Acta Scientiarum
http://www.periodicos.uem.br/ojs/
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v46i1.63302

CROP PRODUCTION

Early rootstock selection under 'tahiti' acid lime crown in Capitão Poço, Pará State, Brazil

Fábio de Lima Gurgel[1], Keny Henrique Mariguele[2], Gilberto Ken Iti Yokomizo[3*], Romeu de Carvalho Andrade Neto[4], Eduardo Augusto Girardi[5], Orlando Sampaio Passos[5] and Walter dos Santos Soares Filho[5]

[1]Empresa Brasileira de Pesquisa Agropecuária, Embrapa Amazônia Oriental, Belém, Pará, Brazil. [2]Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina, Itajaí, Santa Catarina, Brazil. [3]Empresa Brasileira de Pesquisa Agropecuária, Embrapa Amapá, Rodovia Josmar Chaves Pinto, km 5, 2600, 68903-419, Macapá, Amapá, Brazil. [4]Empresa Brasileira de Pesquisa Agropecuária, Embrapa Acre, Rio Branco, Acre, Brazil. [5]Empresa Brasileira de Pesquisa Agropecuária, Embrapa Mandioca e Fruticultura, Cruz das Almas, Bahia, Brazil. *Author for correspondence. E-mail: gilberto.yokomizo@embrapa.br

ABSTRACT. Citrus represents one of the main fruit crops grown in the world, highlighting the 'Tahiti' acid lime tree. The objective was to compare rootstock varieties combined with this scion to identify those with the best agronomic performance and precocity of production, in addition to *Phytophthora* gummosis resistance. The experiment was carried out in Capitão Poço, northeast region of Pará, and the following seven rootstock genotypes were evaluated: 'Sunki Tropical', 'BRS O S Passos', 'BRS Bravo', 'BRS Donadio', 'Citrandarin Indio', 'BRS Matta', and 'LVK x LCR-038'. A randomized block experimental design was used, with three replications and 10 plants per plot. The evaluated characteristics were: plant height (m); crown volume (m^3); number of ripe fruit per plant; total yield of ripened fruit per plant (kg $plant^{-1}$); cumulative fruit yield (fruit kg $plant^{-1}$); and average productive efficiency (fruit kg m^{-3} of crown). The average productive efficiency was high. For early selection, the best rootstocks in terms of yield, stability and adaptability were Sunki Tropical, BRS O S Passos, and Cintradarin Indio. The fruit number had the greatest direct effect on fruit yield, and crown pruning was directly harmful. Further studies to understand the complex interaction of G x E for BRS Donadio and Sunki Tropical should be carried out.

Keywords: *Citrus* spp.; fruticulture; genetic breeding; association measures; predictability.

Received on April 19, 2022.
Accepted on July 28, 2022.

Introduction

Citrus is a main fruit crop and is planted in more than 140 countries around the world. It is consumed as fresh fruit, juice or concentrate and is an excellent source of vitamins, minerals and dietary fiber according to Food and Agriculture Organization of the United Nations (FAO, 2022). Currently, in Brazil, there are 1.49 million rural establishments that mainly produce oranges, tangerines, limes and lemons, with a planted area of 2.9 million hectares and a production of 14.9 million tons (Confederação da Agricultura e Pecuária do Brasil [CNA], 2019). In terms of exports, lemons help the economy by generating direct and indirect jobs, as they are a promising product in the competitiveness of the national and international markets.

In Brazil, one of the hybrid varieties with prominence is the 'Tahiti' acid lime tree (popularly known as green lime), resulting from crossing Sicilian lime with Persian lime (Rossi & Pandolfi, 2019). Its fruit is rich in vitamin C, phenolic and bioactive compounds, and substances with high antioxidant potential, thus constituting a product of great importance for human health (Carvalho, Castro, & Silva, 2008).

In the north region, the state with the highest citrus production is Pará, being in the sixth national position with 447,922 tons produced in a harvested area of 20,582 hectares, resulting in an average productivity of 20.47 t ha^{-1}, with a 2.29% share of the country's production. Lemon production in the state achieves approximately 104,922 tons of lemons, which represents the second position of the largest producer in the country, with a share of 6.94% (Instituto Brasileiro de Geografia e Estatística [IBGE], 2019). This is attributed to the fact that the state is a Citrus Canker Free Area, as recognized by the Ministério da Agricultura, Pecuária e Abastecimento (MAPA), has consumer demand, achieves crop profitability, and has conducive soil and climate characteristics for planting.

The citrus industry of Pará State is located in the Guamá microregion, in the municipalities of Capitão Poço, Irituia, Nova Esperança do Piriá, and Ourém (Agência de Defesa Agropecuária do Estado do Pará

[ADEPARÁ], 2017). The municipality of Capitão-Poço contains about 13,645 hectares of citrus, which represents 66.0% of the total in Pará State, Brazil. In this municipality, 77% of the harvested area is orange (51% of the state), 17% lemon, and 6% tangerine (IBGE, 2019). Thus, citrus farming is of great socioeconomic importance for the municipality, generating around 50 million reais and 30,000 direct and indirect jobs. There are an estimated 4000 producers working with citrus fruit plantations. In addition to the municipality supplying the region, it serves other regions of the country, such as the northeast and southeast, and exports to other countries (Fundação Norte-Rio-Grandense de Pesquisa e Cultura [FUNDEPEC], 2019; IBGE, 2018).

Despite the good yield and the significant social and economic importance of citrus for Pará, there are problems related to crop management. The 'Cravo' lime is still the most used rootstock in the region; however, it is susceptible to *Phytophthora* gummosis, a disease that can cause 100% plant death, in addition to imposing low vigor on plants, a fact that makes it difficult to increase plant density, planting, pest and disease management, and harvesting. Therefore, one of the challenges for citrus growers is to obtain knowledge about the behavior of suitable crown combinations with different rootstocks regarding compatibility, resistance or tolerance to biotic and abiotic factors and agronomic characteristics (Cerqueira et al., 2004; Nogueira, Moares, & Burity, 2001). In addition, diversification allows for greater plant survival in the event of disease (Petry, Reis, Silva, Gonzatto, & Schwarz, 2015).

Thus, studies on the use of different rootstocks are extremely important because, depending on the combination with the crown variety, its characteristics can be influenced, such as production, fruit mass, tolerance to water stress, greater response to fertilization and fruit quality. Therefore, the objective of this work was to compare rootstock varieties, in combination with the 'Tahiti' acid lime tree crown, to identify those with better agronomic characteristics and precocity of production.

Material and methods

Characterization of the study site

The experiment was carried out in the rural area of Capitão Poço, a municipality located in the northeast region of the state of Pará, Brazil, at Fazenda Lima, with geographic coordinates of 01°44'47" S and 47º03'34" W. The Capitão Poço municipality has a temperature range of 25.7 to 26.9ºC, with an annual average temperature of 26.2°C (Silva, Boiça Júnior, Farias, & Barbosa, 2011). According to the Köppen classification, the climate in the region is Am (altitude tropical), with annual rainfall around 2500 mm, a short dry season between September and November (monthly rainfall around 60 mm), and relative air humidity between 75 and 89% in the months with the lowest and highest rainfall, respectively (Schwart, 2007).

The rootstock seedlings were produced in an environment with 50% shading using seeds from the active germplasm bank of Embrapa Mandioca e Fruticultura, located in Cruz das Almas, Bahia State, Brazil. When the rootstocks reached an appropriate diameter, an inverted T-type bud graft was performed using Tahiti acid lime buds.

Conventional soil preparation was carried out with plowing and harrowing. Planting took place in March 2016 at a spacing of 3.0 m between plants x 6.0 m between rows. Specific cultural treatments were carried out for citrus cultivation, according to the farm's practices, such as monitoring and elimination of undesirable plants, crowning of plants, use of mulch, and fertilization, according to the nutritional program of Fazenda Lima.

Treatments and experimental design

In combination with the Tahiti acid lime crown, seven rootstock genotypes were evaluated: 'Sunki Tropical', 'BRS O S Passos', 'BRS Bravo', 'BRS Donadio', 'Citrandarin Indio', 'BRS Matta', and 'LVK x LCR-038'.

A randomized block experimental design was used, with three replications and 10 plants per plot, for a total of 210 plants.

Evaluated characteristics

Over four years (2017, 2018, 2019, and 2020), the following characteristics were evaluated: plant height (m), measured from the base of the stem, at ground level, to the end of the highest branch; crown volume (m^3), according to Mendel (1956), through the formula $V = \frac{2}{3}.\pi.R^2.H$, where V is the volume (m^3), R is the crown radius (m) and H is the plant height (m); and number of ripe fruit per plant, obtained by counting the harvested fruit.

In 2019 and 2020, the following characteristics were evaluated: total yield of ripe fruit per plant (kg $plant^{-1}$), determined by weighing all fruit harvested from the plant in a given season; cumulative fruit production (kg of fruit plant^{-1}), obtained by summing the weight of all fruit harvested in the 2019 and 2020 harvests; and average productive efficiency (kg of fruit m^{-3} of crown), ratio obtained by the accumulated production of fruit and the crown volume before harvest. Yield fruit assessments were only included in the years 2019 and 2020, as it was necessary to carry out drastic pruning, reducing the average crown volume to about 1.0 to 1.5 m^3 in 2018, as the crowns began to show intertwining of branches, which would harm the photosynthesis of the plants and greatly increase the competition between them.

Statistical analysis

Data analysis was initially verified with R v.4.0 (http://cran-r.c3sl.ufpr.br). The assumptions of normality (Shapiro–Wilk test) and homogeneity of variances (Levene's test) were determined using the "car" v.3 package (Fox & Weisberg, 2019). Subsequently, analysis of variance (ANOVA), Scott–Knott average tests ($p < 0.05$), trail analysis with the "agricolae" v.1.3-5 package (Mendiburu, 2021), correlation map with the "corrplot" package v.0.92 (Wei & Simko, 2021) and factor analysis with p package "sciplot" v.1.2-0 (Morales, 2000) were performed.

From the fruit production data, the adaptability and stability of the genotypes were evaluated with the aid of the Genes program (Cruz, 2016) using the methodology proposed by Schmildt, Nascimento, Cruz, and Oliveira (2011):

For the general environment:

$$I_i = \overline{Y_{i.}} - Z_{(1-\alpha)}(\sigma_{i.} / \sqrt{n}) \quad (1)$$

where n is the total number of environments.

For favorable environments:

$$I_{if} = \overline{Y_{if}} - Z_{(1-\alpha)}(\sigma_{if} / \sqrt{f}) \quad (2)$$

where f is the number of favorable environments.

For unfavorable environments:

$$I_{id} = \overline{Y_{id}} - Z_{(1-\alpha)}(\sigma_{id} / \sqrt{d}) \quad (3)$$

where d is the number of unfavorable environments,1 $1 - \sigma$ is equal to 95%, and $Z = 1.6449$.

Schmildt et al. (2011) proposed the decomposition of Ii for favorable (Iif) and unfavorable (Iid) environments, according to the environmental indices. This environmental index is defined as the difference between the average of the grafts/rootstocks evaluated in each environment and the general average. Favorable environments are those with indices greater than or equal to zero, and those with negative indices are unfavorable.

The average productive efficiency was calculated by the quotient of the average production of fruit over time to compensate for the alternation of production by the average volume of the crowns, using the formula: $V = \frac{2}{3}.\pi.R^2.H$, where R is the average radius of the crown and H is the height of the plant (Mendel, 1956).

Pearson's phenotypic correlations were estimated (Cruz, Regazzi, & Carneiro, 2014), which is represented by the letter r and assumes values from -1 to +1. When r = 1, there is a representation of the perfect and positive correlation between two variables, whereas r = -1 represents a perfect negative correlation between two variables; that is, while one increases, the other decreases, and as it approaches 1, the correlation becomes perfect. With the estimates obtained, the correlation graphs were structured, to visualize the behavior of correlations (Hama, 2020).

Results and discussion

The rootstocks Sunki Tropical and BRS O S Passos stood out in terms of plant height and fruit number during the four years of evaluation. BRS Matta stood out in the four years in terms of plant height, and Sunki Tropical presented a higher crown volume in the evaluated years. Sunki Tropical, BRS O S Passos, BRS Donadio, and Citrandarin Indio had the highest fruit number in 2019, and BRS O S Passos had the highest fruit number in 2020 (Table 1).

For the average plant height, Table 1 shows the formation of two groups of average classification; comparatively, there was less formation in relation to the trend of the three groups mentioned by Roncatto et al. (2021). This indicates that the materials were more similar under these conditions. In general, in relation to each specific graft/rootstock, the distribution within the groups was also similar. For the same age of 3/4 years, the height was lower than that obtained by Portella et al. (2016), who studied Tahiti lime. In the crown volume, the classification was similar, as was the CVs, to those presented by Roncatto et al. (2021).

Table 1. Plant height, crown volume, and fruit number of 'Tahiti' acid lime grafted on seven rootstocks between 2017 and 2020*.

Rootstocks	Average plant height (m)				Average
	2017	2018	2019	2020	
Sunki Tropical	2.15ª	2.37ª	2.36ª	2.74ª	2.41ª
BRS O S Passos	2.05ª	2.19ª	2.29ª	2.58ª	2.28ª
BRS Bravo	1.66ᵇ	1.85ᵇ	1.97ª	2.30ᵇ	1.94ᵇ
BRS Donadio	1.50ᵇ	1.75ᵇ	2.05ª	2.18ᵇ	1.87ᵇ
Citrandarin Indio	2.01ª	1.98ᵇ	2.09ª	2.61ª	2.17ª
BRS Matta	1.97ª	2.04ª	2.26ª	2.58ª	2.21ª
LVK x LCR – 038	1.36ᵇ	1.69ᵇ	2.01ª	2.12ᵇ	1.80ᵇ
Average	1.82ᴮ	1.98ᴮ	2.15ᴮ	2.44ᴬ	2.10
CV (%)	10.59	9.13	7.08	11.21	9.41
Rootstocks	Average crown volume (m^3)				Average
	2017	2018	2019	2020	
Sunki Tropical	4.73ª	9.31ª	1.23ª	1.41ª	4.17ª
BRS O S Passos	3.98ª	6.42ᵇ	0.99ª	1.50ª	3.22ª
BRS Bravo	2.58ᵇ	4.56ᶜ	1.03ª	1.30ª	2.36ᵇ
BRS Donadio	1.80ᵇ	4.37ᶜ	0.37ª	1.26ª	1.95ᵇ
Citrandarin Indio	4.21ª	5.79ᵇ	1.32ª	1.68ª	3.25ª
BRS Matta	3.95ª	6.26ᵇ	1.12ª	1.41ª	3.20ª
LVK x LCR – 038	1.32ᵇ	2.51ᵈ	1.50ª	1.26ª	1.65ᵇ
Average	3.22ᴮ	5.60ᴬ	1.08ᶜ	1.41ᶜ	2.83
CV (%)	26.77	13.22	32.50	20.15	29.14
Rootstocks	Average fruits number per plant				Average
	2017	2018	2019	2020	
Sunki Tropical	1.83ª	47.27ª	62.33ª	53.00ᵇ	41.11ª
BRS O S Passos	8.60ª	29.07ª	49.00ª	99.67ª	46.58ª
BRS Bravo	1.37ª	9.10ᵇ	17.67ᵇ	64.00ᵇ	23.03ª
BRS Donadio	5.00ª	12.33ᵇ	42.33ª	29.00ᶜ	22.17ª
Citrandarin Indio	0.83ª	24.00ᵇ	45.00ª	58.00ᵇ	31.96ª
BRS Matta	0.97ª	20.10ᵇ	28.00ᵇ	53.67ᵇ	25.68ª
LVK x LCR – 038	1.07ª	8.57ᵇ	25.67ᵇ	37.80ᶜ	18.27ª
Average	2.81ᴮ	21.49ᴮ	38.57ᴬ	56.45ᴬ	29.83
CV (%)	97.03	61.24	39.03	33.16	55.86

*Means followed by different lowercase letters in a column and uppercase letters in a row differ at the 5% probability level using the Scott–Knott test.

There was a reduction in the crown volume in 2019 due to pruning being carried out because of the initial intertwining between branches of neighboring plants. This conduction process can be beneficial according to Azevedo, Pacheco, Schinor, Carvalho, and Conceição (2015), as it allows for a higher planting density, which is reflected in increased productivity in some orange trees. Another positive factor is associated with the vigor of the trunk of the aerial part, where pruning, which generates shorter branches, can reduce bending and breakage of these branches, according to the care mentioned by Lima, Marinho, Costa, and Vasconcelos (2014).

For the characteristic number of fruit produced, the group with the best performance was the one that used the Citrandarin Indio rootstock (Table 1), which was similar to the superior group identified by Rodrigues, Andrade Neto, Lessa, Girardi, and Soares Filho (2018).

Due to the different classifications between the years, the environmental index was estimated for the graft–rootstock set to confirm which years were favorable. The years 2017 and 2018 were considered unaffordable, while 2019 and 2020 were favorable for the number of fruit (Figure 1). Additionally, there were different intensities in this index; that is, there were environmental conditions with factors of different amplitudes in its phenotypic manifestation, making it important to consider the presence of the effect of the genotype interaction with the environment (Rocha, Ramalho, Teixeira, Souza, & Cruz, 2015).

Environmental indices (Figure 1) are directly reflected in lower plant production efficiency; that is, in the years 2019 and 2020, there is greater fruit productivity per plant (Table 1), even with the pruning of the crown fulfilled. Pruning may have improved the entry of sunlight, favoring photosynthesis and consequently generating better flowering and fruit production per plant, resulting in a higher environmental index. In the first two years of evaluation, the plants, being young, could still not express their full productive potential, while in the later years, the plants approached this potential. For this reason, the drastic pruning process had no harmful effect on productivity. Based on environmental indices, therefore studies on the identification of environments (years) were deepened through the analysis of adaptability and stability, according to Schmildt et al. (2011).

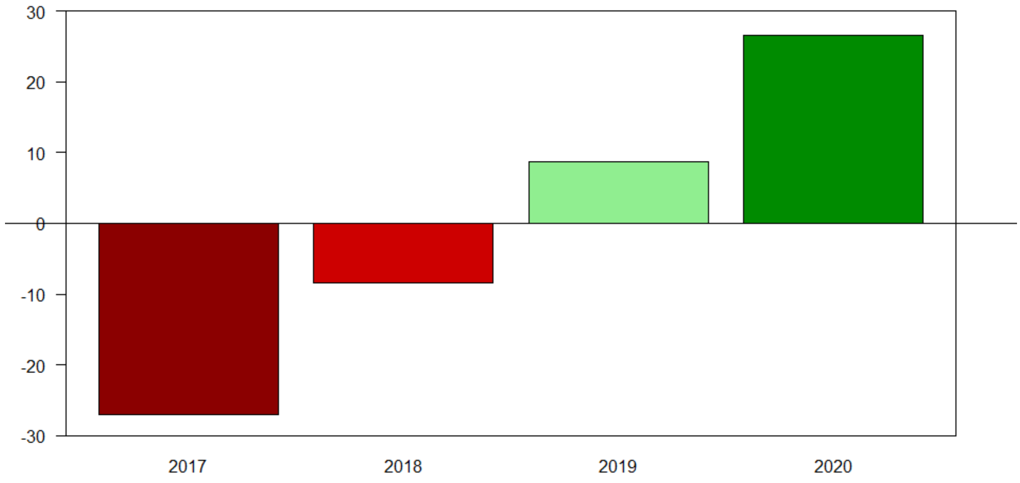

Figure 1. Environmental index by Schmildt et al. (2011) of the fruit number from 'Tahiti' acid lime grafted on seven rootstocks in four years of evaluation.

The rootstocks Sunki Tropical, BRS O S Passos and Cintradarin Indio presented the best performances in terms of general adaptability and stability to favorable environments, and BRS O S Passos stood out in terms of specific adaptability to unfavorable environments and stability (Table 2). In this case, materials that respond better to favorable conditions are better adapted to these conditions when analyzing their behavior in unfavorable environments. The BRS O S Passos rootstock stands out with positive behavior in any condition. The main characteristic of this material is the tendency to flower throughout the year, a response to the induction of flowering by fertilization management, allowing production in the off-season, in addition to a greater shelf life and a lower rate of floral abortion (Bastos et al., 2014). Other rootstocks have been shown to adapt better when favorable environmental conditions are offered.

Table 2. Adaptability and stability parameters according to the methodology of Schmildt et al. (2011) for the fruit number of 'Tahiti' acid lime grafted onto seven rootstocks in four years of evaluation.

	General		Favorable environments		Unfavorable environments	
	Average (%)	W_i	Average (%)	W_i	Average (%)	W_i
Sunki Tropical	135.17	53.90	127.75	71.73	142.60	14.62
BRS O S Passos	186.24	89.37	151.80	110.82	220.68	79.33
BRS Bravo	62.54	22.77	79.59	23.68	45.49	40.28
BRS Donadio	99.12	30.40	80.56	32.27	117.68	17.92
Citrandarin Indio	90.19	42.50	109.71	98.20	70.67	2.81
BRS Matta	73.90	40.84	83.83	65.23	63.97	15.05
LVK x LCR – 038	52.83	34.00	66.75	66.40	38.91	37.34

In the presence of different performances for adaptability and stability, an analysis of genotype x year interaction was performed, which was significant ($p = 0.0141$) for fruit yield, as shown in Figure 2.

Figure 2 shows the presence of a complex interaction between rootstock and years, mainly for BRS Donadio and Sunki Tropical, with changes in the behavior of fruit yield in relation to the set of rootstocks under study. Graphically, it is considered complex because the rootstocks responded in different proportions, changing their rankings according to the environment (year), making recommendations difficult. According to Capistrano et al. (2021), this interaction is undesirable for breeders because, as already presented, it is difficult to predict how the genotypes will behave in relation to changes in the environment, which can lead to different performances in each year of production and make it difficult to predict the behavior of materials (Cruz et al., 2014).

The other rootstocks present G x E interactions of the simple type; that is, regardless of a positive or negative value, the intensity does not change the ranking within the group, regardless of condition changes.

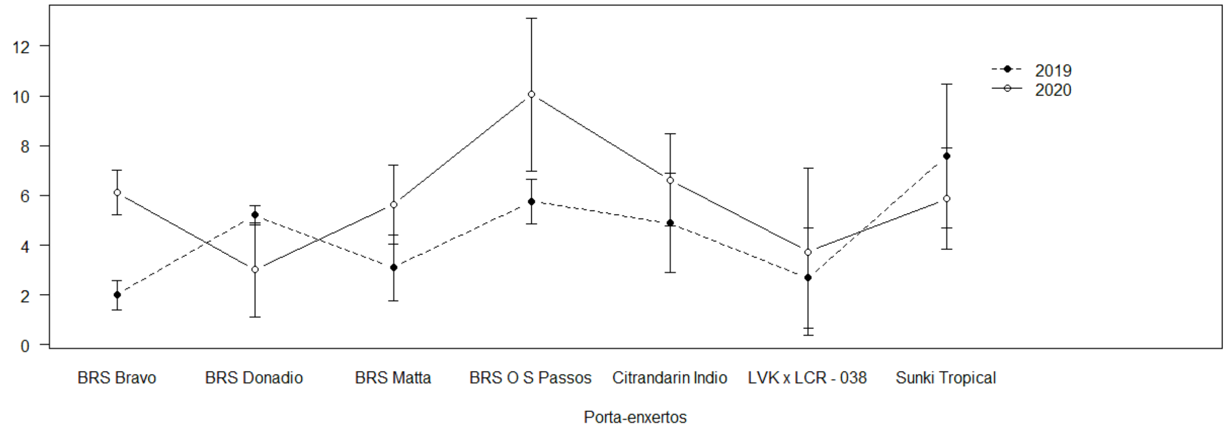

Figure 2. Fruit yield (kg) behavior of 'Tahiti' acid lime grafted on seven rootstocks in two years of evaluation.

Table 4 shows the efficiency of the plant's fruit production in relation to its vegetative development, which, according to Blumer and Pompeu Junior (2005), translates into the plant's ability to take advantage of its architecture.

Table 4. Average productive efficiency and accumulated production of 'Tahiti' acid lime grafted on seven rootstocks in two years of evaluation.

Rootstocks	Average productive efficiency	Accumulated production (kg plant^{-1})
Sunki Tropical	5.24^{a}	13.44^{a}
BRS O S Passos	6.31^{a}	15.81^{a}
BRS Bravo	3.41^{b}	8.13^{b}
BRS Donadio	3.60^{b}	8.22^{b}
Citrandarin Indio	4.01^{b}	11.51^{a}
BRS Matta	3.36^{b}	8.73^{b}
LVK x LCR – 038	2.54^{b}	6.42^{b}
CV (%)	24.03	23.17

Means followed by different letters in the column differ at a 5% probability level using the Scott–Knott test.

The productive efficiency presented in Table 4 of the best rootstocks was higher compared to sweet orange on different rootstocks (Azevedo, Rosseto, Schinor, Martelli, & Pacheco, 2012; Brugnara & Andrade, 2019; Giampani, Tazima, Baba, Yada, & Leite Júnior, 2016; Rodrigues et al., 2019) and also compared to Tahiti acid lime on various rootstocks by Rodrigues et al. (2018). This was similar to the performance presented by Costa et al. (2021), who worked on orange trees with different rootstocks.

Here, the rootstocks Sunki Tropical and BRS O S Passos stood out in the upper group of averages (Table 4). The presence of high productive efficiency for combinations involving rootstocks used in this work was also determined by Portella et al. (2016) and Morais et al. (2020). Graft-rootstock combinations with high productive efficiency are considered important, as they enable the formation of denser plants, resulting in higher production in smaller areas (Santos et al., 2016).

As shown in the comparison of Tables 1 and 4, plants with a greater crown volume tend to have better productive efficiency, a behavior that is not very different from that observed by Pompeu Junior, Blumer, Rodrigues, Stuchi, and Girardi (2022), who identified some Valencia orange treatments with a lower volume and better efficiency.

As for the accumulated production, Sunki Tropical, BRS O S Passos, and Citrandarin Indio did not differ from each other but were statistically superior to the other genotypes. (Table 4). This accumulated production was lower than that obtained by Rodrigues et al. (2018) and Morais et al. (2020), in this case with Tahiti acid lime on other rootstocks at three years of age and on pear orange grafted by Rodrigues et al. (2019).

To understand the interactions between the characteristics, correlation estimates were calculated, where blue colors with larger circles indicate greater positive correlations, decreasing the correlation as the tonality gradually becomes lighter and associated with a circle. This same pattern was used in negative correlations but in red. A positive and significant correlation was observed between plant height and crown volume, fruit production, and fruit number, whose values were 0.41, 0.54, and 0.54, respectively. In addition, a correlation of 0.98 was obtained between fruit production and fruit number (Figure 3). These positive estimates showed that when the value of one of the characteristics increased, there was a tendency for a positive increase in the other.

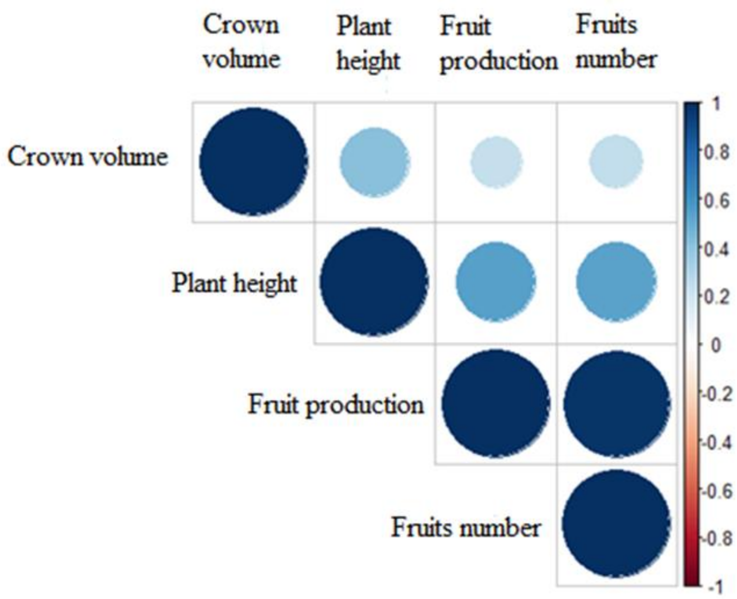

Figure 3. Color map referring to the correlations between the variables plant height, crown volume, fruit yield, and fruit number.

Research on direct and indirect effects aims to understand the behavior of a main variable; in the case of fruit yield, this occurs as a function of explanatory variables (plant height, crown volume and fruit number), according to the methodology described by Cruz et al. (2014).

As shown in Table 5, regarding the estimates of direct and indirect effects on fruit yield, fruit number had the greatest direct effect (0.9722), while plant height had the highest indirect effect (0.5250) via fruit number (Table 5). Thus, the fruit number had an effect on yield, with small contributions from plant height.

Table 5. Estimates of direct and indirect effects of plant height, crown volume, and fruit number on fruit yield.

Explanatory variables	Effects on fruit per plant yield		
	plant height	crown volume	Fruits number
plant height	0.0195	-0.0045	0.5250
crown volume	0.0080	-0.0111	0.2430
Fruits number	0.0106	-0.0028	0.9722
residual effect: 0.1983			
R^2: 0.9607			

Direct effects are marked in bold. Others are indirect effects.

It is expected, as mentioned by Malikouski et al. (2022), that the crown volume presents positive values in fruit yield; here, it was negative, undoubtedly due to the reduction caused by conduction pruning. In addition, the low values observed are indicative that the use of indirect selection in the auxiliary trait may not provide a satisfactory gain (Cruz et al., 2014).

Conclusion

The average productive efficiencies in this set of scions and rootstocks were shown to be high, an indication that environmental factors tend to offer good conditions for the characteristics associated with production. The best rootstocks in terms of means and also in relation to stability and adaptability were Sunki Tropical, BRS O S Passos, and Citradarin Indio. The fruit number had the greatest direct effect on fruit yield. Further studies should be carried out to better understand the G x E interaction between BRS Donadio and Sunki Tropical, which is shown to be of a complex type here.

References

Agência de Defesa Agropecuária do Estado do Pará [ADEPARÁ]. (2017). *Pará é destaque na produção de frutas cítricas*. Retrieved on April 06, 2020 from https://redepara.com.br/Noticia/147728/para-e-destaque-na-producao-de-frutas-citricas

Azevedo, F. A., Pacheco, C. D. A., Schinor, E. H., Carvalho, S. A. D., & Conceição, P. M. D. (2015). Produtividade de laranjeira Folha Murcha enxertada em limoeiro Cravo sob adensamento de plantio. *Bragantia*, *74*(2), 184-188. DOI: https://doi.org/10.1590/1678-4499.0374

Azevedo, F. A., Rosseto, M. P., Schinor, E. H., Martelli, I. B., & Pacheco, C. A. (2012). Influência do manejo da entrelinha do pomar na produtvidade da laranjeira-'Pera'. *Revista Brasileira de Fruticultura*, *34*(1), 134-142. DOI: https://doi.org/10.1590/S0100-29452012000100019

Bastos, D. C., Ferreira, E. A., Passos, O. S., Sá, J. F., Ataíde, E. M., & Calgaro, M. (2014). Cultivares copa e porta-enxertos para a citricultura brasileira. *Informe Agropecuário*, *35*(281), 36-45. Retrieved on Oct. 23, 2023, from https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/1007492/1/Debora214.pdf

Blumer, S., & Pompeu Junior, J. (2005). Avaliação de citrandarins e outros híbridos de trifoliata como porta-enxertos para citros em São Paulo. *Revista Brasileira de Fruticultura*, *27*(2), 264-267. DOI: https://doi.org/10.1590/S0100-29452005000200001

Brugnara, E. C., & Andrade, T. P. R. (2019). Desempenho de dois pomares adultos de laranjeira 'Pêra' no oeste de Santa Catarina, Brasil. *Agropecuária Catarinense*, *32*(1), 53-58. DOI: https://doi.org/10.22491/RAC.2019.v32n1.6

Capistrano, M. C., Andrade Neto, R. C., Santos, V. B., Lessa, L. S., Resende, M. D. V., Mesquita, A.G.G., & Gurgel, F. L. (2021). Use of the REML/BLUP methodology for the selection of sweet orange genotypes. *Pesquisa Agropecuária Brasileira*, *56*, 1-11. DOI: https://doi.org/10.1590/S1678-3921.pab2021.v56.02032

Carvalho, L. M. J., Castro, I. M., & Silva, C. A. B. (2008). A study of retention of sugars in the process of clarification of pineapple juice (*Ananas comosus* L. Merril) by micro and ultrafiltration. *Journal of Food Engineering*, *87*(4), 447-454. DOI: https://doi.org/10.1016/j.jfoodeng.2007.12.015

Cerqueira, E. C., Castro Neto, M. T., Peixoto, C. P., Soares Filho, W. S., Ledo, C. A. S., & Oliveira, J. G. (2004). Resposta de porta-enxertos de citros ao deficit hídrico. *Revista Brasileira de Fruticultura*, *26*(3), 515-519. DOI: https://doi.org/10.1590/S0100-29452004000300034

Confederação Agricultura e Pecurária do Brasil [CNA]. (2019). *A importância da citricultura nacional*. Goiás: Faeg/Senar. Retrieved on Aug. 31, 2022 from https://www.cnabrasil.org.br/noticias/a-importancia-da-citricultura-nacional

Costa, D. P., Stuchi, E. S., Girardi, E. A., Moreira, A. S., Gesteira, A. S., Coelho Filho, M. A., ... Soares Filho, W. S. (2021). Less is more: A hard way to get potential dwarfing hybrid rootstocks for Valencia sweet orange. *Agriculture*, *11*, 1-21. DOI: https://doi.org/10.3390/agriculture11040354

Cruz, C. D. (2016). Genes software – extended and integrated with the R, Matlab and Selegen. *Acta Scientiarum. Agronomy*, *38*(4), 547-552. DOI: https://doi.org/10.4025/actasciagron.v38i4.32629

Cruz, C. D., Regazzi, A. J., & Carneiro, P. C. S. (2014). *Modelos biométricos aplicados ao melhoramento genético*. Viçosa, MG: Editora UFV.

Food and Agriculture Organization of the United Nations [FAO]. (2022). *Markets and Trade – Citrus*. Retrieved on Mar. 31, 2022 from https:// www.fao.org/markets-and-trade/commodities/citrus/en

Fox, J. & Weisberg, S. (2019). *An R companion to applied regression* (3th ed.). Thousand Oaks, CA: SAGE Publications Inc.

Fundo de Desenvolvimento da Pecuária do Estado do Pará [FUNDEPEC]. (2019). *Pará será o maior polo de Citricultura do mundo*. Retrieved on Apr. 16, 2020 from https://bitlybr.com/ITOkE

Giampani, J. S., Tazima, Z. H., Baba, V. Y., Yada, I. F. U., & Leite Júnior, R. P. (2016). Citrus tristeza disease severity and agronomic performance of 'Pêra' sweet orange cultvars and selectons in the North and Northwest regions of the State of Paraná, Brazil. *Revista Brasileira de Fruticultura*, *38*(3), 1-7. DOI: https://doi.org/10.1590/0100-29452016073

Hama, N. (2020). *Uma ferramenta simples para direcionar e fortalecer suas análises*. Retrieved on Aug. 31, 2022 from https:// https://numerapeopleanalytics.com.br/uma-ferramenta-simples-para-direcionar-e-fortalecer-suas-analises/?_ga=2.73341715.1210746864.1661949901-1148291898.1661949901

Instituto Brasileiro de Geografia e Estatística [IBGE]. (2018). *Estatísticas sobre produção agrícola municipal*. Retrieved on Apr. 10, 2022 from https//www.sidra.ibge. gov.br

Instituto Brasileiro de Geografia e Estatística [IBGE]. (2019). *Estatísticas sobre produção agrícola municipal*. Retrieved on Apr. 10, 2020, from https//www.sidra.ibge.gov.br

Lima, C. F., Marinho, C. S., Costa, E. S., & Vasconcelos, T. R. (2014). Qualidade dos frutos e eficiência produtiva da laranjeira 'Lima' enxertada sobre 'Trifoliata', em cultivo irrigado. *Revista Brasileira de Ciências Agrárias*, *9*(3), 401-405. DOI: https://doi.org/10.5039/agraria.v9i3a4433

Malikouski, R. G., Nascimento, E. F., Morais, A. L., Peixoto, M. A., Zucoloto, M., Barbosa, D. H. S. G., & Bhering, L. L. (2022). Interrelations between productive, vegetative, and fruit quality traits in Tahiti acid lime through Bayesian inference. *Ciência Rural*, *52*(5), 1-9. DOI: https://doi.org/10.1590/0103-8478cr20210007

Mendel, K. (1956). Rootstock-scion relationshio in Shamouti trees on light soil. *Ktavim*, *6*, 35-60.

Mendiburu, F. (2021). *Agricolae*: *Statistical Procedure for Agricultural Research*. R package version 1.3-5. Retrieved on Apr. 18, 2022 from https//cran.r-project.org/web/packages/agricolae/agricolae.pdf

Morais, A. L., Zucoloto, M., Malikouski, R. G., Barbosa, D. H. S. G., Passos, O. S., & Altoé, M. S. (2020). Vegetative development and production of 'Tahiti' acid lime clone selections grafted on different rootstocks. *Revista Brasileira de Fruticultura*, *42*(3), 1-12. DOI: https://doi.org/10.1590/0100-29452020585

Morales, M. (2020) *Sciplot: scientific graphing functions for factorial designs*. *R package version 1.2-0.* Retrieved on Apr. 18, 2022 from https//rdrr.io/cran/sciplot/

Nogueira, R. J., Moares, J. A., & Burity, H. A. (2001). Alterações na resistência à difusão de vapor das folhas e relações hídricas em aceroleira submetidas a déficit de água. *Revista Brasileira de Fisiologia Vegetal, 13*(1), 75-87. DOI: https://doi.org/10.1590/S0103-31312001000100009

Petry, H. B., Reis, B., Silva, R. R., Gonzatto, M. P., & Schwarz, S. F. (2015). Porta-enxertos influenciam o desempenho produtivo de laranjeiras-de-umbigo submetidas a poda drástica. *Pesquisa Agropecuária Tropical*, *45*(4), 449-455. DOI: https://doi.org/10.1590/1983-40632015v4537005

Pompeu Junior, J., Blumer, S., Rodrigues, J., Stuchi, E. S., & Girardi, E. A. (2022). Performance of citrumelos in area affected by citrus sudden death. *Research, Society and Development*, *11*(1), 1-9. DOI: https://doi.org/10.33448/rsd-v11i1.24527

Portella, C. R., Marinho, C. S., Amaral, B. D., Carvalho, W. S. G., Campos, G. S., Silva, M. P. S., & Sousa, M. C. (2016). Desempenho de cultivares de citros enxertadas sobre o trifoliateiro 'Flying Dragon' e limoeiro 'Cravo' em fase de formação do pomar. *Bragantia*, *75*(1), 70-75. DOI: https://doi.org/10.1590/1678-4499.267

Rocha, R. B., Ramalho, A. R., Teixeira, A. L., Souza, F. F., & Cruz, C. D. (2015). Adaptabilidade e estabilidade da produção de café beneficiado em *Coffea canephora*. *Ciência Rural*, *45*(9), 1531-1537. DOI: https://doi.org/10.1590/0103-8478cr20141554

Rodrigues, M. J. S., Araújo Neto, S. E., Andrade Neto, R. C., Soares Filho, W. S., Girardi, E. A., Lessa, L. S., ... Araújo, J. M. (2019). Agronomic performance of the 'Pera' orange grafted onto nine rootstocks under the conditions of Rio Branco, Acre, Brazil. *Revista Brasileira de Ciências Agrárias*, *14*(4), 1-8. DOI: https://doi.org/10.5039/agraria.v14i4a6642

Rodrigues, M. J. S., Andrade Neto, R. C., Lessa, L. S., Girardi, E. A., & Soares Filho, W. S. (2018). Desempenho agronômico de lima ácida Tahiti em combinação com diferentes porta-enxertos em Capixaba, Acre. *Enciclopédia Biosfera, Centro Científico Conhecer*, *15*(28), 353-363. DOI: https://doi.org/10.18677/EnciBio_2018B30

Roncatto, G., Romano, M. R., Caravina, S. M., Olibone, D., Girardi, E. A., Soares Filho, W. S., ... Wruck, D. S. M. (2021). *Crescimento vegetativo de limeira ácida 'TAHITI' sobre novos porta-enxertos no norte do Mato Grosso*. Sinop, MT: Embrapa Agrossilvipastoril. (Boletim de Pesquisa e Desenvolvimento, n. 5).

Rossi, P. L., & Pandolfi, C. M. A. (2019). Análise de mercado da lima ácida Tahiti. *Revista Interface Tecnológica*, *16*(2), 255-263. DOI: https://doi.org/10.31510/infa.v16i2.647

Santos, M. G., Soares Filho, W. S., Girardi, E. A., Gesteira, A. S., Passos, O. S., & Ferreira, C. F. (2016). Initial horticultural performance of nine 'Persian' lime selections grafted onto 'Swingle' citrumelo. *Scientia Agricola*, *73*(2), 109-114. DOI: https://doi.org/10.1590/0103-9016-2015-0058

Schmildt, E. R., Nascimento, A. L., Cruz, C. D., & Oliveira, J. A. R. (2011). Avaliação de metodologias de adaptabilidade e estabilidade de cultivares milho. *Acta Scientiarum, Agronomy*, *33*(1), 51-58. DOI: https://doi.org/10.4025/actasciagron.v33i1.5817

Schwart, G. (2007). Manejo sustentável de florestas secundárias: espécies potenciais no Nordeste do Pará, Brasil. *Amazônia*: *Ciência*; *Desenvolvimento*, *3*(5), 125-147, 2007.

Silva, A. G., Boiça Júnior, A. L., Farias, P. R. S., & Barbosa, J. C. (2011). Infestação da mosca-negra-dos-citros, em sistemas de plantio convencional e agroflorestal. *Revista Brasileira de Fruticultura*, *33*(1), 53-60. DOI: https://doi.org/10.1590/S0100-29452011005000038

Wei, T., & Simko, V. (2021) *R package "corrplot": visualization of a correlation matrix.* R package Version 0.92. Retrieved on Apr. 18, 2022 from https//cran.r-project.org/web/packages/corrplot/corrplot.pdf