African Journal of Agricultural Research Vol. 5(10), pp. 1077-1081, 18 May, 2010
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR09.229
ISSN 1991-637X © 2010 Academic Journals

Full Length Research Paper

Fruit yield and quality of Santa Teresa lemon on seven rootstocks in Adana (Turkey)

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Accepted 22 April, 2010

The effects of various rootstocks on yield, yield efficiency, vegetative growth and fruit quality of Santa Teresa lemon variety were evaluated under Adana ecological conditions during 2004 and 2005. Canopy volume was the lowest for trees on *Carrizo citrange*, followed by *Troyer citrange* and *Citrus ampullacea*. Total cumulative yield over two years of production was highest on *C. obovoidea*, followed by that on *Citrus sulcata*. On the other hand, the trees on *C. citrange* were the most efficient in yield per cubic meter of canopy volume (CV) and trunk cross-sectional area (TCSA) due to its small TCSA and CV. The largest fruit size was obtained from the trees on *C. sulcata*, Taiwanica, *C. ampullacea*, followed by sour orange and *Citrus obovoidea*. The highest total acid content of fruits was found with sour orange and *T. citrange*, followed by *C. obovoidea*. When all the results are considered, it can be concluded that *C. obovoidea* was more promising rootstock for Santa Teresa lemon in Çukurova Region.

Key words: Citrus, rootstocks, Santa Teresa, lemon, fruit yield, fruit quality.

INTRODUCTİON

Citrus growing areas of Turkey are situated in the northern hemisphere of the citrus belt and Turkey has very suitable ecological conditions and potential for citrus production. Important citrus production areas are located along the Mediterranean coast and coastal parts of the Aegean and the Eastern Black Sea Regions. In these regions, major citrus species and cultivars are economically grown with very high fruit quality.

Turkey's total citrus fruit production is 3,220,450 tons. This amount consists of 1,535,800 tons of oranges (*Citrus sinensis* (L.) Osb.), 791,255 tons of mandarins (*C. reticulata* Blanco), 710,400 tons of lemons (*Citrus limon* Burm. F.) and 180,000 tons of grapefruit (*Citrus paradisi* Macf.) (FAO, 2009).

Growing area of lemon and limes in the world is approximately 1,013,348 ha; meanwhile Turkey has approximately 25,161 ha lemon growing areas which represent 23% of the Turkish citrus growing area (FAO, 2009). The major lemon producing areas are located along Turkey's east Mediterranean plains. This region almost covers 98% of lemons and 89% of total citrus producing in Turkey. Eastern Mediterranean covers mainly coastal parts of Çukurova Region and in these regions, especially Mersin and Adana are lemon producing provinces. Kütdiken lemon is major lemon cultivar in Turkey and grown mainly in the Mersin-Adana region with high yield and quality. However, this cultivar is susceptible to "mal secco" disease (caused by *Phoma tracheiphila* (Petri) Kanc et. Ghik). Mal Secco disease (*P. tracheiphila*) causes severe losses and threatens lemon production in Mediterranean countries. Santa Teresa is originally a Femminello selection and similar to "Feminello Comune". Almost all femminello selections are very susceptible to the mal secco disease but Santa Teresa lemon is resistant to mal secco (Morton, 1987; Saunt, 2000). The fruit has a roundish shape, moderately thick rind. It is productive and the juice has a high acid content (Morton, 1987). Santa Teresa lemon showed good fruit quality and maturity in Adana ecological conditions.

Rootstocks play an important role in the rapid development of citrus in the world. The necessity of using rootstocks for citrus fruits is to have a profitable production against some limiting factors such as climate, bad soil conditions, diseases and etc. Besides these

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factors, use of the citrus rootstocks provides a large amount of choices to the growers to increase fruit quality and yield, obtain early fruiting, uniform cropping, avoidance of juvenility, control of the tree size and have the opportunity for high density planting etc. These factors give a lot of economic important advantages to the growers and as a result, the citrus fruits are the most produced fresh fruits in the world since several decades (Tuzcu et al., 2005). Choosing a rootstock is an important decision and local climatic and soil conditions are important factors in rootstock selection. Although any citrus variety can be used as a rootstock, some of them are better suited to specific conditions than the others (Davies and Albrigo, 1994; Lawrence and Bridges, 1974).

Sour orange, which is still the main rootstock used in citrus growing in Mediterranean Region and in the world, is used as a rootstock for all citrus cultivars in Turkey (about 95%), especially in the entire Mediterranean and southern part of the Aegean Regions. Although the sour orange has many excellent horticultural advantages, it has a very important disadvantage for its susceptibility to *Citrus tristeza* virus (CTV). This problem has severely reduced the use of this rootstock in many places especially Western Mediterranean. Castle and Gmitter (1999) reported that sour orange no longer has a secure place in today's rootstock portfolios because of its susceptibility to CTV. Castle (1987) indicated that sour orange is an excellent rootstock for areas free of CTV. Ollitrault (2002) reported that the arrival of Tristeza radically called into question of using sour orange in the Mediterranean area, whereas it had been almost the only rootstock in the region.

Tuzcu et al. (1984) indicated that *Citrus sulcata* and *Citrus ampullacea* have functional possibilities as rootstocks because they both showed very resistant reactions to *Phytophthora citrophthora* and grapefruit is known as the best rootstock for lemon. In addition *Citus obovoidea* was found to be resistant for *P. citrophthora* (Tuzcu et al., 1984).

C. obovoidea has been reported as resistant as Gou Tou to *P. citrophthora*, CTV and calcareous soils (Castle, 2002).

The objective of this study was to determine yield and fruit quality of Santa Teresa lemon cultivar which was grafted on several rootstocks.

MATERIALS AND METHODS

Santa Teresa lemon variety was grafted on the rootstocks sour orange (*C. aurantium* L.), Taiwanica (*C. taiwanica* Tan. and Shim.), Carrizo and Troyer citranges (*Citrus sinensis* (L.) Osb. x *Poncirus trifoliata* (L.) Raf.), *C. sulcata*, *C. ampullacea*, *C. obovoidea*.

The grafted trees were planted in 1986 with 8 x 8 m spacing at the Research Station of Çukurova University, Agricultural Faculty Citrus Experiment Station, Adana (Latitude, 35° 23′ N; Longitude, 36° 50′ E, altitude 27 m).

In the experimental area, the soil was a clay-loam (57% clay, 21% silt, 22% sand and contain 12% $CaCO_3$) and the soil pH was in the range of 7.29 to 7.37 at a depth of 0 - 90 cm. The salt content of the soil was 0.22 EC (mmhos/cm). The area has a mean maximum and minimum temperature ranging from 26 and 14.5°C and an average annual rainfall of 465 mm. The trees were irrigated weekly from May to October using drip irrigation. Nitrogen (N) was applied at a rate of 1.5 kg N / tree (2/3 in mid-February and 1/3 in mid-May) and phosphorus (P) was applied at a rate of 1 kg P/tree (December) and potassium (K) at a rate of 1 kg K/tree (January). Pest populations were controlled with recommended pest management program.

Each year, fruit yield of each tree was determined during the harvesting period. Fruits were harvested and weighed at optimum harvest time (at the end of November or at the beginning of December). Each year, random samples of 25 fruits from each tree were collected for fruit quality analysis. The fruit samples were weighed, and fruit diameter at the equator was measured with a digital caliper and also rind thickness was measured after cutting in half with a digital caliper (Mitutoyo CD-15CPX). The fruits were weighed and juiced using a standard juicer; then juice was weighed, and expressed as a percentage of the total fruit weight. Total soluble solids content (TSS) was determined with a portable refractometer (FG-103/113) using a few drops of juice. The total acidity (TA) of the juice was determined by titrating 5 ml of the juice sample with 0.1 N sodium hydroxide (NaOH) using phenolphthalein as the indicator. In January 2005, tree height and canopy diameter in the two tree directions (to obtain the average diameter) were measured after harvesting. Canopy volume (CV) was calculated according to the equation reported by Turrell (1946) as follows: CV = 0.5248 x canopy height x canopy diameter^2. In addition, stock and scion trunk circumferences were measured 10 cm below and above the bud union and their ratio was determined. The scion trunk circumferences were converted into trunk cross-sectional area (TCSA). Yield efficiency was estimated as the ratio of cumulative yield to canopy volume (kg/m^3) and trunk cross sectional unit area (kg/cm^2).

Completely randomized experimental design was used with six replicates for each combination. Data were subjected to ANOVA and analyzed using SPSS statistical procedures (SPSS v17, 2008). Mean comparisons were performed using Duncan's Multiple Range test to examine if differences between rootstocks were significant at $P<0.05$.

RESULTS AND DİSCUSSİON

Vegetative growth

Tree size: Rootstock significantly affected canopy volume and trunk cross-sectional area (TCSA) but not canopy height and diameter (Table 1). The trees budded onto *C. obovoidea* had the highest volume, followed by sour orange. The smallest trees were obtained from *C. citrange*. The trunk sectional area of trees on *C. obovoidea* and *C. sulcata* was significantly higher than those on the remaining rootstocks, while those on *C. citrange* showed the lowest value. The results obtained regarding canopy volume and TCSA are in agreement with those of Georgiou (2009) on Lapithkiotiki lemon, who reported that the highest volume was on sour orange and the lowest on *C. citrange*. In addition, Perez-Perez et al. (2005) mentioned that TCSA of three lemon varieties on sour orange was larger than that of trees on *C. macrophylla*.

Scion: *stock ratio:* Rootstock also has a significant effect on the scion to stock ratio (Table 1). The lemon trees

Table 1. Effects of rootstocks on the vegetative growth of the "Santa Teresa" lemon.

Rootstocks	Canopy height (m)	Canopy diameter (m)	Canopy volume (CV) (m^3)	Trunk cross-sectional area (TCSA) (cm^2)	Scion /stock ratio
Sour orange	5.06	6.28	108.38 ab [y]	646.01 ab	1.02 ab
Carrizo citrange	4.73	5.67	83.99 b	533.77 b	0.83 d
Troyer citrange	5.13	5.80	91.20 ab	641.75 ab	0.87 cd
Taiwanica	5.06	6.25	104.33 ab	649.46 ab	0.90 bcd
C. sulcata	5.22	6.24	108.01 ab	803.84 a	0.96 abc
C. ampulacea	4.88	5.79	90.00 ab	696.46 ab	0.99 abc
C. obovoidea	5.18	6.26	108.68 a	838.61 a	1.06 a
Significance [z]	NS	NS	*	**	**

[y] Values within the columns followed by unlike letters are significantly different by Duncan's multiple range test. [z] N.S.: non significant; * : significant at 0.05 level; ** : significant at 0.01 level.

Table 2. Effects of rootstocks on yield and yield efficinecy (cumulative yield/TCSA and CV) of the "Santa Teresa" lemon trees.

Rootstock	Yield (kg / tree)		Cumulative	Yield efficiency	
	2004	2005	(kg/tree)	kg/cm^2	kg/m^3
Sour orange	255.36 b [y]	125.00	381.39 cd	0.589 ab	3.510 de
Carrizo citrange	275.00 ab	108.50	382.76 cd	0.719 a	4.566 a
Troyer citrange	270.40 ab	127.50	397.93 bc	0.620 ab	4.363 ab
Taiwanica	237.71 b	125.00	362.79 d	0.558 ab	3.477 e
C. sulcata	264.00 ab	146.00	410.83 b	0.510 b	3.796 cd
C. ampullacea	252.00 b	113.75	365.48 d	0.525 ab	4.064 b
C. obovoidea	315.00 a	138.75	453.41 a	0.541 ab	4.175 b
Significance [z]	*	NS	*	*	*

[y] Values within the columns followed by unlike letters are significantly different by Duncan's multiple range test. [z] N.S.: non significant; * : significant at 0.05 level.

budded on *C. obovoidea* and sour orange having significantly higher ratios than those on other rootstocks. The lowest ratio was found with *C. citrange*, followed by *T. citrange*. *C. obovoidea* and sour orange had a growth rate similar to that of scion, whereas Carrizo and *T. citrange* tended to grow more rapidly than the scion. Similar results were reported by several researchers (Georgiou and Gregoriou, 1999; Perez-Perez et al. 2005; Bassal, 2009; Georgiou, 2009).

Yield

Rootstocks significantly affected cumulative yield. The highest cumulative yield of Santa Teresa lemon based on two years period was obtained from the trees on *C. obovoidea*, followed by *C. sulcata*. Trees on Taiwanica and *C. ampullacea* had the lowest cumulative yield (Table 2). Tuzcu et al. (1992) reported that intermediate yield was obtained from Kütdiken lemon on Taiwanica. Similar results were obtained by Al-Jaleel et al. (2005) who mentioned that trees of Allen Eureka lemon on Taiwanica had intermediate cumulative yield.

There were statistically significant differences on fruit yield per tree between rootstocks except in 2005 (Table 2). In 2004, trees on *C. obovoidea* produced a significant higher yield than the trees on all other rootstocks. The lowest yield was obtained from trees on Taiwanica, followed by *C. ampullacea* and sour orange. The trees on Carrizo, *T. citrange* and *C. sulcata* produced similar yield and did not show significant difference from each other. The results obtained regarding sour orange productivity are in agreement with Levy et al. (1980) who reported that trees on sour orange produced less fruit than the most of the rootstocks. In addition, Al-Jaleel et al. (2005) indicated that trees on sour orange were the least productive.

Yield efficiency

Effects of rootstocks on yield efficiency (kg/cm^2 and kg/m^3) were found to be statistically significant (Table 2). Yield efficiency (kg/cm^2) was highest on *C. citrange* and the lowest for *C. sulcata*. Trees on the other rootstocks produced similar yield efficiency (kg/cm^2) and did not

Table 3. Effects of rootstocks on the fruit weight, fruit diameter and rind tickness of the "Santa Teresa" lemon.

Rootstocks	2004 Fruit weight (g)	2005 Fruit weight (g)	2004 Fruit diameter(mm)	2005 Fruit diameter(mm)	2004 Rind thickness (mm)	2005 Rind thickness (mm)
Sour orange	116.11	101.47 abc [y]	58.83	55.72	5.02 ab	3.84
Carrizo citrange	119.15	92.66 c	58.59	53.95	4.46 b	3.09
Troyer citrange	121.67	96.52 bc	57.45	54.20	4.48 b	3.21
Taiwanica	132.18	109.54 ab	58.58	56.84	5.15 a	3.67
C. sulcata	124.50	110.22 a	58.36	57.17	4.50 b	3.41
C. ampulacea	124.80	106.59 ab	57.69	55.84	4.59 b	3.40
C. obovoidea	122.00	99.12 abc	57.05	54.23	4.54 b	3.24
Significance [z]	NS	*	NS	NS	*	NS

[y] Values within the columns followed by unlike letters are significantly different by Duncan's multiple range test. [z] N.S.: non significant; * : significant at 0.05 level.

Table 4. Effects of rootstocks on the juice content, total acids (TA), total soluble solids (TSS), TSS/TA ratio of the "Santa Teresa" lemon.

Rootstocks	2004 Juice content (%)	2005 Juice content (%)	2004 Total acids (%)	2005 Total acids (%)	2004 Total soluble solids (%)	2005 Total soluble solids (%)	2004 TSS / TA	2005 TSS / TA
Sour orange	25.75	45.14	7.58 a [y]	8.17	8.13 bc	9.05 ab	1.07 c	1.11
Carrizo citrange	28.49	47.00	7.28 bc	7.78	8.70 b	9.53 a	1.18 ab	1.21
Troyer citrange	30.46	47.83	7.56 a	7.81	8.57 b	9.45 ab	1.13 bc	1.21
Taiwanica	31.12	45.25	7.25 c	7.63	7.84 c	8.65 b	1.07 c	1.12
C.sulcata	29.32	49.80	7.31 bc	8.22	8.37 bc	9.06 ab	1.15 b	1.10
C.ampulacea	30.64	45.50	7.18 c	7.87	8.56 b	8.82 ab	1.19 ab	1.12
C.obovoidea	31.04	46.20	7.48 ab	8.08	9.36 a	9.10 ab	1.25 a	1.13
Significance [z]	NS	NS	*	NS	*	*	*	NS

[y] Values within the columns followed by unlike letters are significantly different by Duncan's multiple range test. [z] N.S.: non significant; * : significant at 0.05 level.

show differences from each other. On the contrary, Georgiou (2009), on Lapithkiotiki reported that the lowest yield efficiency (kg/cm^2) was on *C. citrange*.

The highest yield efficiency (kg/m^3) was shown by trees on the *C. citrange*, followed by Troyer citrange, *C. obovoidea* and *C. ampullacea*. The lowest yield efficient trees were found on Taiwanica, followed by sour orange (Table 2). These results are in agreement with those of the previous works, where the trees on sour orange were the least productive (Levy et al. 1980; Al-Jaleel et al., 2005; Perez-Perez et al., 2005).

Fruit quality

In 2005, rootstocks had different effects on fruit weight, but not in 2004 (Table 3). Fruits from trees on *C. sulcata* were significantly heavier than those from the other root-stocks, followed by Taiwanica and *C. ampullacea*. The lightest fruits were obtained from the trees on *C. citrange*, followed by Troyer citrange. Growing in the same region, the biggest fruits were found in Kütdiken lemon trees grafted on Yuzu, Volkameriana and Taiwanica, whereas the smallest fruits were obtained from the trees on Benecke trifoliate orange and *T. citrange* (Tuzcu et al. 1992). Even Jimenez et al. (1987) indicated that citranges had the smallest fruits.

The effects of rootstocks on fruit diameter and fruit juice content were not statistically significant and all of the rootstocks gave similar values (Tables 3 and 4). Foguet et al. (1977, 1987) also reported that juice content of Eureka and Genova EEAT lemon varieties was not influenced by the rootstocks. In the contrary, Georgiou (2009) indicated that rootstock significantly affected juice content, but trees on almost all rootstocks produced fruit with juice content similar to that produced by trees on sour orange.

Rootstocks had different effects on rind thickness in 2004, but not in 2005 (Table 3). The thickest fruit rind was shown by fruits from the trees on Taiwanica and sour orange. However, trees on the other rootstocks produced similar rind thickness and did not show significant

difference from each other. Similar results on rind thickness of Kütdiken lemon were obtained by Tuzcu et al. (1992) with the thickest rind in fruits collected from trees on Taiwanica and Brazil sour orange.

Total acid content (TA) was affected by the rootstocks in 2004, but not in 2005 (Table 4). The lemons containing the highest acid were on sour orange and *T. citrange* and the lowest one was on *C. ampullacea* and Taiwanica. These results are in agreement with previous works, where fruits with the highest acid content are on sour orange and Yuma citrange (Georgiou, 2009). The lowest total acid content of fruits on Taiwanica was reported by various authors (Wutscher and Shull, 1976; Al-Jaleel et al., 2005).

Rootstock had a significant effect on total soluble solids (TSS) in both seasons (Table 4). The highest TSS was detected in the fruits from the trees on *C. obovoidea* rootstocks in the first season and on *C. citrange* in the second one. Similar results were reported by Bassal (2009) on Marisol mandarin, who found that the fruits from trees grafted on *C. citrange* gave TSS significantly higher than those on sour orange. In this study, the lowest TSS in the juice was obtained from the trees on Taiwanica in both seasons.

There were significant differences between rootstocks as regards TSS/TA ratio in 2004, but not in 2005 (Table 4). The TSS/TA ratio was the highest for fruits from the trees on *C. obovoidea* and the lowest for those on sour orange and Taiwanica.

Conclusion

In this study, rootstocks had significant effects on plant growth, yield and fruit quality. Carrizo and Troyer citranges have been determined as the rootstocks that have the most yield efficiency. However, on the cumulative yield they had the similar values as sour orange. Also they are not recommended because on the high calcareous soils they infer lime-induced iron chlorosis and do not have good combinations when grafted with the lemon varieties especially the Eureka group. On the other hand, Santa Teresa lemon which is grafted on *C. obovoidea*, the rootstock that has been known as tolerant to CTV, *P. citrophthora* and lime-induced iron chlorosis, having an increase in fruit yield and similar fruit quality like other rootstocks is considerably remarkable. Thus, at the regions where tristeza, phytophtora and iron chlorosis problems occur, using *C. obovoidea* as rootstock should be beneficial.

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