Performance of ‘Tahiti’ lime on twelve rootstocks under irrigated and non-irrigated conditions

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A B S T R A C T
Faced with new challenges, such as emerging diseases, shortening of orchard longevity, and larger social and environmental demands from consumers, practices such as rootstock diversification, irrigation and high density plantings have become relevant for the Brazilian citrus industry. This research had the objective to evaluate the performance of irrigated and non-irrigated ‘Tahiti’ lime trees grafted on 12 rootstocks and one interstock. Plots were distributed following a randomized block design, with four replicates and one plant per plot. Rootstocks influenced plant vigor, especially ‘Flying Dragon’ trifoliate, which reduced tree height by approximately 47% compared to the ‘Rangpur’ lime. Trees that were budded on more vigorous rootstocks showed higher yield when grown without irrigation than with irrigation. The ‘1646’ citradia and ‘Morton’ citrange rootstocks performed particularly well. On the other hand, the plants on less vigorous rootstocks showed better performance in terms of yield under irrigation than the same combinations without irrigation, especially those grafted on the tetraploid ‘Carriazo’ and ‘Troyer’ citranges, ‘Swingle’ citrumelo, ‘Davis A’ trifoliate and ‘Flying Dragon’ trifoliate. Plants budded on the ‘1708’ citradia had high yields under irrigated and non-irrigated conditions. The effect of interstock on plant vigor was dependent of rootstock. Interstocked plants on ‘Davis A’ trifoliate were higher than those without interstock. On the other hand, interstocked plants on Catania 2 ‘Volkamer’ lemon were less vigorous than those without interstock.

1. Introduction

The citrus industry faces new challenges worldwide, including emergence of diseases, shortening of orchard life span, and larger social and environmental demands imposed by consumers. In Brazil, four varieties of sweet orange represent nearly 92% of the citrus plants in the State of São Paulo, and a single type of rootstock, the ‘Rangpur’ lime, accounts for 85% of the rootstocks used in citrus groves (Bové and Ayres, 2007). In this context, rootstock diversification, irrigation and high density planting practices become relevant.

On the other hand, production and international market of ‘Tahiti’ lime have significantly expanded in the recent years. In order to sustain this developing market, it is very important to create adequate conditions to extend ‘Tahiti’ lime harvest period, with rootstock diversification and irrigation. Over 85% of the citrus groves in Brazil are not irrigated. Experiments involving ‘Tahiti’ lime are scarce, but the partial results already allow to characterize some rootstocks (Stuchi et al., 2003; Stenzel and Neves, 2004).

Considering that there has been a growing interest in ‘Tahiti’ lime production driven by the need for higher crop yields and the possibility of producing fruit during the off-season period, at higher market prices, the objective of this study was to evaluate the performance of irrigated and non-irrigated ‘Tahiti’ lime trees budded on 12 rootstocks and on one interstock.

2. Materials and methods

2.1. Field trial and plant material

Trees were planted in December of 2003 in the northern São Paulo State, Brazil (20°53’16”S latitude; 48°28’11”W longitude; 601 m altitude) on an 8.0 m × 5.0 m tree spacing, corresponding to a plant density of 250 trees ha⁻¹. The soil was Haplustoix with a medium texture (38% clay), and the climate was Köppen’s Cwa, with maximum and minimum temperatures of 30.5 °C and 16.8 °C, respectively, and an annual rainfall of 1534.7 mm. ‘IAC-5’ ‘Tahiti’ lime (Citrus latifolia (Yu. Tanaka) Tanaka) was grafted...
on the following rootstocks (treatments): the trifoliates ‘Flying Dragon’ (*Poncirus trifoliata*) and ‘Davies A’; the tetraploid ‘Troyer’ and ‘Carriozo’ citranges and the ‘Morton’ citrange [*Citrus sinensis* (L.) Osbeck × *P. trifoliata*]; the citradias (*C. aurantium* × *P. trifoliata*); the ‘1646’ and ‘1708’; ‘Swingle’ citrusmedeo (*Citrus paradisi* × *P. trifoliata*); Catania 2 ‘Volkamer’ lemon (*Citrus volkameriana* V. Ten. & Pasq.); ‘Orlando’ tangelo (*Citrus ruticulata* Blanco × *C. paradisi* Macf.); ‘Smooth Flat Seville’ (SFS) (*C. aurantium* L.) sour orange and the ‘Rangpur’ lime (*Citrus limonia* Osbeck). ‘Flying Dragon’ trifoliate was also used as interstock for Catania 2 ‘Volkamer’ lemon, ‘Orlando’ tangelo, ‘Morton’ citrange, ‘Swingle’ citrusmedeo, ‘SFS’ sour orange, and ‘Davies A’ trifoliate. Plants grafted on ‘Orlando’ tangelo (not interstocked) and on ‘SFS’ sour orange (interstocked) died in 2007 due to root rot caused by *Phytophthora* spp. The experiment was not pruned, and was managed according with regular cultural practices. The annual rate of fertilization was equivalent to 190 kg *N*, 110 kg P and 116 kg K tree⁻¹ as mono ammonium phosphate and 20–0–20. The experimental orchard was surrounded by several other citrus evaluation experiments.

2.2. Plant yield and fruit quality measurements

Plant height (*H*) and width (in parallel, *Dp*, and perpendicular, *Dd*, direction to the row) were measured, in 2009 to calculate the canopy volume according to the equation \( V = \frac{\pi}{6} \times H \times D_p \times D_d \) (*Zekri, 2000*). Fruit harvests were recorded from 2007 to 2009. Under local conditions, ‘Tahiti’ limes bloom throughout the entire year, leading to a total of three to five harvests evaluated each year. In 2009, yield efficiency was calculated from the relationship between the fruit yield (kilograms per plant) and the canopy volume (cubic meters per plant). Yield (kg tree⁻¹) was recorded on every commercial harvest, and cumulative yield was calculated for two periods, which include the following; from the second year through the fourth year after planting (2005–2007) to estimate early-bearing cumulative yield and from the second year through the sixth year after planting (2005–2009) to evaluate total cumulative yield.

2.3. Experimental design and statistical analysis

The plots were distributed following a randomized block design, with 18 treatments, four replications and one plant per plot. The same experiment was conducted both with and without irrigation. In the irrigated experiment trees were drip irrigated based on a 100% of the crop evaporative transpiration (ETc). The system was comprised of a drip line in each tree row, with three self-compensating drippers (2.3 l h⁻¹) per tree, which were 1.0 m apart. For each variable, row data were initially submitted to exploratory analysis to verify whether they meet the assumptions of homogeneity of variances, normality of errors, and presence of outliers. Data were submitted to analysis of variance, using Fisher’s test. Original data of some variables were transformed using the Box Cox method (*Montgomery, 2005*). For each variable, the individual and joint analyses of variances were performed. Comparisons among means were performed by the Scott Knott test (*P < 0.05*), while the effect of interstock was tested by contrasts.

3. Results

3.1. Plant height and canopy volume

The rootstock clearly affected plant growth. In the non-irrigated experiment, the more vigorous plants reached approximately 3.6 m in height and had 33 m³ of canopy volume, while in the irrigated experiment, the more vigorous plants were 4.0 m in height and had 45 m³ of canopy volume six years after planting. In both experiments, the rootstock that produced the most vigorous ‘Tahiti’ limes plants were Catania 2 ‘Volkamer’ lemon, ‘Orlando’ tangelo, ‘Morton’ citrange and ‘Swingle’ citrusmedeo (Table 1). In the non-irrigated trial, plants with intermediate vigor were approximately 3.2 m in height, with 26 m³ of canopy volume, while in the irrigated trial, plants were 3.7 m in height and had 36 m³ of canopy volume. In both experiments, the rootstocks ‘Rangpur’ lime, the ‘1646’ and ‘1708’ citradias, the tetraploid ‘Carriozo’ and ‘Troyer’ citranges and the ‘Davies A’ trifoliate induced intermediate vigor to the ‘Tahiti’ lime scion. In both experiments, ‘Flying Dragon’ trifoliate and ‘SFS’ sour orange rootstocks induced plant dwarfing (Table 1). Low vigor (or dwarf) plants had their canopy volume reduced by one-third to one-half compared to ‘Rangpur’ limes. Irrigation promoted vegetative plant growth on all the rootstocks; plant height was increased by 11% and the canopy volume by approximately 36%.

The interstock had no effect on plant height and canopy volume in both experiments. Some contradictory and unexpected effects of interstock were observed, such as increasing plant vigor on ‘Davies A’ trifoliate and decreasing plant vigor on Catania 2 ‘Volkamer’ lemon (Table 1).

3.2. Yield

In the fourth year after planting, fruit yield in the irrigated experiment was 148% larger than in the non-irrigated experiment, demonstrating the influence of irrigation on early yield (Table 2). In the fifth and sixth years after planting, higher yields were observed in plants on Catania 2 ‘Volkamer’ lemon, ‘1646’ citradia, ‘1708’ citradia, ‘Orlando’ tangelo, ‘Morton’ citrange and ‘Swingle’ citrusmedeo (Table 2). Rootstocks influenced the early-bearing cumulative yield (second year through fourth year after planting) (Table 3). In the non-irrigated experiment, the rootstocks Catania 2 ‘Volkamer’ lemon, ‘1646’ and ‘1708’ citradias, ‘Orlando’ tangelo and ‘Morton’ citrange induced a larger percentage of early-bearing yields. In the irrigated experiment, larger early-bearing was observed on the ‘1646’ and ‘1708’ citradias as well as on the ‘Morton’ citrange (Table 3). Furthermore, trees on ‘Volkamer’ lemon and ‘Orlando’ tangelo acted similarly in both experiments. These results indicated that irrigation induced higher fruit yields in most rootstocks, including a 257% increase in the ‘Rangpur’ lime, a 379% increase in the ‘Carriozo’ citrange tetraploid, a 324% increase in the ‘Troyer’ citrange tetraploid, and a 432% increase in the ‘Davies A’ trifoliate (Table 3).

Rootstocks also influenced the cumulative yield, from the second year through the sixth year after planting (Table 3). In both experiments, larger cumulative yields were observed for plants on Catania 2 ‘Volkamer’ lemon, the ‘1646’ and ‘1708’ citradias, ‘Orlando’ tangelo and ‘Morton’ citrange (Table 3). The interstock induced higher fruit production in plants on ‘Davies A’ trifoliate in both experiments. The irrigated plants produced an average of 42% more fruits than non-irrigated ones. Paradoxically, ‘1646’ citradia, ‘Orlando’ tangelo, ‘SFS’ sour orange and ‘Flying Dragon’ trifoliate rootstocks produced similarly in both experiments. However, plants grafted on tetraploid ‘Carriozo’ and ‘Troyer’ citranges, ‘Swingle’ citrusmedeo and ‘Davies A’ trifoliate increased their cumulative production by more than 60% when irrigated (Table 3).

Yield efficiency after six years from planting was affected by the rootstocks (Table 3). In the non-irrigated experiment, the plants on ‘Flying Dragon’ trifoliate showed high yield efficiency due to its small canopy. In this condition, the competition between fruit for water, carbohydrates and minerals is more intense than in plants with lower yield efficiency. In the irrigated experiment, higher yield efficiency was observed in plants on ‘1646’ and ‘1708’ citradias, tetraploid ‘Troyer’ citrange, ‘Swingle’ citrusmedeo, ‘Davies A’ trifoliate.
Table 1

<table>
<thead>
<tr>
<th>Rootstocks</th>
<th>Interstock</th>
<th>Non-irrigated experiment</th>
<th>Irrigated experiment</th>
</tr>
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<td></td>
<td>Plant height (m)</td>
<td>Canopy volume (m$^3$)</td>
<td>Plant height (m)</td>
</tr>
<tr>
<td>'Rangpur' lime</td>
<td>3.33 ± 0.10b</td>
<td>24.58 ± 1.1b</td>
<td>3.65 ± 0.20b</td>
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<tr>
<td>Catania 'Volkmamer' lemon</td>
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<td>31.45 ± 0.9a</td>
<td>4.10 ± 0.05a</td>
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<td>Catania 'Volkmamer' lemon</td>
<td>'Flying Dragon'</td>
<td>3.23 ± 0.09b</td>
<td>29.01 ± 1.3b</td>
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<tr>
<td>'1646' citridia</td>
<td>–</td>
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<td>31.06 ± 2.8a</td>
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<tr>
<td>'1708' citridia</td>
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<td>3.18 ± 0.08b</td>
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<td>'Carrizo' citrange tetraploid</td>
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<td>3.46 ± 0.06a</td>
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<td>26.86 ± 2.6b</td>
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<td>'Davis A' trifoliate</td>
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<tr>
<td>'SFS' sour orange</td>
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<tr>
<td>Mean</td>
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<td>27.90</td>
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<td>CV (%)</td>
<td>7.21</td>
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<td>Contrast</td>
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<td>31.30a</td>
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<td>interstocked plants</td>
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<td>31.60a</td>
<td>3.93a</td>
</tr>
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</table>

Interaction Rootstocks × Irrigation in plant height ($P$=0.4142) and canopy volume ($P$=0.2819). Means followed by different letters in columns are significantly different ($P<0.05$) by Scott Knott's test. Values represent means ± SE.

and 'Flying Dragon' trifoliate. In general, non-irrigated plants on less invigorating rootstocks showed higher yield efficiency than the plants watered and grafted on more invigorating rootstocks (Table 3).

4. Discussion

The low vigor and high yield efficiency traits of plants budded on 'Flying Dragon' trifoliate suggest that this rootstock is suitable for high density plantations (Stuchi et al., 2003; Cantuarias-Avilés et al., 2010). Plants on 'Flying Dragon' trifoliate occupied an area of 5.78 m × 2.79 m in the irrigated experiment and an area of 5.05 m × 2.17 m in the non-irrigated trial, as calculated from plant diameter measured after 6 years from planting, assuming 15% of tree overlapping along the row (De Neri et al., 2005). These plant spacings, however, corresponded to six-year-old plants. Therefore, lower plant density would be expected when the plants reach their final size. Researchers have recommended planting spacings of 5.5–6.0 m between the rows, and 1.0–2.0 m between plants along the row for 'Tahiti' limes on 'Flying Dragon' trifoliate (Stuchi and Silva, 2005). In this recommendation, however, the overlapping between canopies seems to exceed 15%. Another important feature of 'Flying Dragon' trifoliate rootstock is its high resistance to root rot caused by Phytophthora spp., observed even in irrigated orchards (Stuchi and Silva, 2005). Nonetheless, 'Flying Dragon' trifoliate seems inappropriate as a rootstock for 'Hamil'
On the other hand, 'Morton' citrange and also caused differences in vegetative growth on different rootstocks; the interstock reduced plant size, while on the 'Davis A' trifoliate, it was observed that on the Catania 2 'Volkamer' lemon rootstock, growth and fruit production was influenced by the rootstock. Itchers have reported that 'Volkamer' lemon and 'Carrizo' citrange interstock and did not show significant differences in vegetative growth.
tion is crucial because the critical periods of flowering and fruit set occur during the dry season. In Brazil, these critical periods coincide with the onset of rain. However, in the São Paulo State, strong droughts and dry periods do frequently occur during flowering and initial fruit set stages, causing intense drop of flowers and developing fruits (Cantuarias-Avilés et al., 2010; Hutton et al., 2007).

‘Rangpur’ lime induced higher yield when grown without irrigation. Irrigation increased vegetative growth and, consequently, decreased plant density. These results may explain, in part, the extensive choice of ‘Rangpur’ lime in Brazil as rootstock for non-irrigated groves. However, this rootstock is very susceptible to root rot caused by *Phytophthora* spp. (Castle et al., 1993; Stenzel and Neves, 2004). Therefore, its use in recent years has decreased in Brazilian nurseries in favor of *P. trifoliata* hybrids (Pompeu and Blumer, 2006). In both experiments, plants budded on ‘SFS’ sour orange and ‘Orlando’ tangelo were the most susceptible to root rot, which caused the elimination of two treatments. Therefore, the use of both rootstocks is not recommended for ‘Tahiti’ lime. These results are supported by studies showing that ‘Orlando’ tangelo induces large plants and high yield, but it is highly susceptible to root rot (Figueiredo et al., 1996). The ‘1708’ citrandia outstood among all the studied rootstocks by inducing high yield, both on irrigated and non-irrigated conditions. Plants on this rootstock were intermediate-sized, with good quality fruit and had no symptoms of root rot susceptibility. The main criteria used in this study to select the rootstocks were yield, early-bearing, fruit quality, vigor, compatibility and tolerance to biotic and abiotic stresses. However, these criteria are insufficient if not coupled with economical aspects (Castell et al., 2010). In ‘Tahiti’ lime, for instance, higher prices are paid for large-dark-green fruits destined for export or for fruits picked in the off season (Gayet and Salvo Filho, 2003).

5. Conclusions

- ‘Flying Dragon’ trifoliate is a suitable rootstock for irrigated high density ‘Tahiti’ lime groves.
- The effect of rootstock on plant size and fruit yield can vary according to use of interstock. The ‘Flying Dragon’ trifoliate used as interstock increases the yield of ‘Tahiti’ lime grafted onto ‘Davis A’ trifoliate and ‘Swingle’ citrusmelo, but reduces the yield of plants budded on ‘Morton’ citrange.
- Invigorating rootstocks grown without irrigation have high yields, with the ‘1646’ citrandia and the ‘Morton’ citrange being strongly recommended for such conditions.
- The rootstocks tetraploid ‘Carrizo’ and ‘Troyer’ citranges, ‘Swingle’ citrusmelo, and the trifoliates ‘Davis A’ and ‘Flying Dragon’ induced higher yields under irrigated conditions.
- The ‘1708’ citrandia can be used as rootstock for irrigated or non-irrigated ‘Tahiti’ lime, inducing high yields in both conditions.

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References


