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The horticultural performance of five 'Tahiti' lime selections grafted onto 'Swingle' citrumelo under irrigated and non-irrigated conditions

Horst Bremer Neto[a], Francisco de Assis Alves Mourão Filho[a,*], Eduardo Sanches Stuchi[b], Erick Espinoza-Núñez[a], Tatiana Cantuarias-Avilés[a]

[a] Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz", 13418-900, Piracicaba, SP, Brazil
[b] Embrapa Mandioca e Fruticultura, Cruz das Almas, BA, Brazil

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ABSTRACT

Maximizing the production and fruit quality of the 'Tahiti' lime (*Citrus latifolia* (Yu. Tanaka) Tanaka) is directly related to the scion/rootstock combination and the production technology applied in groves. Although some research has evaluated the rootstocks for this cultivar, few studies have identified high-performance scion selections. Thus, the present study aimed to evaluate the horticultural performance of five 'Tahiti' lime selections ("IAC 5", "IAC 5-1", "CNPMF/EECB", "CNPMF 2000", and "CNPMF 2001") grafted onto the 'Swingle' citrumelo rootstock [*Citrus paradisi* Macfad. cv. Duncan x *Poncirus trifoliata* (L.) Raf.] under irrigated and non-irrigated conditions. The variables collected over five consecutive crop seasons included vegetative growth, crop season and off-season yields, yield efficiency, fruit quality, and CO_2 assimilation rate. The "CNPMF/EECB" selection had the highest fruit production and yield efficiency, regardless of irrigation. Under irrigated conditions, the "CNPMF/EECB" selection produced the highest fruit yield during the off-season. The "IAC 5-1", "CNPMF/EECB", "CNPMF 2000", and "CNPMF 2001" selections showed increased vegetative growth compared to the "IAC 5" selection, regardless of irrigation. Irrigation caused higher vegetative growth, higher early fruit bearing, increased fruit yield during the crop season and off-season, increased yield efficiency, higher juice content and acidity, and a higher percentage of fruit suitable for export, regardless of the selection evaluated.

1. Introduction

The global market as well as the production of 'Tahiti' lime (*Citrus latifolia* (Yu. Tanaka) Tanaka) have greatly expanded in recent years (EC, 2012; FAO, 2012; USDA, 2012). Among the horticultural variables that influence the economic viability of this crop, yield, especially during the off-season, and early fruit bearing are the most important factors, due to several diseases that reduce the commercial lifespan of the groves. In addition, fruit quality greatly influences the commercialization of the 'Tahiti' lime, especially in the international market, where prices are higher than in local markets, particularly during the main harvest season (the first half of the year in the southern hemisphere).

These variables can be maximized by carefully selecting the scion/rootstock combination. In addition, the use of production technology, particularly irrigation, has produced favorable results, increasing the fruit yield during both the crop season and the off-season (Espinoza-Núñez et al., 2011). Recent studies have evaluated the rootstocks and irrigation regimes used in 'Tahiti' lime production (Figueiredo et al., 2000, 2002; Stuchi et al., 2003, 2009; Angelocci et al., 2004; Castle et al., 2004; Stenzel and Neves, 2004; Silva et al., 2005; Alves Júnior et al., 2007, 2011; Berdeja-Arbeu et al., 2010; Espinoza-Núñez et al., 2011).

In contrast, because of limitations related to the triploidy of 'Tahiti' lime, which hinders the use of conventional improvement techniques, few studies have evaluated the scions of this cultivar (Hodgson, 1967; Jackson et al., 1972; Agustí, 2003). Thus, few selections are used commercially. In Brazil, a leading global producer of 'Tahiti' lime, production is concentrated on only two selections: "IAC-5", a nucellar clone obtained in California, USA, in 1885 (Hodgson, 1967) and "Quebra-galho", a clone contaminated by citrus viroids (Eiras et al., 2010). In contrast, new 'Tahiti' lime selections have been developed, but few have been evaluated for performance. Therefore, the present study aimed to evaluate the horticultural performance of five 'Tahiti' lime selections grafted onto 'Swingle' citrumelo [*Citrus paradisi* Macfad. cv. Duncan x *Poncirus trifoliata* (L.) Raf.], considered an adequate rootstock for this scion (Figueiredo et al., 2000, 2002; Stenzel and Neves, 2004; Espinoza-Núñez et al., 2011), under irrigated and non-irrigated conditions.

* Corresponding author. Tel.: +55 19 34294190; fax: +55 19 34294385.
E-mail address: francisco.mourao@usp.br (F.A.A. Mourão Filho).

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2. Materials and methods

2.1. Site characteristics and treatment description

The experiment was conducted in Bebedouro, São Paulo State, Brazil (20°53′16″S latitude; 48°28′11″ W longitude; 601 m altitude). The region's climate is Cwa according to the Köppen classification. Therefore, it is classified as "humid subtropical climate", with dry winters and rainy hot summers, and average temperatures above 22 °C in the hottest month. The soil was classified as a typical, moderately hypoferric dystrophic red latosol with medium texture. The experiment was initiated in March 2005 and evaluated from 2007 to 2011. The average annual rainfall recorded during the experimental period (2005–2011) was 1408 mm, with average maximum and minimum temperatures of 29.2 °C and 17.1 °C, respectively. The following 'Tahiti' lime selections were evaluated: "IAC 5", "IAC 5-1", "CNPMF/EECB", "CNPMF 2000", and "CNPMF 2001". The "IAC 5" selection was obtained from California, USA, where it is known as "Bearss lime" (Hodgson, 1967), and is one of the most cultivated selections in Brazil. The "IAC 5-1" selection was obtained from the Instituto Agronômico de Campinas (Agronomic Institute of Campinas, IAC, Brazil) by micrografting and pre-immunizing the old 'Tahiti' lime clone (accession no. 304 from the Active Germplasm Bank of the Centro APTA Citrus Silvio Moreira). The "CNPMF/EECB" selection was obtained from the Estação Experimental de Citricultura de Bebedouro (Bebedouro Citriculture Experimental Station, Brazil) from the most productive plants of the pre-immunized "CNPMF-01" selection. The "CNPMF 2000" and "CNPMF 2001" selections are of nucellar origin and were obtained from EMBRAPA Mandioca e Fruticultura (EMBRAPA Cassava and Fruit Crops, Brazil). All of the selections were grafted onto the 'Swingle' citrumelo and evaluated in two different and adjacents sites under two different irrigation conditions: non irrigated (without any irrigation) and irrigated. In the irrigated site, we used an irrigation system comprised of a drip line in each tree row, with three self-compensating drippers (2.3 l h^{-1}), which were 1.4 m apart. Irrigation was programmed for daily applications intended to replace 40% of the potential evapotranspiration (ETp). The non-irrigated site did not receive any irrigation.

2.2. Plant height and canopy volume

The plant height and canopy volume were evaluated at the third and sixth year after planting. These assessments were conducted during the first half of the year (March and April), after the main crop season harvest. The plant height values were obtained by measuring from the soil level to the plant canopy. Assuming that the plants have a geometric shape similar to a prolate semi-ellipsoid (Zekri, 2000; Stenzel and Neves, 2004), the canopy volume was calculated using the equation $V = 2/3\pi(D/2)^2H$, where V is the volume (m^3), D is the canopy diameter (m), and H is the plant height (m). The canopy diameter values were obtained from the average of the two measurements parallel and perpendicular to the plant row. The interaction between the selection and irrigation factors was determined six years after planting, representing the plants' condition at the end of the experimental period.

2.3. Yield and yield efficiency

The fruit yield was evaluated from two to six years after planting (2007–2011). Due to the numerous blooms observed throughout the years studied, we sampled up to four times per year. These harvests occurred when 70% of the fruits reached a minimum diameter of 50 mm. We evaluated the cumulative yield between the second and third year after planting (initial yield) to evaluate plant early bearing, and the cumulative yield between the second and sixth year after planting (total yield). Using the ratio between the fruit yield (kg of fruit plant^{-1}) and canopy volume (m^3), we estimated the plant yield efficiency (kg fruit m^{-3}) (Cantuarias-Avilés et al., 2010, 2011).

2.4. Fruit quality

The fruit quality characteristics were measured in the first half of 2009–2011. In each assessment, we sampled 12 fruits per plot from the median height of four canopy quadrants. The samples were evaluated for weight (g), juice content (%), total soluble solids (°Brix), and total acidity (%). After determining the fruit weight using a digital scale, the fruit juice was mechanically extracted using an extractor (OIC, OTTO 1800). The juice content was calculated using the ratio between the juice weight and fruit weight, expressed as percentage (%). The soluble solid content was determined by direct readings with a digital refractometer (Atago, PAL-1). The total acidity was determined by titration with 0.3125 N sodium hydroxide, and the values were expressed in percentage citric acid. The ascorbic acid (vitamin C) concentration, expressed in mg 100 g^{-1}, was determined by titration with 2,6-dichlorophenol-indophenol in fruits harvested in the first half of 2011.

The fruit skin color was determined in fruit harvested in the first half of 2011 using a colorimeter (Minolta, CR-300). Two readings per fruit were taken on opposite sides of the equatorial region. The following measurements were determined in each reading: brightness (L^*; $L^* = 0$, black; $L^* = 100$, white) and coordinates a^* ($-a^*$, green; $+a^*$, red) and b^* ($-b^*$, blue; $+b^*$, yellow) (Mcguire, 1992). The hue angle (h°; h° = 0°, red; 90°, yellow; 180°, green; 270°, blue) and saturation or chroma index (C^*; $C^* = 0$, gray; $C^* = 60$, vivid colors) were calculated based on the a^* and b^* values (Mcguire, 1992).

The percentages of exportable fruit and fruit unsuitable for export were evaluated in the first half of 2009 and 2010 based on the equatorial diameters of 100 fruit per plot. The fruit classified as exportable were those with equatorial diameter values between 46.5 and 60 mm, and the unsuitable fruit were those with equatorial diameter values less than 46.5 or greater than 60 mm.

2.5. Net CO_2 assimilation rate

The net CO_2 assimilation rate (A, μmol CO_2 m^{-2} s^{-1}) was evaluated in 2010 at the onset of the rainy season (October), when the plants were in bloom, and after regular pluviometric precipitation (December). The A values were recorded in the morning (9:00 am) using a infrared gas analyser (LI-COR Ltd., LI-6400) photosynthetic photon flux density (PPFD) of 1000 μmol m^{-2} s^{-1}, taking into account the citrus light saturation (Machado et al., 2005) and natural conditions for temperature, vapor pressure deficit, and CO_2 concentration (350–360 μmol mol^{-1}).

2.6. Experimental design and statistical analysis

A randomized block design was used in both experimental sites (irrigated and non-irrigated), with five treatments (selections) and four replications. Three plants were grown in each plot. Variables that met the assumptions of normality of errors and homogeneity of variance were analyzed using Fisher's test, and the means were compared by the Duncan test ($P < 0.05$). The variance analysis of the data obtained from the irrigated and non-irrigated sites consisted of a joint analysis. When there was no interaction ($P > 0.05$) between the selection and irrigation (presence or absence) factors, the effects of the factors were evaluated individually. In the case of interaction ($P < 0.05$), we evaluated the effect of the selection factor in the presence or absence of irrigation. The

Table 1
Plant height, canopy volume, initial yield (accumulated between two and three years after planting), total yield (accumulated between two and six years after planting), and yield efficiency (YE) of ‘Tahiti’ lime selections grafted onto ‘Swingle’ citrumelo under irrigated and non-irrigated conditions. Bebedouro, SP, Brazil (2007–2011).

Selection	Plant height (m)		Canopy volume (m^3)		Yield (kg $plant^{-1}$)		YE[c] (kg m^{-3})
	3rd year	6th year	3rd year	6th year	2nd to 3rd year[a]	2nd to 6th year[b]	
IAC 5	2.1 d	2.9 b	6.3 c	21.1 b	9.3 b	73.9 c	1.5 b
IAC 5-1	2.7 a	3.5 a	13.3 a	30.9 a	37.6 a	138.6 b	1.5 b
CNPMF/EECB	2.5 b	3.4 a	9.7 b	28.2 a	49.5 a	186.9 a	2.8 a
CNPMF 2000	2.2 c	3.5 a	7.0 c	28.4 a	1.9 b	10.9 d	0.2 c
CNPMF 2001	2.4 bc	3.3 a	9.9 b	30.6 a	2.0 b	13.8 d	0.2 c
Non-irrigated	2.2 b	3.1 b	7.6 b	24.1 b	15.6 b	52.4 b	1.1 b
Irrigated	2.5 a	3.5 a	10.8 a	31.5 a	24.4 a	117.2 a	1.4 a
C.V. (%)	5.9	6.7	10.0	18.7	14.0	17.6	18.1
Selection (*P*)	<0.0001	<0.0001	<0.0001	0.0060	<0.0001	<0.0001	<0.0001
Irrigation (*P*)	<0.0001	<0.0001	<0.0001	0.0027	0.0264	<0.0001	0.0364
Selection × irrigation (*P*)	0.0197	0.0735	0.0805	0.0552	0.2411	0.9615	0.5418

Means with different letters in the columns indicate significant differences according to the Duncan test ($P < 0.05$).
[a] Transformed data [$\hat{y} = (\log_{10}(y + 1)$].
[b] Transformed data [$\hat{y} = (y + 1)^{0.3}$].
[c] Transformed data [$\hat{y} = (y + 0.1)^{0.4}$].

relationship between the net CO_2 assimilation and fruit yield was evaluated using simple linear regression.

3. Results

3.1. Plant height and canopy volume

The plant height and canopy volume variables showed no interaction between selection and irrigation at six years after planting (Table 1). At three years after planting, the “IAC 5-1” selection plants showed increased canopy height and volume values compared to the other selection plants (Table 1). The greatest differences were recorded in relation to the “IAC 5” selection plants, which showed canopy height and volume values that were 33% and 53% less than the “IAC 5-1” selection plants, respectively. The “CNPMF” selection plants showed intermediate values between the “IAC 5” and “IAC 5-1” selections. On the other hand, six years after planting, no differences were found among the other selections, except for “IAC 5”, which had the lowest canopy height and volume values (Table 1).

Irrigation influenced the canopy height and volume regardless of the selection evaluated (Table 1). During the third year after planting, the irrigated plants showed greater canopy height and volume values than the non-irrigated plants (11% and 40%, respectively). Throughout the sixth year after planting, the canopy height and volume values recorded for the irrigated plants were higher than for the non-irrigated plants (13% and 30%, respectively) (Table 1).

3.2. Yield and yield efficiency

The initial yield, total yield, and yield efficiency values showed no interaction between selection and irrigation (Table 1). In contrast, this interaction was found in the yield obtained during the off-season (Fig. 1).

The initial yield values for the “CNPMF/EECB” and “IAC 5-1” selection plants were an average of 366%, 2170%, and 2079% higher than initial yield for the “IAC 5”, “CNPMF 2000”, and “CNPMF 2001” selection plants, respectively (Table 1). The initial yield values did not differ among the “IAC 5”, “CNPMF 2000”, and “CNPMF 2001” selections.

The total cumulative yield of the “CNPMF/EECB” selection was higher than from the other selections (Table 1). The plants from the “CNPMF/EECB” selection had total yield values that were 152% and 34% higher than the “IAC 5” and “IAC 5-1” selection plants, respectively. The higher yield of the “CNPMF/EECB” selection compared to the “IAC 5” selection may have resulted from the increased plant yield efficiency and canopy volume of “CNPMF/EECB”. However, compared to the “IAC 5-1”, “CNPMF 2000”, and “CNPMF 2001” selections, the higher yield of “CNPMF/EECB” seems to have been associated with its yield efficiency because the canopy volume values were similar among these four selections (Table 1). The “IAC 5-1” selection plants showed total yields that were 87% higher than those of the “IAC 5” selection (Table 1). The lowest total yield values were obtained for the “CNPMF 2000” and “CNPMF 2001” selection plants. Irrigation increased the initial yield, total yield, and yield efficiency by 56%, 123%, and 25%, respectively (Table 1).

The yield obtained during the off-season represented approximately 5% and 10% of the yield from the irrigated and non-irrigated plants, respectively. Without irrigation, the “IAC 5”, “IAC 5-1”, and “CNPMF/EECB” selection plants had similar yields, which were greater than those of the “CNPMF 2000” and “CNPMF 2001” selection plants (Fig. 1). Irrigation increased the fruit yield in the second half of the year for all of the selections ($P < 0.01$) except the “CNPMF 2000” selection. Within the irrigated site, the “IAC 5”, “IAC 5-1”, and “CNPMF/EECB” selection plants also showed higher yields than the “CNPMF 2000” and “CNPMF 2001” selection plants. However, under irrigation conditions, the yield values for the “CNPMF/EECB” selection plants during the off-season were 200% and 80% higher than the “IAC 5” and “IAC 5-1” selection plants, respectively. In addition, the “CNPMF 2001” selection plants showed higher yields than the “CNPMF 2000” selection plants, which, in turn, had the lowest yield values recorded during the off-season, under irrigation (Fig. 1).

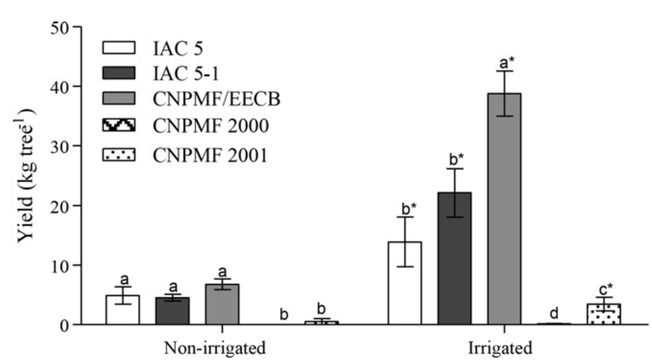

Fig. 1. Fruit yield during the off-season of the ‘Tahiti’ lime selections grafted onto ‘Swingle’ citrumelo, under irrigated and non-irrigated conditions, between two and six years after planting (2007–2011). Bebedouro, SP, Brazil. Different letters indicate significant differences among the selections according to the Duncan test ($P < 0.05$). Transformed data [$\hat{y} = (y + 1)^{0.2}$]. *Indicates a difference between the irrigated and non-irrigated plants according to Fisher’s test ($P < 0.01$). Vertical bars represent the standard error of the mean ($n = 4$).

3.3. Fruit quality

The fruit quality variable showed no interaction between selection and irrigation (Table 2). The "CNPMF 2000" and "CNPMF 2001" selections were not included because the fruit yield quantity was insufficient to perform these analyses.

In general, the variables related to fruit quality of the three evaluated selections were within the same range of the ones reported in previous studies (Figueiredo et al., 2002; Stenzel and Neves, 2004; Stuchi et al., 2009; Cantuarias-Avilés et al., 2012). Moreover, juice and soluble solid contents were above of minimum standards required for Brazilian fresh fruit market, which are 40% and 6.5°Brix, respectively (Gutierrez and Almeida, 2005). The fruit weight produced by the "IAC 5-1" selection plants was lower by 7% and 12% compared to that produced by the "IAC 5" and "CNPMF/EECB" selections, respectively (Table 2). The percentage of small fruit (equatorial diameter less than 46.5 mm) was not influenced by the selections (Table 2). On the other hand, the "IAC 5-1" selection plants showed a higher percentage of fruit suitable for export (equatorial diameter between 46.5 and 60 mm) compared to the "IAC 5" and "CNPMF/EECB" selection plants, which showed higher yields of large fruit (equatorial diameter higher than 60 mm) (Table 2). Fruits originating from the "IAC 5" and "CNPMF/EECB" selection plants had lower acidity values than fruit from the "IAC 5-1" selection plants. The juice content, soluble solid content, vitamin C content, and skin color of the fruit did not vary among the selections evaluated (Table 2).

Irrigation increased the weight, juice content, and acidity values of the fruit by 10%, 7%, and 2%, respectively, without altering the soluble solid content, vitamin C content, or skin color of the fruit (Table 2). In addition, irrigation resulted in an increased percentage of fruit suitable for export and a lower percentage of large fruit.

3.4. Net CO_2 assimilation rate

No interaction between the selection and irrigation factors was found for the CO_2 assimilation rates (A). The selections had similar A values in October 2010. However, irrigated plants showed A values that were 113% higher than those of non-irrigated plants, regardless of the selection studied (Fig. 2). In December 2010, the "CNPMF/EECB" selection plants showed A values that were 20% and 52% higher than those of the "IAC 5" and "CNPMF 2000" selection plants, respectively (Fig. 2). In contrast, there was no difference in the A values between the irrigated and non-irrigated plants, possibly due to regular pluviometric precipitation in December. Regression analysis involving the A values recorded in October 2010 and the fruit yields obtained in the first half of 2011 indicated a positive correlation between these variables (Fig. 3). This correlation was not observed when considering the A values recorded in December ($P > 0.05$).

4. Discussion

Obtaining 'Tahiti' lime selections that result in smaller plants is desirable considering the trend toward increasing planting density and the production costs of controlling pests and diseases, notably Huanglongbing (Fukuda et al., 2010). The higher vegetative growth showed by "IAC 5-1", "CNPMF/EECB", "CNPMF 2000", and "CNPMF 2001" selection plants indicates that orchards composed of these selections would present further limitations in increasing plant density and controlling pests and diseases when compared to those composed of the "IAC 5" selection. Similarly, as it induces higher plant growth, the use of irrigation might accentuate these limitations to a greater extent. The reduction of plant size of selections that are alternatives to the "IAC 5" selection, as well as irrigated

Table 2
Weight, distribution in diameter classes, juice yield (JY), total soluble solids (TSS), acidity, ascorbic acid, lightness (L*), chroma (C*), and hue angle (h°) of fruit originating from the 'Tahiti' lime selections grafted onto 'Swingle' citrumelo under irrigated and non-irrigated conditions. Bebedouro, SP, Brazil, 2009–2011.

Selection[a]	Weight[b] (g)	Diameter classes[c] (%)			JY[b] (%)	TSS[b] (°Brix)	Acidity[b] (%)	Ascorbic acid[d] (mg 100 g^{-1})	L*[d]	C*[d]	h°[d]
		<46.5 mm	46.5–60.0 mm	>60.0 mm							
IAC 5	97.6 a	3.0	82.8 b	14.2 a	48.1	8.5	6.1 b	17.8	49.8	32.6	108.7
IAC 5-1	90.2 b	5.8	88.6 a	5.7 b	49.8	8.5	6.3 a	17.2	48.1	34.2	109.3
CNPMF/EECB	102.8 a	3.2	82.7 b	14.2 a	49.3	8.4	6.1 b	18.3	49.3	30.5	109.5
Non-irrigated	92.6 b	4.3	82.6 b	13.1 a	47.2 a	8.5	6.1 b	17.7	47.9	30.6	109.5
Irrigated	101.1 a	3.7	86.7 a	9.6 b	50.9 b	8.4	6.3 a	17.8	50.3	34.2	108.9
C.V. (%)	5.6	51.9	5.3	27.6	2.5	3.1	2.0	11.8	6.0	20.8	1.6
Selection (P)	0.0019	0.5921	0.033	0.0002	0.0598	0.7545	0.0045	0.6159	0.5	0.5526	0.6482
Irrigation (P)	0.0207	0.7727	0.0406	0.017	<0.0001	0.5929	0.0267	0.9881	0.875	0.1311	0.3095
Selection × irrigation (P)	0.5019	0.7788	0.0967	0.0041	0.5814	0.2101	0.9211	0.0655	0.2707	0.352	0.4736

Different letters in the columns indicate significant differences according to the Duncan test ($P < 0.05$).
[a] The "CNPMF 2000" and "CNPMF 2001" selections were not included because the fruit quantity produced was insufficient to perform these analyses.
[b] Mean values obtained from the assessments in the first half of 2009–2011.
[c] Values obtained in assessments performed in the first half of 2009 and 2010.
[d] Values obtained from the assessment conducted in the first half of 2011.

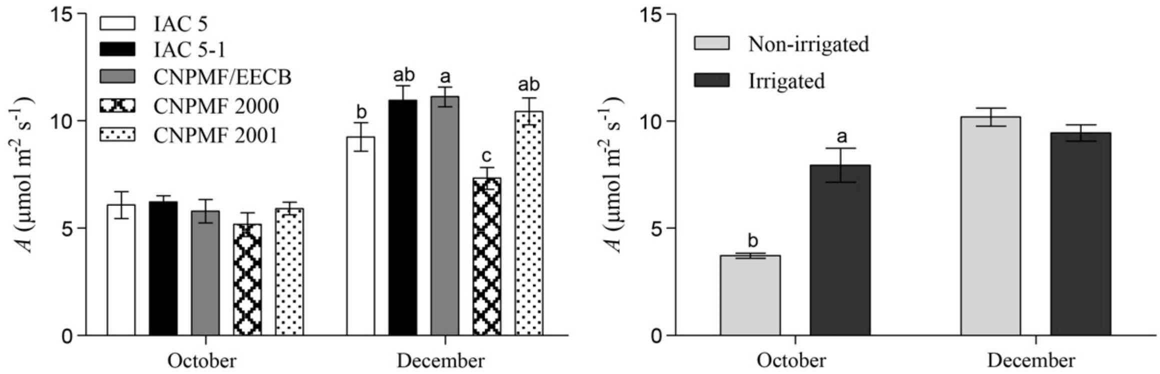

Fig. 2. CO_2 assimilation rate (*A*) of irrigated and non-irrigated 'Tahiti' lime selections grafted onto 'Swingle' citrumelo obtained during the morning (9:00 am) in October (10/06/10) and December 2010 (12/15/10). Bebedouro, SP, Brazil. Bars represent the standard error of the mean ($n = 4$). Different letters indicate significant differences according to the Duncan test ($P < 0.05$).

plants, can be achieved using rootstocks that induce dwarfism, such as the 'Flying Dragon' trifoliate (*Poncirus trifoliata* var. monstrosa) (Stuchi et al., 2003; Cantuarias-Avilés et al., 2010, 2011; Espinoza-Núñez et al., 2011), and by applying canopy reduction techniques, such as pruning.

Despite the limitations associated with increased vegetative growth, the use of the "IAC 5-1" and "CNPMF/EECB" selection plants is more appropriate than the "IAC 5" selection, regardless of irrigation or not, due to their higher early-bearing and higher yield. With irrigation, the "CNPMF/EECB" selection becomes even more advantageous due to its higher fruit yield during the off-season, when prices reach higher values than during the crop season. Similarly, the higher early-bearing and higher fruit yield in irrigated plants during the crop season and off-season justify the use of irrigation in the 'Tahiti' lime cultivation. The unfavorable results related to vegetative growth and low fruit yield prevent the recommendation of the "CNPMF 2000" and "CNPMF 2001" selections for commercial-scale use under conditions that are similar to those used in the present experiment. The low yield values of the "CNPMF 2000" and "CNPMF 2001" selection plants appear to be associated with reduced flowering rates throughout the crop seasons evaluated (data not quantified). Considering the nucellar origin of these selections and the fact that they have rarely been reproduced, it is probable that these selections have not fully matured beyond the juvenile stage.

The favorable influence of irrigation on the vegetative growth and fruit yield of 'Tahiti' lime, as well as of other citrus species, has

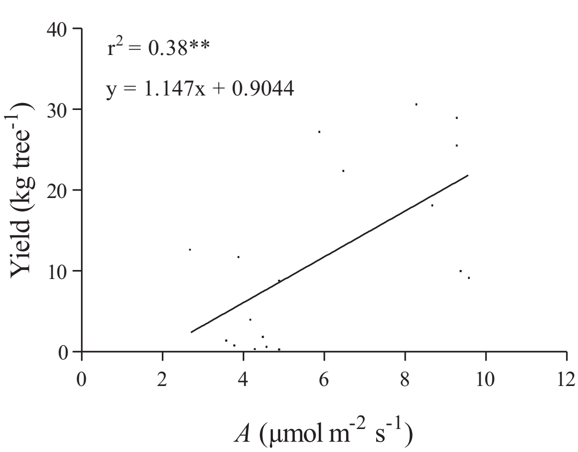

Fig. 3. Fruit yield from 'Tahiti' lime plants in the first half of 2011 according to the net CO_2 assimilation rate (*A*) at flowering (October 2010). Bebedouro, SP, Brazil. **Significant ($P < 0.01$).

been reported in previous studies (Prado et al., 2007; Espinoza-Núñez et al., 2011) and is associated with a higher net CO_2 assimilation rate (Alves Júnior et al., 2005). In fact, the highest yield values were associated with the highest CO_2 assimilation rates recorded at the onset of the rainy season (October), when the plants were flowering. The higher *A* values may have influenced carbohydrate availability, which is essential for determining production processes such as flowering, fixation, and fruit growth (Mehouachi et al., 1995; Iglesias et al., 2003; Prado et al., 2007). Moreover, in the region where the experiment was conducted, the annual water deficit reaches values of up to 250 mm, causing intense leaf and young fruit abscission, hindering vegetative growth and fruit yield in non-irrigated plants.

Fruit quality is a key aspect in 'Tahiti' lime production, especially during the crop season. During this period, the fruit supply is high, and prices at local markets are reduced, making fruit export more economically attractive. The skin color and diameter of the fruit are quality variables that most influence the classification of fruit for export, which requires dark-green-colored fruit between 46.5 and 60 mm in diameter. The fruit skin color was not influenced by the selections, but the "IAC 5-1" selection plants showed a higher percentage of fruit with diameters suitable for export. In this sense, the "IAC 5" and "CNPMF/EECB" selections showed less favorable results due to the higher percentage of fruit with diameters larger than that accepted by the international market. Irrigation did not affect the fruit skin color; however, irrigation resulted in a higher percentage of fruit with diameters suitable for export. Non-irrigated plants were less favorable due to the higher percentage of fruit that reached a diameter greater than 60 mm. Although the quality assessments were conducted in the first half of the year, a period characterized by regular pluviometric precipitation, irrigation also induced higher juice yield and higher fruit weight. This influence was possibly higher in the initial stages of fruit development (October and November), when there was less regular pluviometric precipitation.

5. Conclusions

The "IAC 5-1", "CNPMF/EECB", "CNPMF 2000", and "CNPMF 2001" selections showed increased vegetative growth compared to the "IAC 5" selection, regardless of the use of irrigation.

The "CNPMF/EECB" selection showed precocity in the onset of production, higher fruit yield, and yield efficiency, regardless of the irrigation conditions. With irrigation, this selection showed increased fruit yield during the off-season.

Irrigation induced higher vegetative growth, early-bearing, higher fruit yield during the crop season and off-season, higher yield efficiency, higher fruit weight, juice yield and acidity, and a higher percentage of fruit suitable for export.

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References

Agustí, M., 2003. Citricultura. Mundi-Prensa, Madrid, 422 p.

Alves Júnior, J., Silva, C.R., Ribeiro, R.V., Silva, T.J.A., Folegatti, M.V., 2005. Crescimento de plantas jovens de limeira ácida 'Tahiti' sob lâminas de irrigação. Eng. Agríc. 25, 170–178.

Alves Júnior, J., Folegatti, M., Parsons, L.R., Bandaranayake, W., Silva, C.R., Silva, T.J.A., Campeche, L.F.S.M., 2007. Determination of the crop coefficient for grafted 'Tahiti' lime trees and soil evaporation coefcicient of Rhodic Kandiudalf clay soil in São Paulo, Brazil. Irrig. Sci. 25, 419–428.

Alves Júnior, J., Folegatti, M., Silva, C.R., Silva, T.J.A., Evangelista, A.W.P., 2011. Response of young 'Tahiti' lime trees to different irrigation levels. Eng. Agríc. 31, 303–314.

Angelocci, L.R., Marin, F.R., Oliveira, R.F., Righi, E.Z., 2004. Transpiration, leaf diffusive conductance, and atmospheric water demand relationship in an irrigated acid lime orchard. Braz. J. Plant Physiol. 16, 53–64.

Berdeja-Arbeu, R., Villegas-Monter, A., Ruiz-Posadas, L.M., Sahagun-Castellanos, J., Colinas-Leon, M.T., 2010. Interacion lima persa-portainjertos. Efecto en caracteristicas estomaticas de hoja y vigor del arboles. Chapingo 16, 91–97.

Cantuarias-Avilés, T., Mourão Filho, F.A.A., Stuchi, E.S., Silva, S.R., Espinoza-Núñez, E., 2010. Tree performance and fruit yield and quality of 'Okitsu' Satsuma mandarin grafted on 12 rootstocks. Sci. Hortic. 123, 318–322.

Cantuarias-Avilés, T., Mourão Filho, F.A.A., Stuchi, E.S., Silva, S.R., Espinoza-Núñez, E., 2011. Horticultural performance of 'Folha Murcha' sweet orange onto twelve rootstocks. Sci. Hortic. 129, 259–265.

Cantuarias-Avilés, T., Mourão Filho, F.A.A., Stuchi, E.S., Silva, S.R., Espinoza-Núñez, E., Bremer Neto, H., 2012. Rootstocks for high fruit yield and quality of 'Tahiti' lime under rain-fed conditions. Sci. Hortic. 142, 105–111.

Castle, W.S., Grosser, J.W., Gmitter Jr., F.G., Schnell, R.J., Ayala-Silva, T., Crane, J.H., Bowman, K.D., 2004. Evaluation of new rootstocks for 'Tahiti' lime production in southern Florida. Proc. Fla. State Hortic. Soc. 117, 174–181.

EC, European Commission, 2012. http://exporthelp.europa.eu (22.03.2012).

Eiras, M., Silva, S.R., Stuchi, E.S., Flores, R., Daros, J.A., 2010. Viroid species associated with the bark-cracking phenotype of 'Tahiti' acid lime in the State of São Paulo, Brazil. Trop. Plant Pathol. 35, 303–309.

Espinoza-Núñez, E., Mourão Filho, F.A.A., Stuchi, E.S., Cantuarias-Avilés, T., Dias, C.T.S., 2011. Performance of 'Tahiti' lime on twelve rootstocks under irrigated and non-irrigated conditions. Sci. Hortic. 129, 227–231.

FAO, Food and Agriculture Organization, 2012. http://www.fao.org (22.03.2012).

Figueiredo, J.O., Pompeu Junior, J., Teófilo Sobrinho, J., Pio, R.M., Laranjeira, F.F., Lima, J.E.O., Salibe, A.A., 2000. Porta-enxertos para lima ácida 'Tahiti' na região de Aguaí, SP. Rev. Bras. Frutic. 22, 435–439.

Figueiredo, J.O., Stuchi, E.S., Donadio, L.C., Teófilo Sobrinho, J., Laranjeira, F.F., Pio, R.M., Sempionato, O.R., 2002. Porta-enxertos para lima ácida 'Tahiti' na região de Bebedouro, SP. Rev. Bras. Frutic. 24, 155–159.

Fukuda, L.A., Franco, D., Facio, S.L., Lima Neto, R.S., 2010. Economic sustainability of the citrus industry under the huanglongbing scenario. Citrus Res. Technol. 31, 107–114.

Gutierrez, A.S.D., Almeida, G.V.B., 2005. Beneficiamento e comercialização de frutos *in natura*. In: Mattos Jr., D.de., De Negri, J.D., Pio, R.M., Pompeu Jr., J. (Eds.), Citros. Instituto Agronômico/FUNDAG, Campinas, pp. 824–837.

Hodgson, R.W., 1967. Horticultural varieties of citrus. In: Reuther, W., Webber, H.J., Batchelor, L.D. (Eds.), The Citrus Industry, vol. 1. University of California, Berkley, pp. 431–591.

Iglesias, D.J., Tadeo, F.R., Primo-Millo, E., Talon, M., 2003. Fruit set dependence on carbohydrate availability in citrus trees. Tree Physiol. 2, 199–204.

Jackson, L.K., Shermann, W.B., Campbell, C.W., 1972. Seedlessness in 'Tahiti' lime. Proc. Fla. State Hortic. Soc., 330–332.

Machado, E.C., Schmidt, P.T., Medina, C.L., Ribeiro, R.V., 2005. Respostas da fotossíntese de três espécies de citros a fatores ambientais. Pesqui. Agropec. Bras. 40, 111–117.

Mehouachi, J., Serna, D., Zaragoza, S., Agusti, M., Talon, M., Primo-Millo, E., 1995. Defoliation increases fruit abscission and reduces carbohydrate levels in developing fruits and woody tissues of *Citrus unshiu*. Plant Sci. 107, 189–197.

Mcguire, R.G., 1992. Reporting of objective color measurements. HortScience 27, 1254–1255.

Prado, A.K.S., Machado, E.C., Medina, C.L., Machado, D.F.S.P., Mazzafera, P., 2007. Florescimento e frutificação em laranjeiras 'Valência' com diferentes cargas de frutos e submetidas ou não à irrigação. Bragantia 66, 173–182.

Silva, C.R., Folegatti, M.V., Silva, T.J.A., Alves Jr., J., Souza, C.F., Ribeiro, R.V., 2005. Water relations and photosynthesis as criteria for an adequate irrigation management in 'Tahiti' lime trees. Sci. Agric. 62, 415–422.

Stenzel, N.M.C., Neves, C.S.V.J., 2004. Rootstocks for 'Tahiti' lime. Sci. Agric. 61, 151–155.

Stuchi, E.S., Donadio, L.C., Sempionato, O.R., 2003. Performance of 'Tahiti' lime on *Poncirus trifoliata* var. monstrosa Flying Dragon in four densities. Fruits 58, 1–5.

Stuchi, E.S., Martins, A.B.G., Lemo, R.R., Cantuarias-Avilés, T., 2009. Fruit quality of 'Tahiti' lime (*Citrus latifolia* Tanaka) grafted on twelve different rootstocks. Rev. Bras. Frutic. 31, 454–460.

USDA, United States Department of Agriculture, 2012. http://www.usda.gov (22.03.2012).

Zekri, M., 2000. Citrus rootstocks affect scion nutrition, fruit quality, growth, yield and economical return. Fruits 55, 231–239.