

Growth, Yield and Fruit Quality of Tahiti Lime on Eight Standard Rootstocks Affected by Soil Depth

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Abstract: Two Tahiti lime (*Citrus latifolia* Tan.) experiments were carried out to evaluate the performance of eight standard rootstocks on two different soil locations at Tecoman Colima, Mexico. Rootstocks were selected by their tolerance to Citrus tristeza virus (CTV) and acceptable adaptation to semi-arid hot tropics environment. The first trial was planted in “Cerrito de Aguilar” (CA) location which had sandy-loam soil with a fluctuant water table at 100 cm depth. The second experiment was planted in “Crucero Tecoman” (CT) on a sandy deep soil with no water table restriction. At CT location the best Tahiti lime growth, yield and fruit quality were observed on Alemow rootstock. The same combination at CA showed a poor performance and was affected by diseases due to high moisture conditions by the superficial water table. Taiwanica, Swingle citrumelo and Rangpur lime rootstocks were less productive than Alemow, but showed a good adaptation and acceptable yield on both soil conditions. Among them, Swingle citrumelo was a promising rootstock because it showed standard tree growth, good yield and excellent fruit quality. Swingle citrumelo also showed an acceptable performance on soil with high presence of *Phytophthora* sp. and moderate levels of calcium carbonate (near to 3,500 ppm). Taiwanica and Rangpur lime performed well during the six years of the experiment, but trees began to be affected by root diseases. Better performance of most Tahiti lime/rootstocks were found on sandy depth soil than on superficial wet soils.

Key words: *Citrus latifolia*, soil characteristics, Alemow, water table, tropical conditions.

1. Introduction

Tahiti lime (*Citrus latifolia* Tan.) also known as Persian and Bears lime [1] is botanically classified as an acid lime fruit [2]. Tahiti lime is cultivated in many regions of Mexico under tropical and sub tropical conditions. Export market for Tahiti lime fruit has increased considerably in the last ten years, promoting the expansion of new plantations to new citrus areas in Mexico. The cultivated area increased from 35,000 ha in the 90s to 89,000 ha in 2014 [3]. Most current Tahiti lime plantations in México are established in a diversity of soil types in the tropics and subtropics. In

the valley of Tecomán, Colima, one third of the citrus area shows strong differences in soil texture, range of pH, soil depth and permeability, and carbonate of calcium content [4]. It has been reported that some of these soil characteristics affect the plant growth, production and fruit quality of Mexican lime and orange trees [5, 6]. Most of the soil limitations can be solved using appropriated rootstocks to the climatic and scion characteristic [7, 8].

In Mexico, there is limited information about performance of Tahiti lime on different rootstocks and type of soils. Furthermore, no information is available on the effect of the rootstocks on horticultural characteristics of Tahiti lime on the tropical semiarid conditions. Tahiti lime plantations in Mexico are predominantly on Sour orange [9].

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However, as the entire citrus industry of Mexico is threaten by Citrus tristeza virus (CTV) and Huanglongbing (HLB), the Mexican government has established a national campaign of rootstock diversification by using CTV tolerant rootstocks and certified virus and HLB free scion cultivars [10, 11]. A number of citrus rootstocks with tolerance to CTV and some other virus and viroid diseases are known [7, 8, 12, 13]. Also HLB resistant rootstocks are required.

Citrus rootstocks need to be evaluated under field conditions in order to determine their performance on local climate and soil conditions before their establishment on a large scale in any particular citrus area [5, 8]. In Mexico, there have been some reports on the performance of sweet orange [6, 14] and Mexican lime [5, 14-16] cultivars on different citrus rootstocks and diverse soil conditions. However, the information of the performance of Tahiti lime on different citrus rootstocks in México is insufficient.

Preliminary reports revealed that Tahiti lime on Sour orange rootstocks under hot dry tropics of Colima, Mexico, were less productive than Mexican lime trees [17]. Conventional Tahiti lime plantations on Sour orange rootstocks performed well under the tropical wet conditions, but the threat of CTV promoted the evaluation of other rootstocks [9]. Some studies conducted in Veracruz México, appointed that the use of Carrizo citrange and Swingle citrumelo rootstocks performed well for growing Tahiti lime in savanna superficial and acid soils [18]. In contrast, from 16 rootstocks evaluated for Tahiti lime on a sandy soil, pH 7.1, at 8 m × 6 m, it was found that Morton citrange, followed by C-35 and Troyer citranges, showed higher yield than the control Sour orange rootstock [19]. In that report, the trifoliolate "Flying Dragon" showed the less vigorous growth, but high yield efficiency, which is appropriate for high density plantations.

Rootstock trials conducted in Florida, showed that

Tahiti lime developed vigorous and productive trees on Rangpur lime, Alemow, Kalpi (*C. webberii*), Rough lemon (*C. jambhiri*) and Leonardy grapefruit [20-23]; from these reports, Alemow and Rough lemon were recommended for a number of years for Tahiti lime in Florida [21]. In Brazil, several rootstocks studies for Tahiti lime have also been reported [23-29]. Before the 80s, the vigorous rootstocks Rangpur lime and Volkamer lemon [23] and moderate size Cleopatra and Sunki mandarin [27] were the best by their growth, yield and tolerance to diseases. In 2000, moderate EEL trifoliolate and Swingle citrumelo rootstocks [24] and dwarfing Flying Dragon trifoliolate rootstock [26, 29] were also reported as good rootstocks for Tahiti limes in Brazil, by their appropriated tree size, high yields, better tolerance to a wider range of disease complex and suitable to high density plantations. Recently, Tahiti lime also performed well on Cleopatra mandarin and Citrandarin 1710 (*C. reticulata* × *P. trifoliata*) [28]. In Cuba, Tahiti lime trees showed high tree growth and yield and higher tolerance to most of local disease, using Volkamer lemon and Amblycarpa mandarin as rootstocks [30, 31]. Also high productivity and fruit quality of lime trees budded on Troyer and Carrizo rootstocks was reported in this country [31, 32].

In México, the Tahiti lime orchards have been expanding into new areas, so there is a need to evaluate its performance on different rootstocks under different soil conditions. Therefore, the objectives of this work were to determine tree growth, yield and fruit quality of eight rootstocks established on two soil conditions on the dry tropics of Colima, Mexico.

2. Materials and Methods

The present study was carried out in the Mexican lime growing area located in Tecoman valley, México. The climates is hot and dry (BS), with an annual mean temperature of 27 °C, and the rainfall average is of

700 mm from July to October.

2.1 Rootstocks

The selected rootstocks were: Alemow (*Citrus macrophylla* Wester), Rangpur lime (*C. limonia* Osb.), Sour orange (*C. aurantium* L.), Taiwanica (*C. taiwanica*), Troyer and Carrizo citranges (*Poncirus trifoliata* (L.) Raf. × *Citrus sinensis* L.), Rough lemon (*C. jambhiri* Lush.), Swingle citrumelo (*P. trifoliata* × *Citrus paradisi* Macf.). All the rootstocks seeds and Tahiti lime budwood were obtained from Willits and Newcomb Nursery (California, USA).

2.2 Soil Conditions

Two sites with different soil conditions were selected to establish rootstocks experiments. The first experiment was established in Cerrito de Aguilar (CA) where the soil is superficial limited by a fluctuant water table at 100 cm. The soil characteristics were sandy-loam texture, pH 7.8, 2,150 ppm of calcium carbonate and an electric conductivity of 0.880 dS/cm. Soil characteristics in the Crucero Tecoman (CT) site were: sandy texture, pH 7.2, 1,200 ppm of calcium carbonate and an electric conductivity of 0.490 dS/cm.

2.3 Orchard Management

In both locations, the Tahiti lime on eight rootstocks were planted at 9.0 m × 9.0 m distance. Conventional flood irrigation system so-called “fish bone” was used in both locations for better control of water and to prevent spread of soil root pathogens. At CA location, 12 to 14 irrigations were applied every 15 d except during the rainy season. Adequate soil moisture conditions were present all year around because of the water table. In CT, the irrigation water was applied (every 22 d). Soil fertilizations were applied in July, November and March each year by using a 1.2 kg N, 0.6 kg P₂O₅ and 0.6 kg K₂O, respectively. Ammonium sulfate, super phosphate and potassium sulfate were used as N, P and K source.

Pruning was applied in November every year to eliminate diseased and dead branches, as well as those close to ground. Pest management was addressed to control whiteflies, aphids, soft scales and citrus leafminer as recommended [18].

2.4 Variables

The following tree growth variables were registered yearly: tree height (*h*), canopy diameter (*CD*) and trunk perimeter (*TP*). Canopy volume (*CV*) was determined by the formula:

$CV = 2.094r^2h$, where, *r* = canopy ratio and *h* = tree height.

Area of soil covered by canopy (*SAC*) was also measured calculating the area of circumference ($AC = 3.1416r^2$). *TP* was measured at 5 cm up of the bud union. Yield in kg/tree (*Y*), was registered every 22 d from April to October during five years. Yield efficiency (*YE*) was calculated as: $YE_{cv} = \text{yield per tree}/CV$, and also $YE_{sac} = \text{yield per tree}/SAC$. Potential yield (*PY*) was obtained using the next equation: $PY = 10,000/(CD)^2(Y)$. The used *CD* values were those at six years old. Lime fruit samples were taken four times during summer season to determine fruit quality parameters during the fourth and fifth years. The fruit quality parameters were: weight (g), percent of juice (%), acidity content (%), juice percent (weight/volume), total soluble solids (%) and essential oil content (%). These parameters were determined by using the standard analytical procedures described in previous works [5, 6, 15].

2.5 Statistical Procedures

An experimental random block design was employed in each location. Statistical design used to the analysis in all variables was a factorial A × B. The site was considered factor A and the rootstock factor B. Four replications of each tree treatment were used. The experimental units were integrated by one single tree. To compare means treatments the Tukey test at 0.05 was used.

3. Results and Discussion

3.1 Tree Growth

Tree growth on the rootstocks was greatly influenced by the soil type characteristics (Table 1). In the case of the CT experiment, the tallest Tahiti lime trees (> 3 m) were developed on Alemow, Swingle citrumelo, Rough lemon and Troyer citrange rootstocks (Table 1). Whereas, smaller Tahiti lime trees (2.76 m) were those budded on Carrizo citrange. The canopy diameter measurements indicated that lime trees on Alemow followed by Rangpur lime and Rough lemon showed the larger tree canopy. The canopy volume and soil surface area projected by the foliage was the greatest with Alemow and Rough lemon. Troyer citrange rootstock showed the bigger trunk perimeter, followed by Alemow and Sour orange (Table 1).

At the location CA, the highest Tahiti lime trees

were those budded on Sour orange followed by Taiwanica and Rangpur lime. Rough lemon and Alemow rootstocks developed smaller trees in this site. Taiwanica rootstock had the biggest diameter of canopy, while Rough lemon and Alemow also showed the smaller diameter. Consequently, the greatest canopy volume and area of soil projected by canopy was Tahiti lime on Taiwanica rootstocks.

3.2 Yield and Production Efficiency

In the deep sandy soil of CT location, Tahiti lime on Alemow rootstock was the most productive combination with 130.4 kg/tree/year, followed by Rangpur lime and Swingle citrumelo, which produced 98.7 kg/tree/year and 91.9 kg/tree/year, respectively. Carrizo and Troyer citranges and Rough lemon yielded close to 50% less in this site (Table 2).

The most productive combinations were also the most efficient in both parameters *YECv* and *YESac* of

Table 1 Growth of Tahiti lime trees on eight rootstocks at two locations with different characteristics in the Tecoman valley, Mexico. (average of five years)

Rootstock	Tree height (m)	Canopy diameter (m)	Trunk perimeter (cm)	Canopy volume (m ³)	SAC (m ²)
Crucero Tecoman location (sandy deep soil)					
Alemow (Ale.)	3.22 ^a	4.60 ^a	44.52 ^{ab}	40.56 ^a	17.5 ^a
Taiwanica (Tai.)	2.90 ^{bcd}	4.38 ^b	41.36 ^b	31.88 ^{bc}	15.8 ^{ab}
Rangpur (Ran.)	2.76 ^d	4.4 ^{ab}	41.64 ^b	29.35 ^c	15.6 ^{ab}
Swingle (Swi.)	3.06 ^{ab}	4.02 ^d	41.68 ^b	28.10 ^c	13.1 ^b
Sour orange (S.O.)	2.86 ^{cd}	4.24 ^{bc}	43.42 ^{ab}	29.74 ^c	14.8 ^{ab}
Carrizo (Carr.)	2.76 ^d	4.12 ^{cd}	40.52 ^b	26.27 ^c	13.8 ^{ab}
Troyer (Troy.)	3.02 ^{bc}	4.3 ^{bc}	47.92 ^a	33.22 ^{bc}	15.5 ^{ab}
Rough lemon (R.L.)	3.08 ^{ab}	4.44 ^{ab}	42.18 ^b	38.25 ^{ab}	16.6 ^{ab}
Tukey 0.05	*	*	*	*	*
Cerrito de Aguilar location (superficial sandy-loam soil)					
Alemow (Ale.)	2.64 ^{bcd}	3.48 ^{de}	29.58 ^c	17.29 ^{de}	9.6 ^{bc}
Taiwanica (Tai.)	2.92 ^{ab}	4.58 ^a	40.30 ^{ab}	34.87 ^a	17.1 ^a
Rangpur (Ran.)	2.88 ^{ab}	4.04 ^{bc}	42.52 ^a	25.18 ^{bc}	12.8 ^{bc}
Swingle (Swi.)	2.96 ^a	4.08 ^b	40.12 ^a	27.13 ^{bc}	13.3 ^{ab}
Sour orange (S.O.)	3.00 ^{aa}	4.10 ^b	39.70 ^{ab}	28.75 ^b	13.6 ^{ab}
Carrizo (Carr.)	2.74 ^{abc}	3.82 ^{bc}	37.74 ^b	21.92 ^{cd}	11.7 ^{bc}
Troyer (Troy.)	2.42 ^d	3.66 ^{cd}	40.60 ^a	17.70 ^{de}	10.9 ^{bc}
Rough lemon (R.L.)	2.52 ^c	3.12 ^e	30.08 ^c	13.16 ^e	7.7 ^c
Tukey 0.05	*	*	*	*	*
Location effect					
Crucero Tecomán	2.9	4.3	43	32	15.4
Cerro de Aguilar	2.7	3.8	42	23	12.0
Tukey 0.05	NS	NS	NS	*	NS

The same letter in each one of the columns means no difference between treatments at the 95% of confidential level. *Tukey test at 95 of probability. NS: non significant. SAC = area of soil covered by tree canopy.

Table 2 Yield and productive efficiency of Tahiti lime trees at two locations with different characteristics in the Tecoman valley, Mexico. (average of five years)

Rootstocks	kg/tree	Yield (ton/ha)	Productive efficiency		Potential yield (ton/ha)
			<i>YE_{cv}</i> (kg/m ³)	<i>YE_{sac}</i> (kg/m ²)	
Crucero Tecoman location (sandy deep soil)					
Alemow (Ale.)	130.4 ^a	15.9 ^a	3.5 ^a	7.3 ^a	30.0 ^{ab}
Taiwanica (Tai.)	82.5 ^{bcd}	10.1 ^{bcd}	2.5 ^b	4.9 ^{ab}	21.2 ^{bc}
Rangpur (Ran.)	98.7 ^b	12.1 ^b	3.4 ^{ab}	6.3 ^{ab}	30.0 ^{ab}
Swingle (Swi.)	91.9 ^{bc}	11.3 ^{bc}	3.3 ^{ab}	6.7 ^{ab}	30.7 ^a
Sour orange (S.O.)	72.7 ^{cd}	8.9 ^{cd}	2.4 ^b	4.6 ^b	20.2 ^{bc}
Carrizo (Carr.)	57.1 ^e	7.0 ^e	2.1 ^b	3.9 ^b	19.0 ^c
Troyer (Troy.)	65.9 ^{de}	8.1 ^{de}	1.9 ^b	3.9 ^b	16.9 ^c
Rough lemon (R.L.)	73.5 ^{bcde}	9.0 ^{bcde}	2.4 ^b	4.6 ^{ab}	16.3 ^c
Tukey 0.05	*	*	*	*	*
Cerrito de Aguilar location (superficial sandy-loam soil)					
Alemow (Ale.)	52.5 ^d	6.5 ^d	3.0 ^a	5.3 ^{ab}	25.0 ^b
Taiwanica (Tai.)	100.1 ^a	12.3 ^a	2.5 ^a	5.2 ^{ab}	25.7 ^b
Rangpur (Ran.)	97.7 ^{ab}	12.0 ^{ab}	3.6 ^a	7.2 ^a	40.8 ^a
Swingle (Swi.)	92.6 ^{abc}	11.4 ^{abc}	3.3 ^a	6.6 ^{ab}	31.0 ^{ab}
Sour orange (S.O.)	64.1 ^c	7.9 ^c	2.6 ^a	5.0 ^b	18.7 ^b
Carrizo (Carr.)	68.3 ^{bd}	8.4 ^{bd}	2.8 ^a	5.2 ^{ab}	26.9 ^b
Troyer (Troy.)	61.7 ^d	7.5 ^b	3.4 ^a	5.5 ^{ab}	24.3 ^b
Rough lemon (R.L.)	38.9 ^d	4.7 ^d	2.7 ^a	4.8 ^b	26.0 ^b
Tukey 0.05	*	*	NS	*	*
Location effect					
Crucero Tecomán	84	10.3	2.7	5.3	23.0
Cerro de Aguilar	72	8.8	3.0	5.6	27.4
Tukey 0.05	NS	NS	NS	*	*

The same letter in each one of the columns means no difference between treatments at the 95% of confidential level. *Tukey test at 95 of probability. NS: non significative. *YE_{cv}* = yield efficiency by canopy volume. *YE_{sac}* = yield efficiency by area of soil covered by tree canopy.

fruit production. The potential yield for a moderate tree densities estimated on the base of canopy diameter was higher (30 ton/ha) on the Tahiti lime on Alemow combination followed by Rangpur and Swingle citrumelo rootstocks. The potential yield of Tahiti lime on Alemow was twofold as compared to Rough lemon rootstock.

At CA location, the most productive rootstocks were Taiwanica, Rangpur lime and Swingle citrumelo which yielded 100.1, 97.7 and 92.6 kg/tree/year, respectively. Also these rootstocks were the best in both parameters of yield efficiency (Table 2).

3.3 Fruit Quality

In general, Tahiti lime fruits scored more acidity and higher essential oil, but less ascorbic acid content on sandy deep soil (CT location) than on sandy-loam superficial soil (CA site) (Table 3).

Most of the Tahiti lime/rootstock combinations in CA produced larger fruits than trees on Sour orange. The greatest fruit size was obtained on Rangpur lime rootstock followed by Alemow and Taiwanica. Acidity and solid soluble content of fruits were very similar for all rootstocks as compared to Sour orange, except Rough lemon and Carrizo citrange. The ascorbic acid content values varied from 369 mg/100 mL to 437 mg/100 mL in Rough lemon and Carrizo citrange, respectively. Tahiti lime on Rough lemon, Carrizo and Troyer citranges showed a high essential oil content, similar to Sour orange (Table 3).

At CA location with sandy-loam and superficial wet soil, Taiwanica rootstocks produced lower fruit acidity and ascorbic acid content, while Rangpur lime the lowest brix percentage. In contrast, Rangpur lime, Sour orange and Alemow rootstocks produced fruits with the highest acidity, brix percentage and ascorbic

Table 3 Fruit quality of Tahiti lime trees on eight different rootstocks at two locations with different soil characteristics in the Tecoman valley, Mexico. (average of two years of production)

Rootstock	Acid (%)	Brix (%)	Ascorbic acid (mg/100 mL)	Essential oil (%)	Juice (%)
Crucero Tecoman location (sandy deep soil)					
Alemow (Ale.)	6.6 ^{ab}	11.0 ^a	412 ^{ab}	0.446 ^b	49
Taiwanica (Tai.)	6.6 ^{ab}	9.9 ^b	406 ^{abc}	0.610 ^{ab}	51
Rangpur (Ran.)	6.5 ^a	10.3 ^{ab}	375 ^{bc}	0.656 ^{ab}	47
Swingle (Swi.)	6.7 ^a	10.6 ^{ab}	391 ^{bc}	0.650 ^{ab}	50
Sour orange (S.O.)	6.8 ^a	10.4 ^{ab}	407 ^{abc}	0.655 ^{ab}	47
Carrizo (Carr.)	6.4 ^{abc}	10.4 ^{ab}	394 ^b	0.715 ^a	53
Troyer (Troy.)	6.1 ^c	9.9 ^a	369 ^c	0.745 ^a	44
Rough lemon (R.L.)	6.3 ^{bc}	10.5 ^{ab}	437 ^a	0.730 ^a	45
Cerrito de Aguilar location (superficial sandy-loam soil)					
Alemow (Ale.)	5.5 ^{ab}	10.8 ^{ab}	464 ^a	0.510	48
Taiwanica (Tai.)	5.2 ^b	10.4 ^{ab}	380 ^c	0.555	50
Rangpur (Ran.)	5.8 ^a	9.7 ^b	406 ^{bc}	0.502	52
Swingle (Swi.)	5.7 ^{ab}	10.7 ^{ab}	413 ^{abc}	0.522	53
Sour orange (S.O.)	5.3 ^{ab}	11.0 ^a	429 ^{abc}	0.670	51
Carrizo (Carr.)	5.6 ^{ab}	1.4 ^{ab}	430 ^{abc}	0.530	44
Troyer (Troy.)	5.3 ^{ab}	10.6 ^{ab}	426 ^{abc}	0.616	50
Rough lemon (R.L.)	5.5 ^{ab}	10.9 ^{ab}	459 ^{ab}	0.640	45
Location effect					
Crucero Tecomán	6.5 ^a	10.4	399 ^b	650 ^a	48
Cerro de Aguilar	5.5 ^b	10.5	426 ^a	568 ^b	49
Tukey 0.05	*	NS	*	*	NS

The same letter in each one of the columns means no difference between treatments at the 95% of confidential level. *Tukey test at 95 of probability. NS: non significative.

acid content. Juice content was statistically similar among rootstocks, although it was a noticeable tendency by Troyer and Carrizo citranges and taiwanica rootstock to produce up to 50% juice in fruits.

In general, Tahiti lime trees were more vigorous and productive on Alemow and Rough lemon rootstocks on sandy deep soil than in superficial soil. Both rootstocks also developed vigorous and productive trees when budded with Mexican lime trees on similar soil conditions [5, 15, 16]. Growth and yield of Tahiti lime trees on most rootstocks at CA location (superficial soil), started to show the effect of the superficial water table on growth and yield (Figs. 1-3) since the second year. As a consequence around 30% to 40% of trees budded on Alemow and Rough lemon rootstocks died (data not shown). Poor performance of Tahiti lime on Alemow rootstocks under superficial and fluctuant water table has been previously reported [21, 33, 34].

It was previously reported that Alemow and Rough

lemon developed a deeper root system than Taiwanica in sandy deep soils [6, 35]. Likewise, it has been proposed that when citrus trees are grown under flood conditions, the root system stops to grow causing a limited absorption of water and nutrients; as a consequence, canopy may wilt and trees eventually die [9, 18]. To support this, it was demonstrated that Tahiti lime budded on Alemow rootstock subjected to intermittent or flooding irrigation strongly reduced the net photosynthesis assimilate rate, transpiration and the efficiency use of water, and increased the plant mortality as compared to Tahiti lime trees propagated by marcottage [34]. There is a possibility that the growth of the root system of vigorous rootstocks like Alemow and Rough lemon was affected since the second year, and the negative effect on yield and efficiency of production were observed in the following years. Lime trees on these two rootstocks on superficial soil, showed symptoms of canopy and trunk damage by *Phytophthora* sp.. According to Castle et al. [8, 35], Rough lemon rootstock is reported

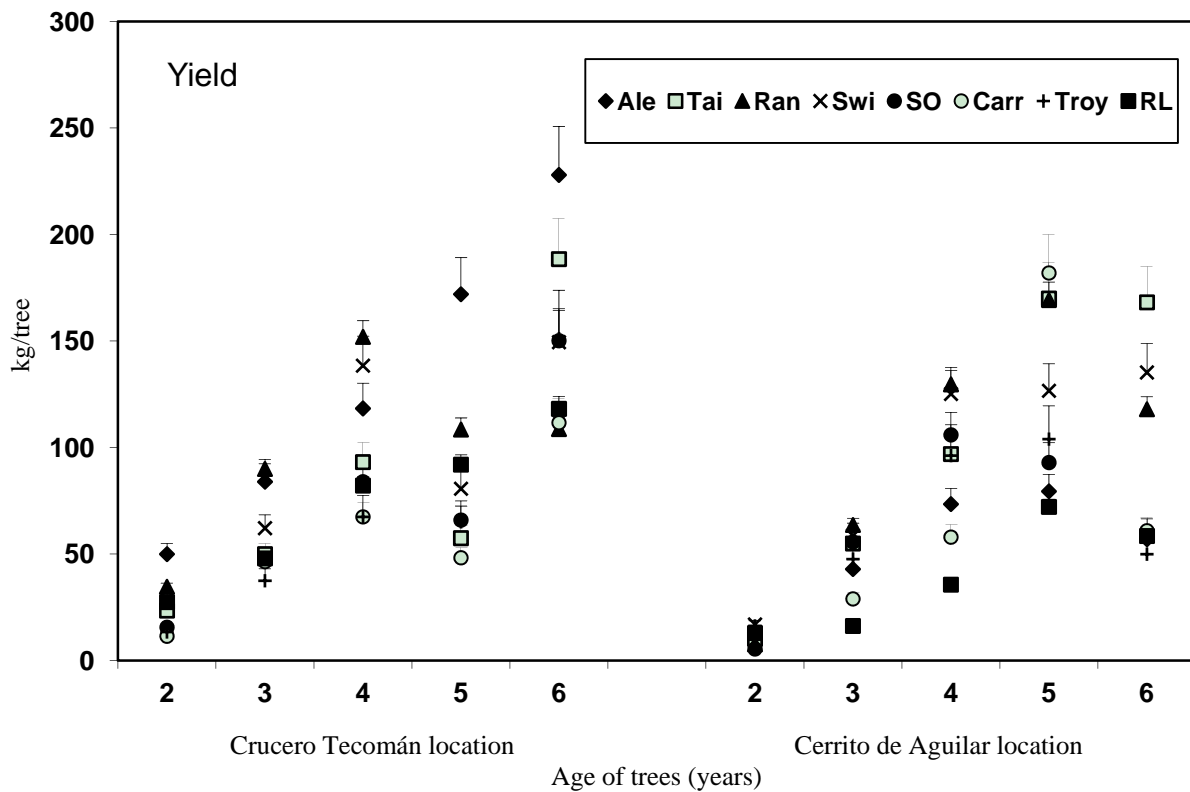


Fig. 1 Annual yield of Tahiti lime trees on eight standard rootstocks at two locations with different soil characteristics.

as susceptible, while Alemow is tolerant to *Phytophthora*. The lower height of budding favored the *Phytophthora* infection in the trunk of scion in most combinations including Alemow rootstocks at CA wet soils. In Florida, it was reported that 27% of the Valencia sweet orange on Rough lemon and 73% of the Red Blush grapefruit on Carrizo citrange combinations are prone to die by the presence of *Phytophthora* and citrus blight diseases [36]. Otero et al. [37] found that Satsuma mandarins on Pomeroy rootstocks exposed to flooding reduced the root function and stomata conductance and caused an accumulation of leaf starch and early fruit drop.

It was evident in our work that Tahiti lime on Alemow rootstock is a promising combination in sandy deep soils. Since trees were very productive in early years and can be adapted at higher planting densities. Using the growth of canopy data, the potential tree density and yield were 230 tree/ha and

30 ton/ha, respectively. However the use of this rootstock in sandy wet superficial soil is quite limited.

Trees on Rangpur and Swingle citrumelo showed an acceptable growth and yield at both soil conditions. Nevertheless, these rootstocks were not as vigorous and productive as Alemow trees on deep soil, and they seemed to be better adapted to superficial soil than Alemow. By that reason these rootstocks along with Taiwanica were the most promising combinations on superficial wet soil. Rangpur lime is reported as a *Phytophthora* susceptible rootstock [8, 35]. However, Tahiti lime trees on this rootstock were less affected by diseases than Rough lemon on sandy deep soil location or than Alemow and Rough lemon rootstocks on superficial wet soil during the period of the experiment.

Swingle citrumelo showed a good performance on both soil conditions. Carrizo and Troyer citranges were less vigorous and productive on both types of

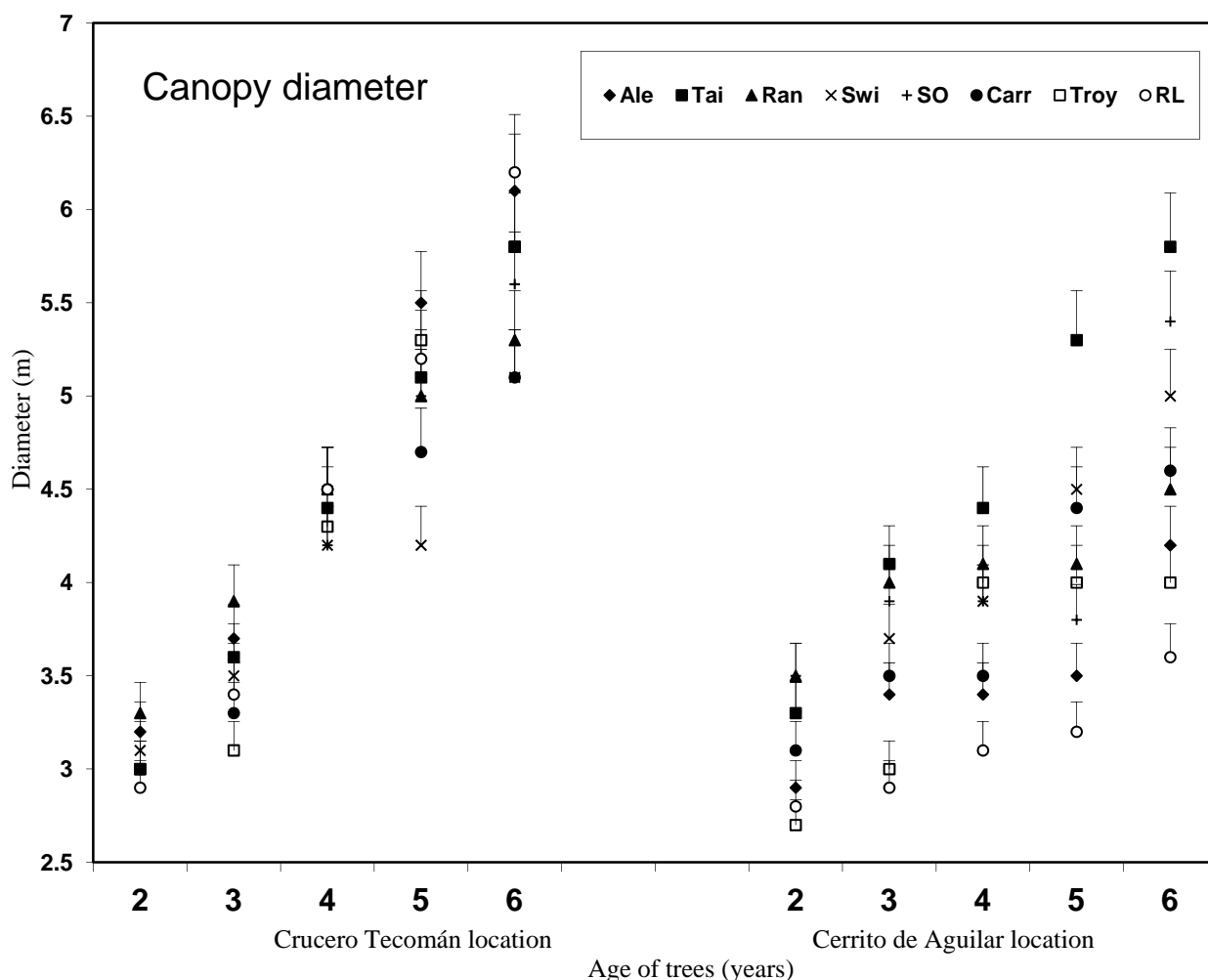


Fig. 2 Annual canopy diameter growth of Tahiti lime trees on eight standard rootstocks at two locations with different soil characteristics.

soils (Table 1). These three trifoliolate rootstocks are reported as tolerant or resistant to *Phytophthora* [8, 32]. There is a report that Troyer and Carrizo citranges had poor performance on soils susceptible to flooding [19]. Based on leaf net gas exchange, chlorophyll fluorescence and water relations, it was found that Troyer citrange was less tolerant to flooding than Carrizo and CT33, whereas Tucuman, Pomeroy and Rubidoux had similar tolerance to anoxia regardless of temperature [38]. Although Swingle citrumelo showed ability for good growth and yield on both locations, its adaptation to poor irrigation conditions in the sandy deep soil was evident. Likewise, there is a report from Brazil that Swingle citrumelo was less affected by

water stress than other citrus rootstocks [25]. High soil calcium carbonate scored on superficial soil, induced leaf ferric chlorosis symptoms on three trifoliolate rootstocks as was reported previously in other citrus [7, 8, 35, 36]. Iron leaf deficiency symptoms were more severe during the first two years. Nevertheless, Swingle citrumelo was susceptible to this problem, and iron deficiency symptoms were more noticeable on Carrizo and Troyer citranges. No field reports about the critical levels of calcium carbonate on soil affecting Tahiti lime on trifoliolate rootstocks performance are known. However, there are reports that Mexican lime trees on Swingle citrumelo showed leaf chlorosis by severe iron deficiency symptoms, poor

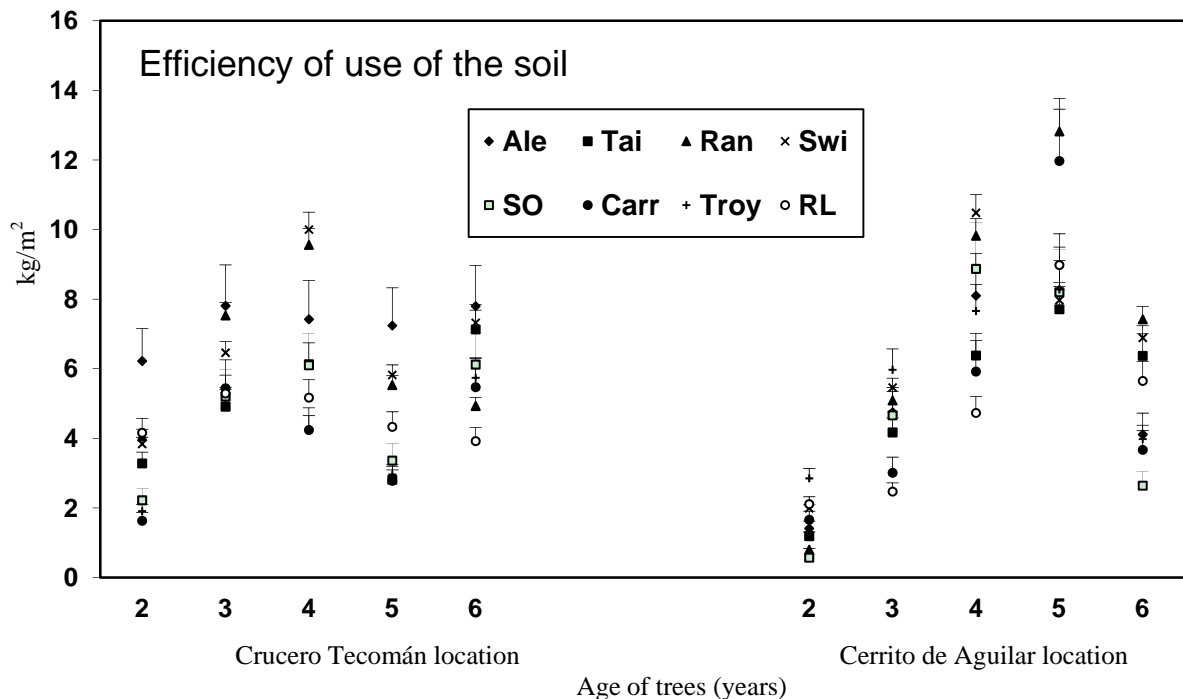


Fig. 3 Annual yield efficiency (YE_{5ac}) of Tahiti lime trees on eight standard rootstocks at two location with different soil characteristics.

tree growth and yield performance on deep soils with 20,000 ppm of calcium carbonate and pH of 8.3 [5, 15]. In Florida, citrus varieties on Swingle citrumelo were able to grow on 1.5 m deep soil, pH 8.0 and 1,980 kg/ha of calcium content [36]. In our work, calcium carbonate content in the soil varied from 1,435 ppm (CT) to 3,280 ppm (CA), and 308 ppm (CT) to 913 ppm (CA) at 30 cm and 60 cm depth, respectively. Swingle citrumelo showed acceptable growth development and yield with temporal iron leaf deficiency symptoms during the first years. Iron deficiency problems were not a significant problem on Carrizo or Troyer citranges in sandy deep soil location. Growth and yield of Tahiti lime on Carrizo and Troyer citranges in deep soil were comparable to those observed in Florida [22].

Growth and yield of Tahiti lime on Sour orange was surpassed by some rootstocks with similar or better fruit quality. It can be anticipated that Tahiti lime

yields could be increased if the irrigation program can be improved on sandy deep soil location. It was demonstrated previously that Mexican lime on Sour orange can produce more than 100 kg/tree if an appropriate grove management is applied, focusing on efficient water management program [17].

Yield results in this experiment were comparable to those of Florida [22, 38]. In Florida, Tahiti lime trees on Alemow, Rough lemon, Troyer citrange and Taiwanica rootstocks produced between 110 kg/tree and 149 kg/tree [22]. Tahiti lime trees produced an average yield of 6.9 ton/ha to 11 ton/ha on Rangpur lime, Swingle citrumelo and Troyer citrange after six years in Aguai, and 5.7 ton/ha to 6.6 ton/ha in Bebedouro, Brazil, respectively [25]. In these experiments, drought periods and the presence of *Colletotrichum acutatum* caused the fruit drop and reduced yield [25]. Tahiti lime trees on Alemow, Volkamer lemon and Amblycarpa rootstocks showed

the highest yields during eight years of evaluation. The less productive rootstocks under Cuban conditions were Sour orange, Troyer and Carrizo citranges, which produced 56, 37 and 25 kg/tree/year [22]. These former rootstocks were the less productive in our conditions in Colima, but with better yields results than those of Cuba (Table 2). Tahiti lime yields in this experiment were higher than those reported previously in Cuban and Brazilian experiments and with similar fruit quality showing the high potential of Tahiti lime on the dry tropics if a suitable rootstock for soil condition is selected. However these results need to be confirmed by several more years.

4. Conclusions

At the deep sandy soil location CT, the best tree growth, yield and fruit quality was achieved on Tahiti/Alemow combination. The same combination at CA site characterized by a superficial water table at 100 cm depth, showed a poor performance and was affected by root diseases and lower budding height. Taiwanica, Swingle citrumelo and Rangpur lime were less productive than Alemow, but showed a good tree growth and yield performance in both soil conditions. Among them, Swingle citrumelo was a promising rootstock because its high tolerance to disease problems, good adaptation to calcium carbonate soil contents, good growth and yield, excellent fruit quality. Taiwanica and Rangpur lime performed well during the period of the experiment, but they are expected to be affected by root diseases in the long term.

References

- [1] Saunt, J. 1990. *Citrus Varieties of the World*. England: Sinclair International Limited, 127.
- [2] Hodgson, R. W. 1967. "Horticultural Varieties of Citrus." In *The Citrus Industry*, edited by Reuther, W. H., Webber, J., and Batchelor, L. D. Vol. 1. USA: University of California, 431-586.
- [3] SIAP. 2014. *Annual Report of Production of Agriculture, Livestock And Fishery*. System of Information of Agriculture, Livestock and Fishery, Mexico. (in Spanish)
- [4] Pérez-Zamora, O. 2004. *Description of Soils of the Tecomán, Colima Valley as a Reference for Planning and Transference*. México: INIFAP-SAGARPA, 72. (in Spanish)
- [5] Medina-Urrutia, V. M. 1996. *Rootstocks for Mexican Lime in Colima*. México: INIFAP-CIRPAC-Campo Experimental Tecomán Colima, 36. (in Spanish)
- [6] Pérez-Zamora, O., Medina-Urrutia, V. M., and Becerra-Rodríguez, S. 2002. "Growth, Yield and Fruit Quality of Valencia Orange Budded on 16 Citrus Rootstocks on Calcareous Soil." *Agrociencia* 36: 137-48. (in Spanish)
- [7] Castle, W. S. 1987. "Citrus Rootstocks." In *Rootstocks for Fruit Crops*, edited by Rom, R. C., and Carlson, R. F. New York: Wiley, 361-99.
- [8] Castle, W. S., Tucker, D. P. H., Krezdorn, A. H., and Youtsey, C. O. 1993. *Rootstocks for Florida Citrus*. Vol. 42. USA: IFAS, University of Florida, 92.
- [9] Curti-Díaz, S. A., Loreda-Salazar, R. X., Díaz-Zorrilla, U., Sandoval-Rincón, J. A., and Hernández, J. 2000. *Technology for Tahiti Lime Production*. Libro Técnico No. 8. Veracruz, Mexico: Campo Experimental Ixtacuaco, 145. (in Spanish)
- [10] Robles-García, P., Sánchez-Anguiano, H. M., and Delgado-Castillo, J. P. 2005. "National Program for Citrus Production of Certified Material." In *Memoria Científica: III, Simposio Internacional Citrícola*. Vol. 1. Colima, Mexico: INIFAP-Campo Experimental Tecoman, 96-102. (in Spanish)
- [11] Oficial Newspaper. 2010. "Oficial Agreement to Establish the Phytosanitary Measures to Be Applied to Control Huanglongbing (*Candidatus liberibacter*) and Its Vector." *SAGARPA*, August, 2010. (in Spanish)
- [12] Newcomb, D. A. 1978. "Selection of Rootstocks for Salinity and Diseases Resistance." *Proc. Int. Soc. Citriculture* 1: 117-20.
- [13] Wutscher, H. K. 1979. "Citrus Rootstocks." In *Hort. Reviews*, edited by Janick, J. Westpoint, CT: Avi. Publish, 237-69.
- [14] Padrón-Chávez, J. E. 1990. "Yield and Fruit Quality of Valencia Late Orange (*Citrus sinensis* Osb.) on Different Rootstocks in General Teran N. L." *Agric. Tec. México*. 16: 3-17. (in Spanish)
- [15] Valdez-Verduzco, J., and Medina-Urrutia, V. M. 1981. "Influence of Rootstocks on Mexican Lime Performance in Colima, Mexico." *Proc. Int. Soc. Citriculture* 1: 142-4.
- [16] Medina-Urrutia, V. M., Alcalde-Blanco, S. 1981. "Effect of Mexican and Persian Limes on the Root System Characteristics of Three Rootstocks." *Proc. Int. Soc. Citriculture* 1: 140-2.
- [17] Becerra-Rodríguez, S., Valdez-Verduzco, J., and Medina-Urrutia, V. M. 1979. "Performance of Mexican

- Lime, Tahiti Lime and Eureka Lemon in the Tropical Area of Tecoman Colima." *Proc. Trop. Region Am. Soc. Hort. Sci.* 23: 92-4. (in Spanish)
- [18] Curti-Díaz, S. A., Hernández-Guerra, C., and Loredó-Salazar, R. X. 2012. "Commercial Productivity of Tahiti Lime on Four Rootstocks in Veracruz, México." *Revista Chapingo Serie Horticultura* 18: 291-305. (in Spanish)
- [19] Leal-Barrera, R., Curti-Díaz, S. A., and Hernández-Guerra, C. 2012. "Agronomic Performance of Tahiti Lime (*Citrus latifolia* Tan.) on 16 Rootstocks on Sandy Soil." Presented at Citrus Research Congress, Cedefrut A. C. de Veracruz. (in Spanish)
- [20] Campbell, C. W. 1972. "Rootstock Effects on Tree Size and Yield of 'Tahiti' Lime (*Citrus latifolia* Tanaka)." *Proc. Fla. Sta. Hort. Soc.* 85: 332-4.
- [21] Campbell, C. W. 1979. *Tahiti Lime Production in Florida*. USA: IFAS, University of Florida Extensión Service, 45.
- [22] Colburn, B. F. E., Gardner, G., and Horanic, G. E. 1963. "A Rootstock Trial for Tahiti Limes in Dade County, Florida." *Fla. Sta. Hort. Soc.* 76: 24-35.
- [23] Passos, O. S., and da Cunha, A. P. 1981. "Citrus Rootstocks in Brasil." In *Proceedings of Int. Soc. Citriculture*, 102-5.
- [24] Amaro, A. A., Salibe, A. A., and Sobrinho, J. T. 2000. "'Eureka' Lemon and 'Thaiti' Lime Production in Brazil." In *Proceeding of Int. Soc. Citriculture*, 581.
- [25] Figueiredo, J. O., Laranjeira, F. F., Sobrinho, J. T., Pio, R. M., Stuchi, E. S., Donadio, L. C., Sempionato, O., and Olima, J. E. 2000. "Rootstocks for Tahiti Lime in São Paulo State, Brasil." In *Proceeding of Int. Soc. Citriculture*, 487-9.
- [26] Sanchez, S. E., Donadio, L. C., and Sempionato, O. R. 2000. "Behavior of Thaiti Lime on Trifoliate Orange 'Flying Dragon' Rootstock at Four Spacings in Bebedouro." In *Proceeding of Int. Soc. Citriculture*, 586.
- [27] Salibe, A. A. 1974. "The Brazilian Citrus Industry." In *Proc. First. Int. Citrus Short Course*, edited by Jackson, L. K., Krezdorn, A. H., and Soule, J. Gainesville: University of Florida, 44-50.
- [28] Alves, R. R., Machado, D. L. M., Salomao, L. C. C., Siqueira, D. L., and Silva, S. D. R. 2012. "Evaluation of Rootstocks for Tahiti Lime in the Municipality of Jaiba Brazil." In *Proceeding of Int. Soc. Citriculture*, 181.
- [29] Machado, D. L. M., Alves, R. R., Siqueira, D. L., Salomao, L. C. C., and Silva, S. D. R. 2012. "Development and Production of Tahiti Lime IAC-5 Grafted on Flying Dragon *Poncirus trifoliata* var. *monstrosa*) Grown in High Planting Densities." In *Proceeding of Int. Soc. Citriculture*, 181.
- [30] Jiménez, R. A., Simón, A., García, E., and Frometa, E. 2004. "Results of Long Year Studies on the *Citrus amblycarpa* Ochse Rootstock in Combination with Different Commercial Cultivars in Cuba." In *Proceeding of Int. Soc. Citriculture*, 137.
- [31] Jiménez, V. R., Orams, R., Frometa, E., and García, E. 1986. "Influence of Six Rootstocks on Tahiti Lime SRA-SB (*Citrus latifolia* Tan.) Performance under the Tropical Conditions of Cuba." *Memorias Simp. Int. Citricultura Tropical*. 1: 125-37. (in Spanish)
- [32] Del Valle-Valdez, N. 1997. *How to Select a Citrus Rootstock*. Veracruz, México: Promotora Citrícola del Golfo (PROCIGO), 54. (in Spanish)
- [33] Medina-Urrutia, V. M., Alcalde-Blanco, S., and Sadowski, A. 1980. "Root Distribution of Eight Citrus Rootstocks Budded with Tahiti lime (*Citrus latifolia* Tan.)." *Agric. Tec. Mex.* 6: 67-76. (in Spanish)
- [34] Shaffer, B., and Moon, P. A. 1990. "Influence of Rootstocks on Flood Tolerance of Tahiti Lime Trees." *Proc. Fla. Sta. Hort. Soc.* 103: 318-21.
- [35] Castle, W. S., Tucker, D. P. H., Krezdorn, A. H., and Youtsey, C. O. 1992. *Rootstocks*. USA: Institute of Food and Agricultural Services (IFAS), Florida Cooperative Extension Service HS-152, 11.
- [36] Castle, W. S., Wutscher, H. K., Youtsey, C. O., and Pelosi, R. R. 1989. "Citrumelo as Rootstocks." *Citrus Industry* 70 (9): 25-30.
- [37] Otero, A., Goñi-Altuna, C. T., and Syvertsen, J. P. 2012. "Flooding and Soil Affect Photosynthesis of Citrus Rootstocks Leaves." In *Proceeding of Int. Soc. Citriculture*, 126.
- [38] Castle, W. S., Schnell, R. J., Crane, J. H., Grosser, J. W. Gmitter Jr., F. G., Ayala-Silva, T., and Bowman, K. D. 2004. "Evaluation of New Citrus Rootstocks for Tahiti Lime Production in Southern Florida." *Proc. Fla. Sta. Hort. Soc.* 117: 174-81.