications.

<sup>y</sup>VOL = Volkamer lemon; CAR = Carrizo citrange; TAI = Taiwanica; RLE = rough lemon; BAT = Batangas mandarin; MAC = macrophylla.

<sup>z</sup>Mean separation within columns by Duncan's multiple range test,  $P = 0.05$ .

Table 2. Fruit quality characteristics of 'Fairchild' mandarin on six rootstocks.<sup>1</sup>

Rootstock <sup>y</sup>	Fruit wt (g)	Juice content (ml/fruit)	Percent juice (w/w)	SSC (%)	TA (%)	SSC : TA ratio
VOL	109 ab*	53.8 ab	51.3 a	11.1 d	0.97 d	11.5 a
CAR	107 b	51.7 bc	50.6 a	12.1 a	1.13 b	10.8 ab
TAI	116 a	56.5 a	50.7 a	11.4 c	1.11 bc	10.4 bc
RLE	103 b	49.5 c	50.3 a	11.2 d	1.02 d	11.0 ab
BAT	110 ab	51.6 bc	48.9 b	11.8 b	1.24 a	9.6 c
MAC	105 b	51.3 bc	50.7 a	11.4 c	1.11 bc	10.4 bc

<sup>1</sup>Each value is the mean of 3 years (1987-89) with four two-tree replications.

<sup>y</sup>VOL = Volkamer lemon; CAR = Carrizo citrange; TAI = Taiwanica; RLE = rough lemon; BAT = Batangas mandarin; MAC = macrophylla.

<sup>z</sup>Mean separation within columns by Duncan's multiple range test,  $P = 0.05$ .

were low in N compared to citrus leaf standards (Smith, 1966a), although not all differences between these and the other entries were significant. The application of 1.5 kg N/tree was apparently not sufficient. Leaves of trees on macrophylla showed higher N concentrations than those on Carrizo citrange and Taiwanica and higher Mn but relatively lower Ca than those on other rootstock (Table 3). A significant negative correlation coefficient ( $r = -0.60$ ) was found between leaf N and Ca. Antagonism between leaf N and Ca on calcareous soil is common (Smith, 1966a). Sieve tube necrosis observed in the trees on macrophylla may have contributed to high leaf N, Mn, and Fe concentrations. Leaves of trees on Batangas mandarin had a sufficient level of K compared to the citrus leaf standard values (Smith, 1966a), and this level was significantly higher than those of trees on other rootstock, except Carrizo citrange (Table 3). High leaf K in the trees on Batangas can be attributed to a

lower yield in these trees (Table 1). The K content in leaves of low-yielding trees is higher than in high-yielding ones because more K is deposited in the fruit of the heavy-cropping trees (Smith, 1966b). A negative correlation between yield and leaf K was previously reported (Fallahi et al., 1985). Leaves from trees on Carrizo citrange had significantly higher K but lower Mn than those on rough lemon rootstock, which agrees with the results in other citrus cultivars (Smith, 1975). No correlation was found between leaf Ca-Mg or leaf Ca-K. Leaves of 'Fairchild' trees on Taiwanica and Carrizo citrange had lower levels of Mn and Fe than those on most other rootstock. Low Mn content in the leaves of 'Fairchild' trees on Carrizo is also in agreement with a similar experiment conducted on 'Coorg' and 'Kinnow' mandarins in India (Iyengar et al., 1982). Carrizo and Taiwanica are likely to be adaptable to acid soils with high levels of available Mn. However, trees on these two rootstock

Table 3. Effects of rootstock on 'Fairchild' mandarin leaf mineral nutrient concentration (dry-weight basis).<sup>1</sup>

Rootstock <sup>y</sup>	N (%)	K (%)	Ca (%)	Mg (%)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)
VOL	2.52 ab*	0.90 bc	4.47 cd	0.54 a	9.3 b	31.0 a	16.9 b	53.9 ab
CAR	2.41 b	1.09 ab	5.10 b	0.52 ab	13.9 a	21.8 b	9.4 d	44.7 bc
TAI	2.37 b	0.97 bc	5.65 a	0.41 bc	10.8 ab	22.0 b	10.5 d	39.5 c
RLE	2.44 ab	0.83 c	4.90 bc	0.52 ab	12.6 ab	21.5 b	15.8 b	51.1 ab
BAT	2.44 ab	1.20 a	4.91 bc	0.38 c	10.3 b	22.1 b	13.9 c	47.6 bc
MAC	2.72 a	1.00 bc	4.15 d	0.44 abc	10.4 b	25.6 ab	19.2 a	57.6 a

<sup>1</sup>Each value is the mean of four, two-tree replications and two years of data (1987 and 1988).

<sup>y</sup>VOL = Volkamer lemon; CAR = Carrizo citrange; TAI = Taiwanica; RLE = rough lemon; BAT = Batangas mandarin; MAC = macrophylla.

<sup>z</sup>Mean separation within columns by Duncan's multiple range test,  $P = 0.05$ .

tend to be susceptible to Fe and Mn deficiencies (Table 3) under high pH conditions, although there were no visible symptoms of Fe and Mn chlorosis in our experiment. Low leaf Mn in the trees on Carrizo concurs with a previous report (Smith, 1975). Trees on Volkamer lemon had a sufficient level of leaf Zn (Platt, 1981; Smith, 1966a), which was significantly higher than those on Carrizo citrange, rough lemon, Taiwanica, and Batangas mandarin (Table 3).

**Overall performance.** Considering growth, yield, fruit quality, and mineral nutrient uptake, Carrizo citrange, Volkamer lemon, Taiwanica, and rough lemon are suitable rootstock for 'Fairchild' mandarin under the hot, dry climate of southwestern Arizona. Cumulative yields of trees on all of these rootstock were similar to those of trees on rough lemon but higher than cumulative yields of trees on macrophylla. Trees on Carrizo citrange produced high yields and high-quality fruit even though Carrizo had the lowest leaf Mn (Table 3) and citranges are purported to suffer Mn deficiency on calcareous soils such as the one in our experiment (Smith, 1975; Wutscher and Schull, 1972, 1976). The reason for the good performance of 'Fairchild' trees on Carrizo under conditions of this experiment is not clear. Trees on Volkamer lemon and rough lemon produced high yields of fruit with high SSC : TA ratios despite the low SSC. 'Fairchild' fruit from trees on these two rootstock would reach optimum maturity earlier, thus lengthening the harvest season when they are planted together with trees on other rootstock on which fruit reach a similar ratio later in the season. Volkamer lemon is also desirable for its ability to take up and translocate Zn and Fe to the leaves of 'Fairchild' trees, because Zn and Fe deficiencies are common and difficult to correct under the high-pH soil conditions of southwestern Arizona. Taiwanica is also an acceptable rootstock for 'Fairchild' at 7.0 x 7.0 m spacing. Trees on Taiwanica were vigorous and had a cumulative yield similar to trees on rough lemon, while fruit from trees on Taiwanica were heavier and juicier than those on rough lemon and macrophylla. Planting 'Fairchild' mandarin trees on macrophylla may sometimes be advisable for heavy cropping in the first bearing years. Macrophylla, however, is not recommended for long-term planting because of unacceptable tree decline and, thus, yield. Planting 'Fairchild' mandarin on Batangas mandarin is not advisable. Similar to 'Orlando' tangelo on Cleopatra mandarin (Castle and Krezdorn, 1975; Krezdorn, 1977), 'Fairchild' trees on Batangas mandarin had large canopies but low yield.

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