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YIELD AND QUALITY OF 'PERA' SWEET ORANGE GRAFTED ON DIFFERENT ROOTSTOCKS UNDER RAINFED CONDITIONS[1]

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ABSTRACT- This study aimed to evaluate, under field conditions, different combinations between 'Pera' sweet orange and eight rootstocks: 'Rangpur' lime (RL), 'Volkamer' lemon (VL), 'Cleopatra' mandarin (CM), 'Sunki Maravilha' mandarin (SMM), 'Indio' and 'Riverside' citrandarins, and VL x RL ('Rangpur' lime)-010 and TH-051 hybrids. The soil water matric potential (Ψm) was characterized for all scion-rootstock combinations at distance of 1.0m from the trunk at the plant row direction and depths of 0.25 m, 0.50 m 0.90 m in the dry and wet seasons. For two years, fruit production parameters and fruit quality were assessed. Differences of Ψm among scion-rootstock combinations were observed during the dry season ($p \leq 0.05$). The lowest Ψm values for RL and the highest for TH-051 indicate the existence of different intrinsic mechanisms affecting the water extraction of each scion-rootstock combination. Rootstocks have influenced fruit yield and quality ($p \leq 0.05$). The best combinations for fruit quality and production were sweet orange grafted on 'Riverside', 'Indio' and TH-051 rootstocks.
Index terms: Citrus, matric potential, drought tolerance, rootstock.

PRODUÇÃO E QUALIDADE DE FRUTOS DA LARANJEIRA-'PERA' EM COMBINAÇÃO COM DIFERENTES PORTA-ENXERTOS EM CONDIÇÕES DE SEQUEIRO

RESUMO- Este trabalho objetivou avaliar, em condição de campo, combinações entre a copa laranjeira 'Pera' e oito diferentes porta-enxertos: limoeiro 'Cravo' (LCR), limoeiro 'Volkameriano' (LVK), tangerineira 'Cleópatra' (CLEO), tangerineira 'Sunki Maravilha' (TSKMA), citrandarins 'Indio' e 'Riverside', híbridos LVK x LCR (limoeiro 'Cravo')-010 e HTR (híbrido trifoliado)-051. Foi estimado o potencial matricial do solo (Ψm) para todas as combinações copa-porta-enxerto na posição a 1,0 m do tronco, na linha de plantas, nas profundidades de 0,25 m, 0,50 m e 0,90 m, nos períodos secos e úmidos. Durante dois anos, foram avaliadas a produção e a qualidade dos frutos. Foram observadas diferenças entre as combinações copa-porta-enxertos em relação ao Ψm ($p \leq 0{,}05$) apenas para o período seco. O menor valor de Ψm para limoeiro 'Cravo' e o maior para o HTR (híbrido trifoliado)-051 indicaram a existência de diferentes mecanismos intrínsecos de cada combinação estudada que influenciaram na extração de água do solo, na posição avaliada. Em relação à produção e à qualidade de frutos, os porta-enxertos 'Riverside', 'Indio' e HTR (híbrido trifoliado)-051 destacaram-se como as melhores combinações com a laranjeira 'Pera'.
Termos para indexação: Citros, potencial mátrico, tolerância à seca, porta-enxertos.

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INTRODUCTION

The need for diversification in the use of the Brazilian citrus rootstock for different production systems and environmental conditions is currently a major challenge to ensure the sector's growth with reduction of risks caused by biotic and abiotic factors. According to Passos et al. (2006), this diversification is imperative because the citrus industry has faced many threats, mainly due to pathogens affecting orchards grafted with Rangpur lime (*Citrus limonia* Osbeck), the rootstock most widely used in the country (STUCHI et al., 2004; PRUDENTE et al, 2004).

The citrus cultivation in Brazil is predominantly without irrigation, being necessary the use of drought tolerant scion-rootstock combinations in view of the occurrence of temporary water shortage in various citrus regions (ORTOLANI et al., 1991; Ribeiro et al., 2006). In this sense, plants grafted on Rangpur lime are considered more tolerant to drought, with mechanisms of greater development of the root system, coupled with the high hydraulic conductivity of roots (MAGALHAES FILHO et al, 2008; SUASSUNA et al, 2012; MEDINA et al., 1998).

The substitution of traditional rootstocks in citrus such as 'Volkamer' lemon (*C. volkameriana* V. It. & Pasq.), 'Rough' lemon (*C. jambhiri* Lush.) and Rangpur lime must be made with caution because in addition to virtues in relation to tolerance to pathogens, new genotypes should be adapted to adverse environmental conditions such as higher air temperature and soils with low water availability, and also tolerate changes in edaphic factors connected to the chemical and physical soil properties, and ultimately, with increased production and fruit quality.

Breeding programs of citrus, like those developed by *Embrapa Mandioca e Fruticultura* have made efforts to provide new rootstock varieties resistant to biotic and abiotic factors as alternatives to increase the genetic basis for the protection of national citrus production. The formation of lemon, mandarin and *Poncirus trifoliata* hybrids will be able to meet the current need for new materials, like promising tests already carried out with TH-051 and TH-069 (Cerqueira et al., 2004; Peixoto et al. 2006; Soares et al, 2015), SMFL x CTTR-017 (SUASSUNA et al, 2012) and VL x RL-10 hybrids (CARVALHO et al, 2012).

In order to propose the use of new rootstocks in rainfed condition, this study evaluated fruit production and quality and estimated the soil water matric potential in dry and wet periods in 'pera' sweet orange grafted on eight different rootstocks under rainfed conditions, in Cruz das Almas, Bahia.

MATERIAL AND METHODS

The work was carried out in citrus experimental field of *Embrapa Mandioca e Fruticultura*, Cruz das Almas, Bahia (12º40'39 "S, 39º06'23''W, 225m asl), between July 2010 and December 2012. Adult 'Pera' sweet orange plants were evaluated [*C. sinensis* (L.) Osbeck] in 9-year-old orchard grown in spacing of 6m x 4m grafted on eight rootstocks: 'Rangpur' lime (RL), 'Volkamer' lemon (VL), 'Cleopatra' mandarin (CM), 'Sunki Maravilha' mandarin (SMM), 'Indio' and 'Riverside' citrandarins, and VL x RL ('Rangpur' lime)-010 and TH-051 hybrids.

The soil of the experimental area is a dystrophic cohesive yellow latosol, flat relief, with the following horizons: Ap: 0-0.09 m; AB: 0.09-0.38 m; Bw1: 0.38-0.72 m and Bw2: 0.72-1.20 m, LAd3 reference in Souza and Souza (2001). Grain size, water holding capacity, saturated hydraulic conductivity, density, porosity and soil chemical analyses were performed at the Laboratories of Physics and Chemistry of *Embrapa Mandioca e Fruticultura* (Tables 1, 2 and 3). At the beginning of the experiment, dolomitic lime was applied (1.3 t ha^{-1}) to raise to 70% the soil base saturation and, according to the rainfall, cover fertilizations were carried out at the canopy projection area with nitrogen sources (600 g of urea per plant) and potassium (300 g of potassium chloride per plant), installments twice a year (Azevedo, 2003).

Information on rainfall and air temperature was obtained from the automatic station of the National Institute of Meteorology (INMET), located at *Embrapa Mandioca e Fruticultura*, for the definition of dry and wet periods from the water balance in the soil, according to the method of Thornthwaite and Mather (1955). The depth of 1.2 m was considered for soil water storage calculation, and limits for soil water retention, field capacity (-10 kPa) and wilting point (-1500 kPa) were determined in laboratory with Richards' extractors (Richards, 1965) for available water calculations (AW).

Soil volumetric moisture was measured in dry and wet periods through TDR probes (Time Domain Reflectometry), made with three stainless steel rods fixed to a polyester resin block and connected to a 50 ohms coaxial cable. These were calibrated for each soil horizon at the Laboratory of Soil Physics of *Embrapa Mandioca e Fruticultura* according to methodology described in Santos et al. (2010)

for sample with non-deformed structure. Samples were placed on the ground at depths of 0.25 m, 0.50 m 0.90 m, representing the average depths of AB (0.09-0.38m), Bw1 (0.38-0.72m) and Bw2 horizons (0.72-1.20m), respectively, and positioned 1.0 m from the stem on the planting row, in two plants for each rootstock. This distance was chosen because the effective distance of the citrus root system is approximately 1.5 m (SOUZA et al., 2007, COELHO et al., 2002;) and studies involving spatial distribution of the root system of citrus plants every 0.5 m, corresponding to the median point.

The soil water matric potential (Ψm) of each scion-rootstock combination was estimated using the Van Genuchten model (1980) from soil moisture values obtained by TDR. The water available (WA) percentage in soil at the three depths was also determined according to methodology of Coelho et al. (2010). Four Ψm determinations in the dry season were held on October 27 and November 24, 2010, January 26 and February 11, 2011, when the AW percentage in soil was less than 30%. Similarly, in the wet season, four determinations were carried out, on April 28, May 26, June 17 and July 28, 2011, when the soil WA was greater than 50%.

Fruit yield (kg plant^{-1}) was recorded in harvests performed in June and December 2011 and 2012. To determine fruit quality, fruits collected in June 2011 were used, which were selected in external position of the canopy, following the criteria of uniformity of samples from the skin color. The following physical parameters were determined: height (cm), diameter (cm), fruit weight (g) and juice yield [JY = (juice weight / fruit weight) x 100].

The following chemical parameters were also determined: total soluble solids (TSS), measured in ºBrix by means of reading in refractometer with values corrected for 20°C; titratable acidity (TA) of the juice, determined by titration with 0.1 N NaOH and a phenolphthalein indicator (AOAC, 1990), with results being expressed as g / 100 g citric acid. The study also determined the TSS / TTA ratio and the technological index (TI), corresponding to the amount of soluble solids in the juice (kg) in a 40.8 kg fruit crate, obtained by the following formula: TI = (RS x TSS x 40.8) / 10^4 (Di Giorgi et al., 1990).

The experimental design was completely randomized, considering for Ψm of soil water 8 x 3 factorial, eight rootstocks and three depths, analyzing separately for dry and wet periods, with n = 2x4, two monitored plants and four evaluations for each period. For fruit analysis, the design consisted of eight rootstocks as treatments and four replicates. The experimental plot was one plant for productivity analysis and ten fruits per plant for analysis of the physicochemical quality. Data were submitted to analysis of variance and Skott-Knott test at 5% probability.

RESULTS AND DISCUSSION

The climatic conditions in the experimental period followed the trend of historical averages for the Reconcavo Baiano region (D'ANGIOLELLA et al., 2012) in years 2010 and 2011, with the wet season between April and July and the dry season between months of October and March and annual rainfall of 1,251 mm and 1,269 mm, respectively (Figure 1). The year 2012 was considered atypical for the Reconcavo region, with longer dry period, which resulted in annual rainfall of 739 mm (Figure 1).

There was no significant interaction (p = 0.05) between rootstock factors and soil depth, in which the soil matric potential was estimated. Only in the dry season, there were significant differences (p = 0.05) between Ψm values estimated for each scion-rootstock combination. In this period, the ψm values were lower for RL rootstock, and higher for TH, and this was not significantly different from other genotypes (Table 4), while the average water availability value (WA) in the three depths evaluated was 7.6% for RL and 31.9% for soil profile monitored in TH plants.

The lower Ψm in the dry period of the RL rootstock compared to TH confirms the mechanism of increased use of soil water in the position to 1.0 m from the stem by Rangpur lime, which is probably associated to a greater root growth under water deficit, according to findings of Magalhaes Filho et al. (2008) and Suassuna et al. (2012) and to a greater hydraulic conductivity of roots found by Medina et al. (1998). On the other hand, the greater Ψm of soil water observed for TH characterizes this rootstock as the conservative genotype associated with lower soil water extraction, which is related to its small size, as reported by Cerqueira et al. (2004) and Peixoto et al. (2006).

The distinct mechanisms observed in the interaction grafted 'Pera' sweet orange and RL and TH rootstocks bring the following question: the ideal rootstock is one that has higher water extraction capacity or that presenting savings in its use under drought conditions? The answer to this question involves several edaphic and phytotechnical factors related to drought tolerance such as water deficit intensity and duration, soil type and depth, planting spacing, root system characteristics, sensitivity to biotic factors and compatibility with the canopy and increased fruit production capacity.

In relation to fruit production capacity, significant differences were found among scion-rootstocks combinations for fruit production, fruit weight and fruit size parameters (Table 5). In the 2011 harvest, 'Riverside', SMM, 'Indio' and TH genotypes stood out with best performances in relation to production. The 'Pera'-RL combination, even presenting feature of increased water use, did not show better performance, demonstrating that this is not the only determining factor for fruit production. Regarding the average fruit length and weight, the highest averages were observed for 'Pera' sweet orange grafted on VL x RL, 'Indio' and TH rootstocks (Table 5).

In the 2012 harvest, in which only 739 mm annual rainfall were recorded, again 'Riverside', 'Indio' and TH rootstocks along with CM and VL x RL showed higher canopy production. This year, it was observed that the longer dry season caused a reduction in fruit production in all scion-rootstock combinations, compared to the previous year, except for 'Pera'-CM combination. The largest reduction in fruit production occurred for SMM, VL and RL rootstocks (Table 5).

The good performance of CM rootstock with 'Pera' canopy was also observed by Donadio et al. (1993) in Bebedouro-SP, with higher productivity in 7m x 2m spacing in the dry period, contrary to expectations of being drought intolerant, unlike Rangpur lime. These authors also reported that the initial 'Cleopatra' production were very low, only reaching a reasonable level in 5th year of planting.

The low performance of VL and RL rootstocks diverge from results already reported with the 'Pera' sweet orange canopy (MOURÃO FILHO et al., 1991; LEDO et al., 1999; STUCHI et al., 2004). Mourao Filho et al. (1991) studied in younger orchard, 'Pera' orange production on eight rootstocks, among which RL, VL, CM, 'Sunki' and 'Trifoliata', showing in the first three years of production, higher yields for combinations with RL and VL, and CM and 'Sunki' rootstocks showing intermediate production and higher than 'Trifoliata'.

'Indio', VL x VL and RL rootstocks, which led to greater length and average fruit weight of 'Pera' sweet orange, did not influence juice yield compared to other rootstocks (Table 6). With the exception of juice yield, parameters total acidity (TTA), total soluble solids (TSS), TSS / TTA ratio and technological index were significantly determined ($p \leq 0.05$) by rootstocks (Table 6).

Lower TTA in 'Pera' fruits was observed when grafted onto VL and VL x RL (Table 6). In relation to total soluble solids (TSS), the lowest values were observed for 'Pera' fruits grafted onto VL x RL, RL, SMM and CM (Table 6). The differences observed for total acidity and °Brix can be attributed to the early fruit formation induced by rootstock.

Except for 'Pera'-CM, ATT / SST ratio greater than 8.0 was observed for other scion-rootstock combinations, exceeding the minimum required for fresh consumption (LEDO et al., 1999). The 'Pera'-VL combination had the highest ATT / SST ratio, and' Pera'-CM, the lowest value, suggesting that the first rootstock can provide earlier harvests in relation to others. Regarding the technological index, which demonstrates greater ability of producing juice of high °Brix content from a fruit crate, the 'Pera'-SMM and' Pera' - VL x RL combinations had lower performance, with values below those observed for citrus, which are 2.49 to 2.86 kg TSS fruit crate $^{-1}$ (DI GIORGI et al., 1990).

Some reasons explain the differences of TTA and TSS for the same canopy grafted onto different rootstocks. According to Stuchi et al. (1996), more vigorous rootstocks are better soil water extractors and keep plant well hydrated, being the most important reason for induction of low TSS concentrations in the fruit. For Castle (1995), differences in TSS concentration can be explained by the influence of the rootstock on the number of canopy leaves that perform the synthesis of carbohydrates translocated to fruits. Ledo et al. (1999) studied the production of 'Pera' CNPMF D-6, between the 4th and 7th years and observed a trend of increased fruit production, lower °Brix and total acidity for combination with 'Rangpur' lime rootstock compared to 'Cleopatra' mandarin and other rootstocks such as 'Sunki 'and 'Carrizo' citrange, differing from this study only in fruit production parameter.

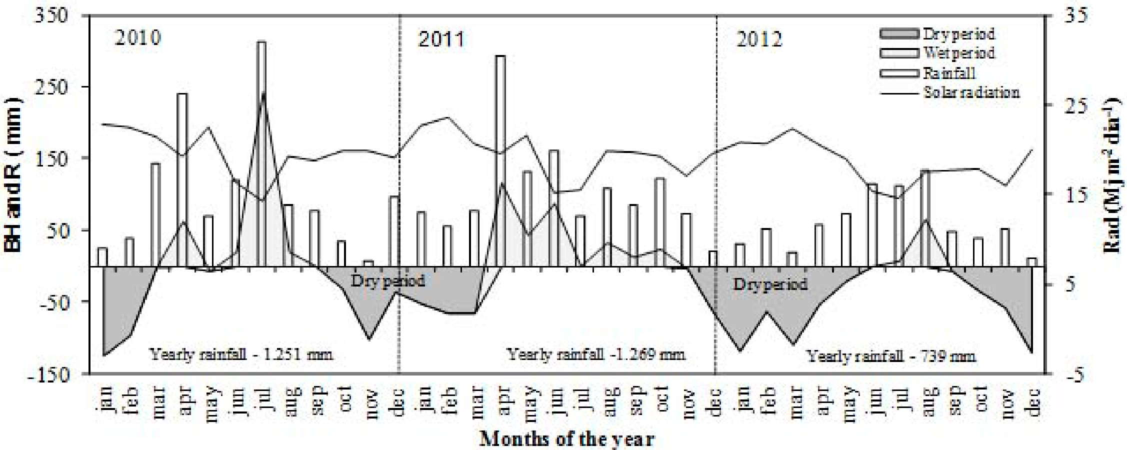

FIGURE 1- Monthly water balance (WB) and rainfall (R) from January 2010 to December 2012, data from the meteorological station of *Embrapa Mandioca e Fruticultura*, Cruz das Almas-Bahia.

TABLE 1-Particle size of Ap (0-0,09m), AB (0.09-0.38m), Bw1 (0.38-0.72m), Bw2 (0.72-1.20m) horizons and textural classification of dystrophic cohesive yellow latosol, *Embrapa Mandioca e Fruticultura*, Cruz das Almas-Bahia.

Grain size composition (g kg^{-1})									
	Sand								Textural Classification
Horizon	VT	T	M	F	VF	Total	Silt	Clay	
Ap	34	97	139	193	34	497	154	349	sandy clay
AB	32	111	158	244	62	607	147	246	sandy clay loam
Bw1	35	111	127	179	48	500	128	372	sandy clay
Bw2	22	88	116	168	23	417	170	413	sandy clay

Note: VT - very thick, T - thick, M - medium, F - fine, VF - very fine.

TABLE 2- Water retention in soil held by the relationship between potential and volumetric moisture (Θ), saturated hydraulic conductivity ($K\Theta_{Sat}$), density (Ds) and porosity of Ap (0-0.09m), AB (0.09- 0.38m), Bw1 (0.38-0.72m) and Bw2 horizons (0.72-1.20) of a dystrophic cohesive yellow latosol, *Embrapa Mandioca e Fruticultur* experimental field, Cruz das Almas-Bahia.

	Potential (kPa) x Θ (cm cm^{-3})					$K_{\Theta Sat}$	Ds	Porosity (%)	
	10	33.3	100	300	1500	mm h^{-1}	kg dm^{-3}	Macro	Micro
Ap	0.206	0.190	0.190	0.179	0.156	463	1.52	11.6	24.6
AB	0.179	0.162	0.161	0.157	0.134	23	1.56	9.8	22.0
Bw1	0.245	0.227	0.236	0.213	0.185	7	1.63	5.3	26.8
Bw2	0.228	0.209	0.183	0.178	0.166	34	1.46	12.8	26.1

TABLE 3- Chemical analysis of soil, *Embrapa Mandioca e Fruticultur* experimental field, Cruz das Almas-Bahia.

Depth (m)	pH	P	K	Ca	Mg	Al	Na	H+Al	SB	CTC	V	M.O
	H_2O	mg dm^{-3}	cmol$_c$ dm^{-3}								%	g kg^{-1}
0 - 0.25	5.2	58	0.23	1.70	0.70	0.2	0.03	2.75	2.66	5.41	49	4.86
0.25 - 0.50	4.9	13	0.12	1.10	0.80	0.2	0.03	2.42	2.05	4.47	46	6.73

TABLE 4-Soil water matric potential (Ψm,kPa) and available water (WA,%) at depths of 0.25m, 0.50m and 0.90m in 'Pera' sweet orange on eight rootstocks: 'Rangpur' lime (RL), 'Volkamer' lemon (VL), 'Cleopatra' mandarin (CM), 'Sunki Maravilha' mandarin (SMM), 'Indio' and 'Riverside' citrandarins, and VL x RL ('Rangpur' lime)-010 and TH-051 hybrids estimated from moisture measurements (n = 2x4) in the dry and wet periods.

Rootstocks	Depth (m)	Dry period Ψm	Dry period WA	Wet period Ψm	Wet period WA
RL	0.25	-837	13.6	-46	66.5
	0.50	-1500	0.0	-357	30.0
	0.90	-702	9.3	-49	57.0
Mean		-1013 a	7.6	-150 a	51.2
VL	0.25	-514	23.7	-27	86.1
	0.50	-877	21.2	-75	59.1
	0.90	-169	31.6	-25	80.9
Mean		-520 ab	25.5	-42 a	75.34
CM	0.25	-524	23.3	-23	93.0
	0.50	-885	21.1	-59	63.8
	0.90	-222	27.3	-38	65.1
Mean		-543 ab	23.9	-40 a	73.9
SMM	0.25	-783	15.0	-18	100.0
	0.50	-834	21.9	-240	36.2
	0.90	-773	7.8	-37	65.9
Mean		-797 ab	15.0	-98 a	67.4
Indio	0.25	-771	15.3	-15	100.0
	0.50	-1157	17.7	-80	58.0
	0.90	-788	7.5	-29	74.8
Mean		-905 ab	13.5	-41 a	77.5
Riverside	0.25	-294	35.4	-14	100.0
	0.50	-851	21.6	-239	36.2
	0.90	-740	8.5	-49	57.0
Mean		-628 ab	21.8	-100 a	64.4
VL x RL 10	0.25	-650	18.9	-15	100.0
	0.50	-799	22.4	-117	50.3
	0.90	-109	38.5	-25	80.8
Mean		-519 ab	26.6	-52 a	77.1
TH-051	0.25	-216	41.8	-22	95.0
	0.50	-864	21.4	-70	60.4
	0.90	-160	32.49	-27	77.7
Mean		-413 b	31.9	-39 a	77.7

(*) Means followed by the same letter do not differ by the Tukey test ($P \leq 0.05$).

TABLE 5- Annual production, average weight, length, diameter and number of seeds in 'Pera' sweet orange fruits on eight rootstocks: 'Rangpur' lime (RL), 'Volkamer' lemon (VL), 'Cleopatra' mandarin (CM), 'Sunki Maravilha' mandarin (SMM), 'Indio' and 'Riverside' citrandarins, and VL x RL ('Rangpur' lime)-010 and TH-051, *Embrapa Mandioca e Fruticultur* experimental field, Cruz das Almas, Bahia, in 2011 and 2012.

Rootstocks	Production (kg planta^{-1})		Average weight (g)	Length (cm)	Diameter (cm)	Seeds/ fruit
	2011	2012				
RL	22.13 b	16.07 b	173.30 b	6.52 b	6.75	5.90
VL	34.76 b	24.25 b	174.47 b	6.51 b	6.71	5.40
CM	21.82 b	36.75 a	167.10 b	6.38 b	6.63	5.63
SMM	50.21 a	13.27 b	167.27 b	6.40 b	6.70	5.80
Indio	47.98 a	32.85 a	188.83 a	6.68 a	6.90	5.23
Riverside	65.28 a	41.35 a	179.17 b	6.55 b	6.84	5.37
VL x RL	38.49 b	32.25 a	206.30 a	6.90 a	7.10	5.13
TH	55.06 a	29.55 a	188.37 a	6.79 a	6.90	5.63

* Equal letters belong to the same group by the Skott-Knott test (p = 0.05).

TABLE 6- Yield (Juice yield), titratable acidity (TTA), total soluble solids (TSS), TSS / TTA ratio and technological index of 'Pera' orange juice on eight rootstocks: 'Rangpur' lime (RL), 'Volkamer' lemon (VL), 'Cleopatra' mandarin (CM), 'Sunki Maravilha' mandarin (SMM), 'Indio' and 'Riverside' citrandarins, and VL x RL ('Rangpur' lime)-010 and TH-051, *Embrapa Mandioca e Fruticultur* experimental field, Cruz das Almas, Bahia, in 2011 and 2012.

Rootstock	Juice yield (%)	TTA Citric acid g/100g	TSS (%)	TSS / TTA	Technological index
RL	59.68	1.25 a	10.60 b	8.51 c	2.58 a
VL	56.71	1.04 b	11.13 a	10.76 a	2.58 a
CM	58.92	1.36 a	10.67 b	7.85 c	2.56 a
SMM	52.11	1.26 a	10.60 b	8.41 c	2.25 b
Indio	58.01	1.22 a	11.20 a	9.16 c	2.65 a
Riverside	54.70	1.27 a	11.27 a	8.92 c	2.51 a
VL x RL	54.84	1.09 b	10.53 b	9.67 b	2.36 b
TH	57.96	1.19 a	11.40 a	9.62 b	2.69 a

* Equal letters belong to the same group by the Skott-Knott test (p = 0.05).

CONCLUSIONS

In the dry season, the lower soil water matric potential for Rangpur lime in relation to TH (hybrid trifoliate) -051, under 'Pera' orange canopy indicates differences in water extraction in the position at 1.0 m from the stem.

Under rainfed condition, 'Riverside' rootstock, followed by 'Indio' and TH-051 rootstocks are the most promising, as they provide 'Pera' orange canopy higher fruit production.

'Sunki Maravilha' rootstock (SMM) was the most sensitive to drought and the genotype with increased susceptibility to climate risks.

The concentration of soluble solids and titratable acidity in 'Pera' sweet orange fruits showed changes when assessed in different canopy combinations of this variety with the evaluated rootstocks.

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