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Productive performance of sweet orange trees on different rootstocks, in the Extreme South of the State of Bahia

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Abstract: In the Extreme South of Bahia, in the Municipality of Ibirapuã, under irrigation, the productive performance of 20 varieties of sweet orange trees, with different maturation times, was evaluated, with the main focus on the orange trees 'Pera' (18 clones), 'Valencia' (18 clones) and 'Natal' (five clones), totaling 58 tops varieties. The rootstocks used were the mandarin tree 'Sunki Tropical' and the citrandarins 'Indio', 'Riverside' and 'San Diego'. Each top/rootstock combination, totaling 232, was represented by five plants, observing a planting spacing of 6 m x 3 m. The experiment was implemented on April 21, 2015. The tops Pera Selection CNPMF A15; 'Pera C-21'; Pera Selection CNPMF D3; 'Pera D25'; 'Pera CNPMF E-6'; Pera Selection CNPMF CE-03; Pera Selection Olímpia; 'Pera Bianchi'; Pera Selection Vacinada; Pera Selection Ipeal-E3; Pera Selection Ibotirama; 'Valencia CNPMF Montemorelos'; 'Natal CNPMF-112'; Selection Berna, Selection F-Menuda; 'BRS Sincorá'; 'Aquiri'; Selection Early Oblong; Selection Russas P.S.; 'Seleta Itaboraí'; 'Pineapple' and 'Westin' were more productive on the 'Sunki Tropical' rootstock. The tops Pera Selection Ibotirama; Valencia Selection CNPMF 02; Valencia Selection CNPMF 03; 'Valencia CNPMF-27'; Valencia Selection CNPMF 36; Valencia Selection L. White; 'Natal CNPMF 112'; Selection Berna; 'Aquiri'; Selection Early Oblong; 'Salustiana'; 'Diva' and 'Hamlin 20' were more productive on the 'San Diego' rootstock. The tops Pera Selection CNPMF 02; Pera Selection CNPMF C-32; 'Pera CNPMF D-6'; 'Pera D25'; Pera Selection Olímpia; Valencia Selection CNPMF 01; Valencia Selection CNPMF 02; Valencia Selection CNPMF; 'Valencia CNPMF 27'; Valencia Selection CNPMF 36; Valencia Selection CNPMF-F11; Valencia Selection Chapman; 'Valencia CNPMF Montemorelos'; 'Valencia CNPMF Tuxpan'; Natal Selection CNPMF 02; Natal Selection Ipeal; 'Natal CNPMF 112'; Selection F-Menuda, 'Seleta Itaboraí'; 'Salustiana'; 'Pineapple'; 'Hamlin 20' and 'MelRosa' were more productive on the 'Riverside' rootstock. The tops Pera Selection CNPMF A15; 'Pera D25'; Pera Selection Ipeal E3; Valencia Selection CNPMF 01; Valencia Selection CNPMF 02; Valencia Selection CNPMF; Valencia Selection CNPMF 36; Valencia Selection CNPMF-F11;

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Valencia Selection Delta; Valencia Selection Chapman; 'Valencia CNPMF Montemorelos'; Valencia Selection Registro; 'Valencia CNPMF Tuxpan'; Valencia Selection CNPMF 21; Natal Selection CNPMF 01; 'Natal CNPMF 112'; Selection Berna; 'Aquiri'; 'Diva' and 'Hamlin 20' were more productive on the 'Indio' rootstock.

Index Terms: *Citrus sinensis*, production, cultivars

Desempenho produtivo de laranjeiras-doce sobre diferentes porta-enxertos, no Extremo Sul do Estado da Bahia

Resumo: No Extremo Sul baiano, Município de Ibirapuã, sob irrigação, avaliou-se o desempenho produtivo de 20 variedades de laranjeiras-doces, com distintas épocas de maturação, com foco principal nas laranjeiras 'Pera' (18 clones), 'Valência' (18 clones) e 'Natal' (cinco clones), totalizando 58 variedades copa. Os porta-enxertos utilizados foram a tangerineira 'Sunki Tropical' e os citrandarins 'Indio', 'Riverside' e 'San Diego'. Cada combinação copa/porta-enxerto, totalizando 232, foi representada por cinco plantas, observando o espaçamento de plantio de 6 m x 3 m. A implantação do experimento deu-se em 21 de abril de 2015. As copas Pera Seleção CNPMF A15; 'Pera C-21'; Pera Seleção CNPMF D3; 'Pera D25'; 'Pera CNPMF E-6'; Pera Seleção CNPMF CE-03; Pera Seleção Olímpia; 'Pera Bianchi'; Pera Seleção Vacinada; Pera Seleção Ipeal-E3; Pera Seleção Ibotirama; 'Valência CNPMF Montemorelos'; 'Natal CNPMF-112'; Seleção Berna; Seleção F-Menuda; 'BRS Sincorá'; 'Aquiri'; Seleção Early Oblong; Seleção Russas P.S.; 'Seleta Itaboraí'; 'Pineapple' e 'Westin' foram mais produtivas no porta-enxerto 'Sunki Tropical'. As copas Pera seleção Ibotirama, Valência Seleção CNPMF 02, Valência Seleção CNPMF 03; 'Valência CNPMF-27'; Valência Seleção CNPMF 36; Valência Seleção L. White; 'Natal CNPMF 112'; Seleção Berna; 'Aquiri'; Seleção Early Oblong; 'Salustiana'; 'Diva' e 'Hamlin 20' foram mais produtivas no porta-enxerto 'San Diego'. As copas Pera Seleção CNPMF 02; Pera Seleção CNPMF C-32; 'Pera CNPMF D-6'; 'Pera D25'; Pera Seleção Olímpia; Valência Seleção CNPMF 01; Valência Seleção CNPMF 02; Valência Seleção CNPMF; 'Valência CNPMF 27'; Valência Seleção CNPMF 36; Valência Seleção CNPMF-F11; Valência Seleção Chapman; 'Valência CNPMF Montemorelos'; 'Valência CNPMF Tuxpan'; Natal Seleção CNPMF 02; Natal Seleção Ipeal; 'Natal CNPMF 112'; Seleção F-Menuda; 'Seleta Itaboraí'; 'Salustiana'; 'Pineapple'; 'Hamlin 20' e 'MelRosa' foram mais produtivas no porta-enxerto 'Riverside'. As copas Pera Seleção CNPMF A15; 'Pera D25'; Pera Seleção Ipeal E3; Valência Seleção CNPMF 01; Valência Seleção CNPMF 02; Valência Seleção CNPMF; Valência Seleção CNPMF 36; Valência Seleção CNPMF-F11; Valência Seleção Delta; Valência Seleção Chapman; 'Valência CNPMF Montemorelos'; Valência Seleção Registro; 'Valência CNPMF Tuxpan'; Valência Seleção CNPMF 21; Natal Seleção CNPMF 01; 'Natal CNPMF 112'; Seleção Berna; 'Aquiri'; 'Diva' e 'Hamlin 20' foram mais produtivas no porta-enxerto 'Indio'.

Termos para indexação: *Citrus sinensis*, produção, cultivares.

Introduction

Brazil is the world's lead producer of oranges and the largest exporter of concentrated orange juice. In 2021, Brazil produced 16,214,982 tons of oranges, corresponding to 21.5% of all world production (FAO, 2023). Between the years 2001 and 2021, there was a decrease in the Brazilian production of 4.5%, however, the cultivated area increased from 824,693 ha in 2001 to 578,057 ha in

2021, which indicates an increase in productive yield of almost 8 $t.ha^{-1}$, transposing from 20.59 $t.ha^{-1}$ in 2001 to 28.05 $t.ha^{-1}$ in 2021 (IBGE, 2023). This is associated with the development of technologies, such as the inclusion of new top and rootstock cultivars, in addition to the denser spacing that allowed the use of a greater quantity of plants in the same cultivated area (VIDAL, 2021).

However, the Brazilian citrus production scenario is inserted in a narrow genetic base, with few top and rootstock cultivars. For canopy cultivars, the Brazilian citrus industry prefers cultivars used in industrialization such as the sweet orange trees 'Pera', 'Valencia', and 'Natal', given that around 50% of the world's juice production comes from Brazil, and approximately 98% of all juice produced in Brazil is destined for export, with only 2% remaining for domestic consumption (SIQUEIRA; SALOMÃO, 2017).

In relation to rootstocks, it is estimated that 55 and 27% of seedlings produced by nurseries in the State of São Paulo use the citrumelo 'Swingle' and lemon tree 'Cravo', respectively (EMBRAPA, 2022). The 'Swingle', has desirable characteristics such as tolerant to citrus tristeza, exocortion, xyloporosis, decline, and sudden death, however, it is incompatible with the tops of the 'Pera' orange tree (SIQUEIRA; SALOMÃO, 2017). The 'Cravo', on the other hand, has excellent vigor, tolerance to water deficit, easy obtaining of seedlings, high productivity, precocity, and high productivity, although, it has been one of the main rootstocks used in Brazilian orchards since the 1960, it contributes to phytosanitary problems, leaving Brazilian plantations susceptible to new diseases (BASTOS et al., 2014).

Furthermore, it should be noted that new rootstocks have not been tested in all regions, climate, soil, management, and canopy cultivars, which means that the work is endless. Therefore, studies that can accurately characterize the different combinations of top and rootstock are essential, seeking those that present superior characteristics for the region and its scope. In addition, the southern region of the State of Bahia has great potential for the production of orange crops, due to areas with flat relief, which allow mechanization, ease of production flow via highways, edaphoclimatic conditions considered ideal, and the absence of diseases of great importance for the crop with Greening, or Huanglongbing (HLB), which has been devastating orchards in the main producing regions of Brazil.

Thus, the objective of this study was to evaluate the productive performance of 232 combinations of tops and rootstock, with 58 sweet-orange top cultivars on the rootstocks, mandarin 'Sunki Tropical' and hybrids of mandarin 'Sunki' with 'Trifoliate', Citrandarin 'San Diego', 'Riverside' and 'Indio', in the Extreme South of the State of Bahia.

Material and Methods

The study was conducted in an 8-year-old citrus orchard located at Chão Bello Farm, belonging to the Bello Brazilian Exotic Fruit Company, located in the municipality of Ibirapuã, in the Extreme South of the State of Bahia, Brazil, under the following geographic coordinates: 18° 03' 09.4" South latitude 39° 52' 26.2" East longitude. The orchard was established on April 21, 2015, using seedlings from asexual propagation through grafting, obtained by joining rootstocks produced by mature seeds of plants with good health with top cultivars obtained through buds taken from productive mother plants and pre-immunized.

The distance used was 6 meters between rows and 3 meters between plants, with a micro-sprinkler type localized irrigation system, with a flow rate of 72 L/h, maintained by a KSB Meganorm 50-200 centrifugal pump with 40 hp and a maximum service pressure of 10 bar, divided into two

fixed watering shifts of 6 mm/day. All cultural treatments, such as pest and disease management, invasive plant management, and harvesting, were carried out as established by the company Bello Brazilian Exotic Fruit, as described by Siqueira and Salomão (2017).

The climate of the region according to the Köppen classification is Tropical Am (ALVARES et al., 2014). The climatology with values of maximum and minimum temperatures (°C), in addition to precipitation (mm), in the municipality of Ibirapuã, calculated for each month of the year, during the 30-year historical data series (CLIMATEMPO, 2023), can be observed in Figure 1.

The chemical characteristics of the soil in the experimental area in the 0-20 cm layer are shown in Table 1.

Fertilization was carried out through fertigation, the quantity and number of applications of which can be seen in Table 2.

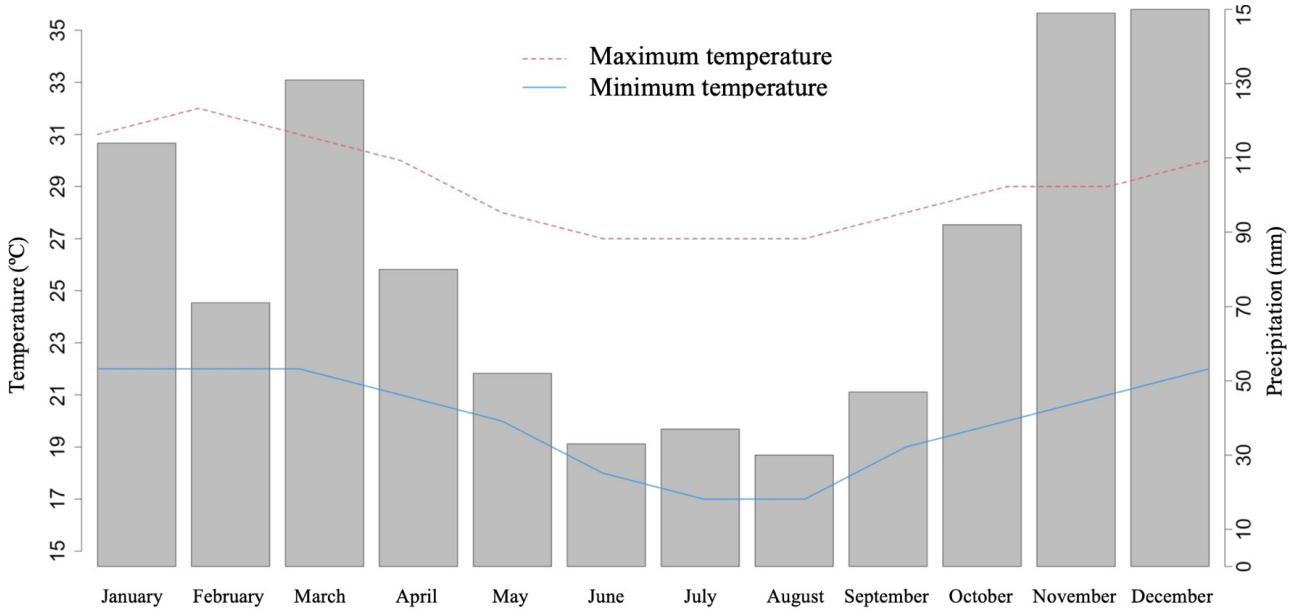

FIGURE 1. Maximum and minimum temperatures (°C) and precipitation (mm), in the municipality of Ibirapuã, State of Bahia, Brazil
SOURCE: adapted from CLIMATEMPO, 2023.

TABLE 1. Chemical attributes of the soil in the experimental area of Fazenda Chão Bello, in the municipality of Ibirapuã, BA, at a soil depth of 0-20 cm

pH	MO	P	K	Ca	Mg	Al	H+Al	SB	T	V
(H_2O)	dag dm $^{-1}$	--- mg dm^{-3} ---			---------- cmol$_c$ dm^{-3} ----------					- % -
5.2	1.88	16	74	0.9	0.3	0.1	2.8	1.4	4.2	33.5

TABLE 2. Fertilizer, quantity (kg) and number of annual applications in the experimental area of Fazenda Chão Bello, in the municipality of Ibirapuã, BA.

	Adubo							
	Urea	Potassium chloride	Calcium nitrate	Manganese sulfate	Copper sulfate	Zinc sulfate	Magnesium nitrate	Boric acid
Applied dose (kg)	239.0	306.7	159.2	8.8	8.8	10.0	44.0	2.2
Number of applications (years^{-1})	29	29	29	6	6	6	6	3

232 tops and rootstock combinations were evaluated. Among the treatments, fifty-eight different sweet orange tree cultivars were used, namely: Pera (Selection CNPMF 01, Selection CNPMF 02, Selection CNPMF A-15, 'B-12', 'C-21', Selection CNPMF C- 32, Selection CNPMF D-3, 'CNPMF D-6', 'CNPMF D-9', 'D-12', 'D-25', Selection Ipeal-E3, 'CNPMF E-6', Selection Olímpia, 'Bianchi', Selection CE-03, Selection Vacinada e Selection Ibotirama); Natal (Selection CNPMF 01, Selection CNPMF 02, 'CNPMF 112', Selection Ipeal e 'Folha Murcha'); Valencia (Selection CNPMF, Selection CNPMF 01, Selection CNPMF 02, Selection CNPMF 03, Selection CNPMF 21, 'CNPMF 27', Selection CNPMF 36, Selection CNPMF F-11, 'Midknight', Selection Criola, Selection Delta, 'Late', Selection L.Shaffey, Selection Chapman, Selection L.White, 'CNPMF Montemorelos', Selection Registro, 'CNPMF Tuxpan'); and others (Selection Berna, 'Jaffa', Selection F- Menuda, 'BRS Sincorá', 'Aquiri', Selection Early Oblong, Selection Russas P.S, 'Seleta de Itaboraí', 'Salustiana', 'Pineapple', Selection Rubi CN-01, 'Westin', 'Diva', 'Hamlin 20', Selection Crescent, 'Melrosa' e Selection Flor de Brumadinho). The rootstocks evaluated were: 'Sunki' mandarin, Selection 'Sunki Tropical' (*Citrus sunki* (Hayata) hort. ex Tanaka) and the hybrids of mandarin 'Sunki' with 'Trifoliata', Citrandarin 'San Diego' from the cross between the mandarin 'Sunki' *C. sunki* (Hayata) hort. ex Tanaka x *Poncirus trifoliata* (L.), 'Riverside' comes from the cross between the mandarin 'Sunki' *C. sunki* (Hayata) hort. ex Tanaka x *P. trifoliata* (L.) and 'Indio' comes from the cross between the mandarin 'Sunki' *C. sunki* (Hayata) hort. ex Tanaka x *P. trifoliata* (L.). 5 experimental plots (plants) were evaluated, totaling 1,160 plants in the experimental field.

In the field, the total mass of fruits per plant, in kg, was evaluated over the 6 years, from 2018 to 2023, for each year. As planting was carried out in 2015, each year evaluated was defined as 2018 (3 years after planting (YAP)); 2019 (4 YAP); 2020 (5 YAP); 2021 (6 YAP); 2022 (7 YAP) and 2023 (8 YAP). Therefore, each year had the total accumulated fruit mass calculated in each combination. In each period, the total mass of the fruits was obtained by weighing the fruits on a precision electronic scale. With production data per plant and several five hundred and fifty-five plants per hectare, total productivity was estimated, in $t.ha^{-1}$.

To determine productive performance, logistic model equations were adjusted, represented by: $Yi = \frac{\alpha}{1 + e^{(y-kx)}}$ where total productivity ($t.ha^{-1}$) was used as the dependent variable (y) depending on the YAP as an independent variable (x). Thus, in the model presented, Y_i is the value of the evaluated characteristic (productivity); $\boldsymbol{x}$ is the number of years after planting; α is the maximum value reached by the evaluated characteristics, that is, the value at which the characteristic stabilizes; $\boldsymbol{y}$ is the parameter to maintain the sigmoidal shape of the model; $\boldsymbol{k}$ is the parameter associated with growth, the higher the value of $\boldsymbol{k}$, the less time is needed for the fruits to reach the value of. Also, the amount of YAP needed for each cultivar to reach the maximum productivity value was calculated, using each adjusted equation, based on the values obtained.

All statistical analyses and graphical representations were held using the R program (R CORE TEAM, 2023), through the ExpDex.pt data package (FERREIRA, et al., 2018).

Results and Discussion

The maximum productive performance (PROD) of the 'Pera' orange tops on the rootstocks, obtained based on the adjusted logistic equations, are shown in Table 3. The maximum productivity for each combination was achieved between 4.58 and 10.25 Years after planting depending on the top and rootstock. The combinations that

show productivity greater than 80 t.ha^{-1} in the tops of the 'Pera' orange tree (Figure 2) were the Selection CNPMF A-15, 'C-21', Selection CNPMF D-3, 'D-25', 'CNPMF E-6', Selection Olímpia, 'Bianchi', Selection CNPMF CE-03, Selection Vacinada, Selection CNPMF Ipeal-E-3 and Selection Ibotirama on the rootstock 'Sunki Tropical', Selection Ibotirama on the rootstock San Diego, Selection CNPMF 02, Selection CNPMF C-32, 'CNPMF D-6', 'D-25' and Seleção Olímpia on the rootstock 'Riverside' and Selection CNPMF A-15, 'D-25' and Selection CNPMF Ipeal-E3 on the rootstock 'Indio'.

The 'Pera' orange tree top is the most cultivated in Brazil due to its easy adaptation to the climate and soil conditions of the different Brazilian regions, in addition to presenting an appearance and flavor acceptable to consumer standards, being used both for the fresh market, when for the juice production industry (COELHO et al., 2019; BASTOS et al., 2021a). Thus, the cultivation of the 'Pera' orange tree has already been studied in several regions of Brazil, with varying yields being obtained, such as 45 and 42 t.ha^{-1} in 11 and 13-year-old orchards, in the State of Santa Catarina, in the municipalities of Xaxim and Chapecó (BRUGNARA; ANDRADE, 2019). In a plantation located in Londrina in the State of Paraná, the average productivity in nine harvests ranged from 31.18 to 39.05 t.ha^{-1} (TAZIMA et al., 2010). In research led in Rio Branco, Acre, average yields of 6.72 t.ha^{-1} were obtained in 7-year-old orchards (RODRIGUES et al., 2019). In the main Brazilian orange-producing region, which involves the State of São Paulo and Triângulo/Southwest of the State of Minas Gerais, the average productivity was 717 boxes of 40.8 kg per hectare, corresponding to 29.25 t.ha^{-1} (FUNDECITRUS, 2021). All these values are lower than those found for the 'Pera' orange tree tops in the most productive combinations in the present study.

TABLE 3. Maximum productivity value (PROD) and years after planting (YAP) in which the combinations reached the maximum productivity value obtained through logistic model equations, for tops of 'Pera' sweet orange trees on rootstocks' Sunki Tropical', 'San Diego', 'Riverside' and 'Indio'

Tops/Rootstock	'Sunki Tropical'		'San Diego'		'Riverside'		'Indio'	
	PROD (t.ha^{-1})	YAP (years)	PROD (t.ha^{-1})	YAP (years)	PROD (t.ha^{-1})	YAP (years)	PROD (t.ha^{-1})	YAP (years)
Selection CNPMF 01	70.01	7.42	36.91	6.85	69.45	6.21	57.91	6.98
Selection CNPMF 02	66.38	8.76	43.00	5.93	89.70	7.76	64.35	6.24
Selection CNPMF A-15	89.72	8.70	32.30	5.76	77.83	8.05	83.50	6.83
'B-12'	72.17	7.68	72.00	9.23	52.60	5.56	78.98	5.11
'C-21'	81.84	8.78	48.07	7.24	69.53	4.70	61.97	5.97
Selection CNPMF C-32	79.05	9.80	62.23	8.91	87.04	8.49	52.15	4.81
Selection CNPMF D-3	84.99	8.24	64.34	10.25	70.31	7.30	66.52	6.44
'CNPMF D-6'	68.70	7.44	64.83	10.07	85.20	7.63	62.50	8.00
'CNPMF D-9'	56.10	6.24	56.10	5.95	79.54	8.13	62.20	5.65
'D-12'	62.53	8.22	48.18	6.15	51.42	6.60	56.46	6.68
'D-25'	112.72	9.04	79.10	6.97	89.69	8.45	91.91	7.71
'CNPMF E-6'	100.48	9.24	60.20	5.88	73.97	9.18	45.60	5.84
Selection Olímpia	97.01	10.02	68.61	7.45	88.48	7.69	67.30	6.87
'Bianchi'	102.98	9.64	78.34	9.12	77.94	6.88	70.97	6.93
Selection CNPMF CE-03	108.98	9.60	60.39	6.52	66.04	6.67	59.90	5.74
Selection Vacinada	83.13	9.28	42.83	4.58	62.23	6.69	64.54	6.22
Selection Ipeal E-3	85.89	9.28	74.81	5.27	62.68	5.15	89.55	6.16
Selection Ibotirama	84.22	9.50	88.43	9.83	71.27	9.02	74.21	8.48

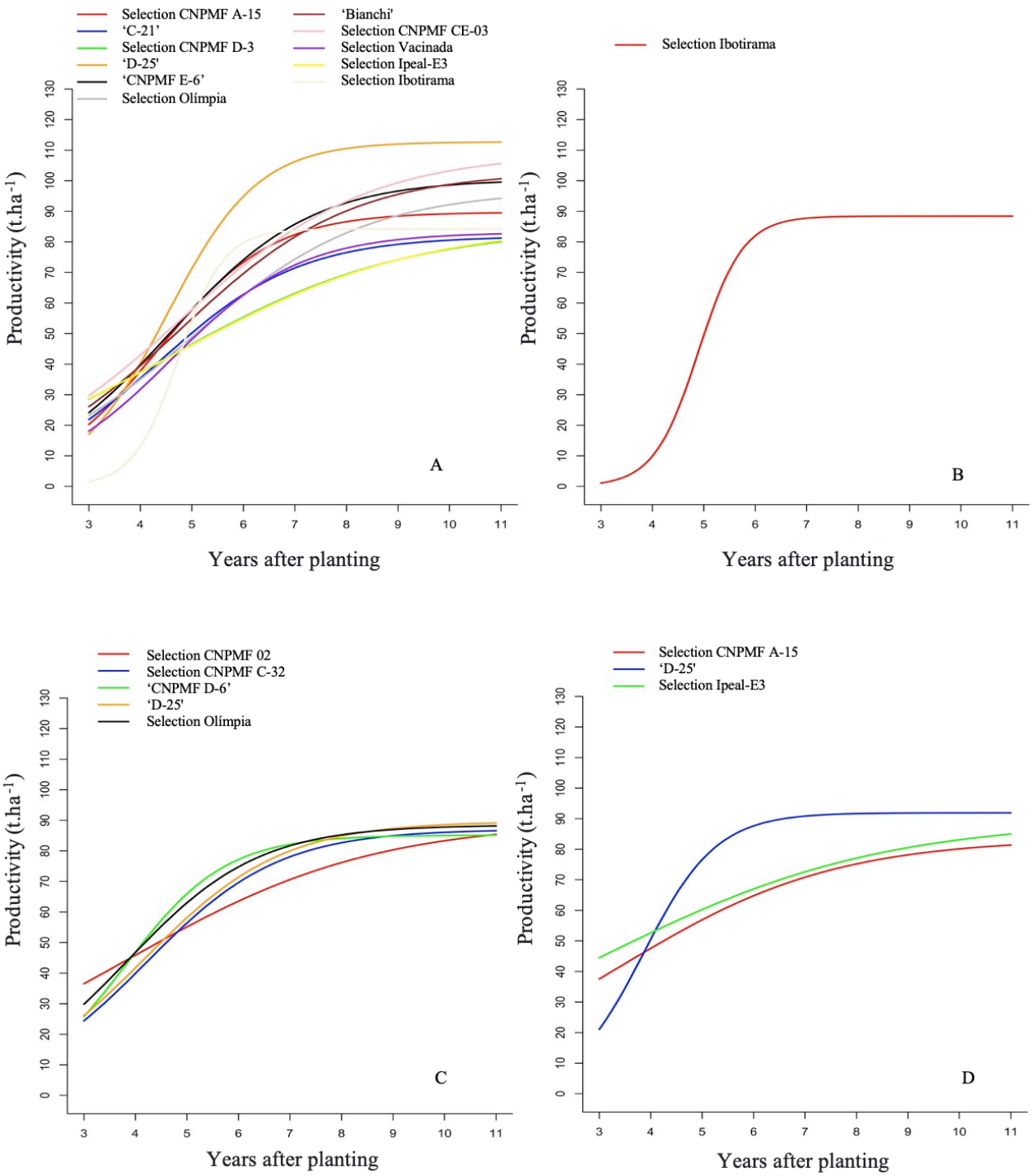

FIGURE 2. Productive performance curve obtained through logistic equations using productivity as a function of years after harvesting 'Pera' orange tree tops on the rootstock 'Sunki Tropical'(A), 'San Diego'(B), 'Riverside'(C) and 'Indio'(D).

In table 4, the maximum productive performance and time required for the 'Valencia' orange tree tops to reach this value. It is noted that the canopies that showed the highest productivity, exceeding 80 t.ha^{-1} (Figure 3), were 'CNPMF Montemorelos' on the rootstock 'Sunki Tropical', Selection CNPMF 02, Selection CNPMF 03, 'CNPMF 27', Selection CNPMF 36 and Selection L. White on the rootstock 'San Diego', Selection CNPMF 01, Selection CNPMF 02, Selection CNPMF, 'CNPMF 27', Selection CNPMF 36, Selection CNPMF F-11, Selection Chapman', 'CNPMF Montemorelos'and 'CNPMF Tuxpan' on the

rootstock 'Riverside' and Selection CNPMF 01, Selection CNPMF 02, Selection CNPMF, Selection CNPMF 36, Selection CNPMF F-11, Selection Delta, Selection Chapman, 'CNPMF Montemorelos', Selection Registro, 'CNPMF Tuxpan' and Selection CNPMF 21, on the rootstock 'Indio'. With emphasis on the CNPMF 01 Selection top on the 'Indio' rootstock, which showed the highest productivity among all those evaluated, with 121.97 t.ha^{-1}. Regarding the time needed for the combinations to reach maximum productive performance, the values varied from 7.74 to 11.18 years after planting in all combinations.

Regarding the tops of 'Valencia' orange tree, Tazima et al. (2008), recorded, in an orchard 10 to 12 years after planting, with 7 x 6 m spacing, in Londrina in the State of Paraná, an average production of 157.14 to 264.38 kg per plant, corresponding to 37.38 at 62.92 t.ha^{-1}. Frighetto et al. (2014), reported production ranging from 22 to 104 kg or 12.22 to 57.77 t.ha^{-1} in a 6-year-old orchard in the northern region of the State of Rio Grande do Sul. In the citrus belt region of the State of São Paulo and Triângulo/Southwest of the State of Minas Gerais, the average productivity was estimated at 853 boxes of 40.8 kg per hectare, corresponding to 34.80 t.ha^{-1} (FUNDECITRUS, 2021). Thus, the results demonstrate that in the four rootstocks evaluated, there are combinations with 'Valencia' orange tree tops that present higher productivity than those recorded in the main Brazilian producing regions, indicating potential use for these combinations in the national production scenario.

TABLE 4. Maximum productivity value (PROD) and years after planting (YAP) in which the combinations reached the maximum productivity value obtained through logistic model equations, for tops of 'Valencia' sweet orange trees on rootstocks' Sunki Tropical', 'San Diego', 'Riverside' and 'Indio'

Tops/Rootstock	'Sunki Tropical'		'San Diego'		'Riverside'		'Indio'	
	PROD (t.ha^{-1})	YAP (years)	PROD (t.ha^{-1})	YAP (years)	PROD (t.ha^{-1})	YAP (years)	PROD (t.ha^{-1})	YAP (years)
Selection CNPMF 01	57.23	9.04	69.11	9.73	114.71	10.31	121.97	10.60
Selection CNPMF 02	38.96	8.68	88.56	9.59	84.44	9.05	81.16	9.68
Selection CNPMF	38.28	8.58	71.75	9.03	87.09	9.36	83.96	10.22
Selection CNPMF 03	46.15	8.80	90.43	9.59	78.20	9.84	69.28	9.60
'CNPMF 27'	49.38	9.14	81.64	9.26	88.90	9.52	76.20	9.46
Selection CNPMF 36	47.49	8.48	95.48	9.59	105.96	9.21	108.53	10.09
'Midknight'	39.08	10.0	60.97	10.34	41.05	8.88	61.81	11.18
Selection CNPMF F-11	69.23	9.84	62.85	8.78	87.48	9.08	83.78	10.10
Selection Criola	50.64	9.00	52.58	8.48	77.26	9.22	69.18	9.80
Selection Delta	35.61	8.62	54.93	7.74	45.58	8.12	91.70	10.26
'Late'	67.23	8.56	62.12	9.56	64.05	9.05	76.45	10.00
Selection L. Shaffey	59.46	9.34	70.91	9.38	77.01	9.16	78.59	10.31
Selection Chapman	75.44	8.72	75.62	8.59	89.84	8.79	85.62	9.27
Selection L. White	68.02	8.98	81.40	9.21	75.77	8.75	76.53	10.00
'CNPMF Montemorelos'	81.14	9.24	71.60	9.02	95.47	9.15	99.65	10.10
Selection Registro	43.42	8.22	53.96	9.18	60.89	8.09	80.46	9.13
CNPMF Tuxpan	43.74	9.08	56.38	9.09	84.39	9.80	98.59	10.13
Selection CNPMF 21	44.79	8.52	67.82	8.87	76.69	9.33	106.77	9.43

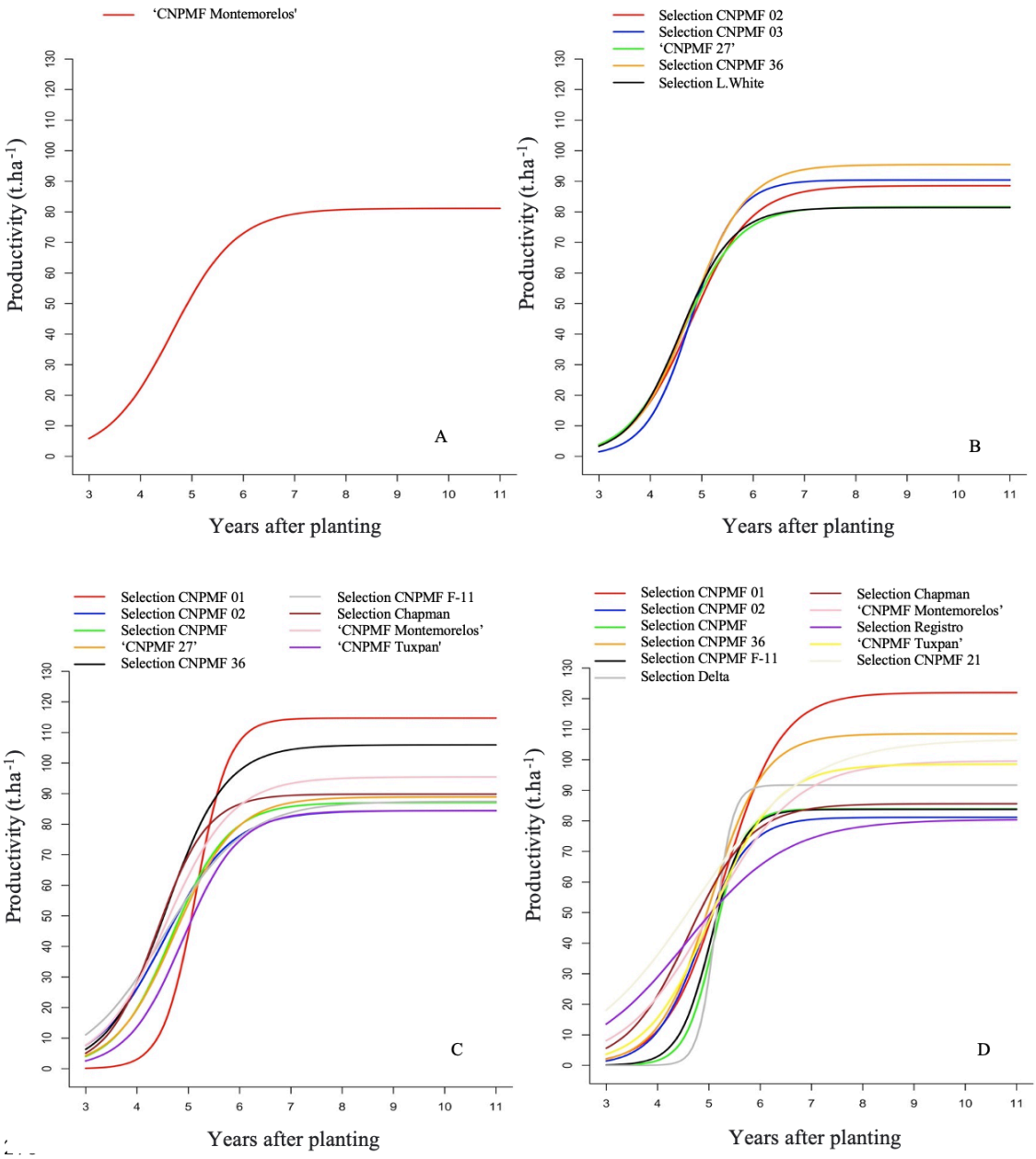

FIGURE 3. Productive performance curve obtained through logistic equations using productivity as a function of years after harvesting 'Valencia' orange tree tops on the rootstock 'Sunki Tropical' (A), 'San Diego' (B), 'Riverside' (C) and 'Indio' (D).

For the 'Natal' orange cultivars, the maximum productive performance was observed in the Natal CNPMF 112 cultivar on all rootstocks analyzed (Table 5). These results found in the present study are superior to those found by Bastos et al., (2021b) who, evaluating different rootstocks for 'Natal CNPMF 112' orange trees in Juazeiro, in the State of Bahia, found average yields of 4.82, 11 .44 and 12.68 t.ha^{-1} in an irrigated orchard, 5, 6 and 7 years after planting, respectively. Also noteworthy, in the 'Natal' orange tops, are the combinations Selection CNPMF 02, Selection Ipeal on the rootstock 'Riverside' e Selection CNPMF 01 on 'Indio' rootstock with productivity above 80 t.ha^{-1} (Figure 4). It should be noted that the 'Natal' orange cultivars are late maturing, with more time between flowering and fruit maturation. Therefore, it is possible to serve the consumer market in periods between harvests, where sales prices are more attractive.

TABLE 5. Maximum productivity value (PROD) and years after planting (YAP) in which the combinations reached the maximum productivity value obtained through logistic model equations, for tops of 'Natal' sweet orange trees on rootstocks' Sunki Tropical', 'San Diego', 'Riverside' and 'Indio'

Tops/Rootstock	'Sunki Tropical'		'San Diego'		'Riverside'		'Indio	
	PROD ($t.ha^{-1}$)	YAP (years)	PROD ($t.ha^{-1}$)	YAP (years)	PROD ($t.ha^{-1}$)	YAP (years)	PROD ($t.ha^{-1}$)	YAP (years)
Selection CNPMF 01	78.44	8.10	79.98	8.54	72.57	7.28	95.95	9.52
Selection CNPMF 02	46.47	7.84	68.48	7.88	83.80	8.72	72.01	7.52
Selection Ipeal	63.09	8.74	52.76	8.72	93.15	10.36	61.48	7.77
'CNPMF 112'	85.74	9.04	106.61	9.60	97.28	9.20	102.75	9.12
'Folha Murcha'	55.49	10.96	54.25	10.16	60.36	10.28	56.12	10.13

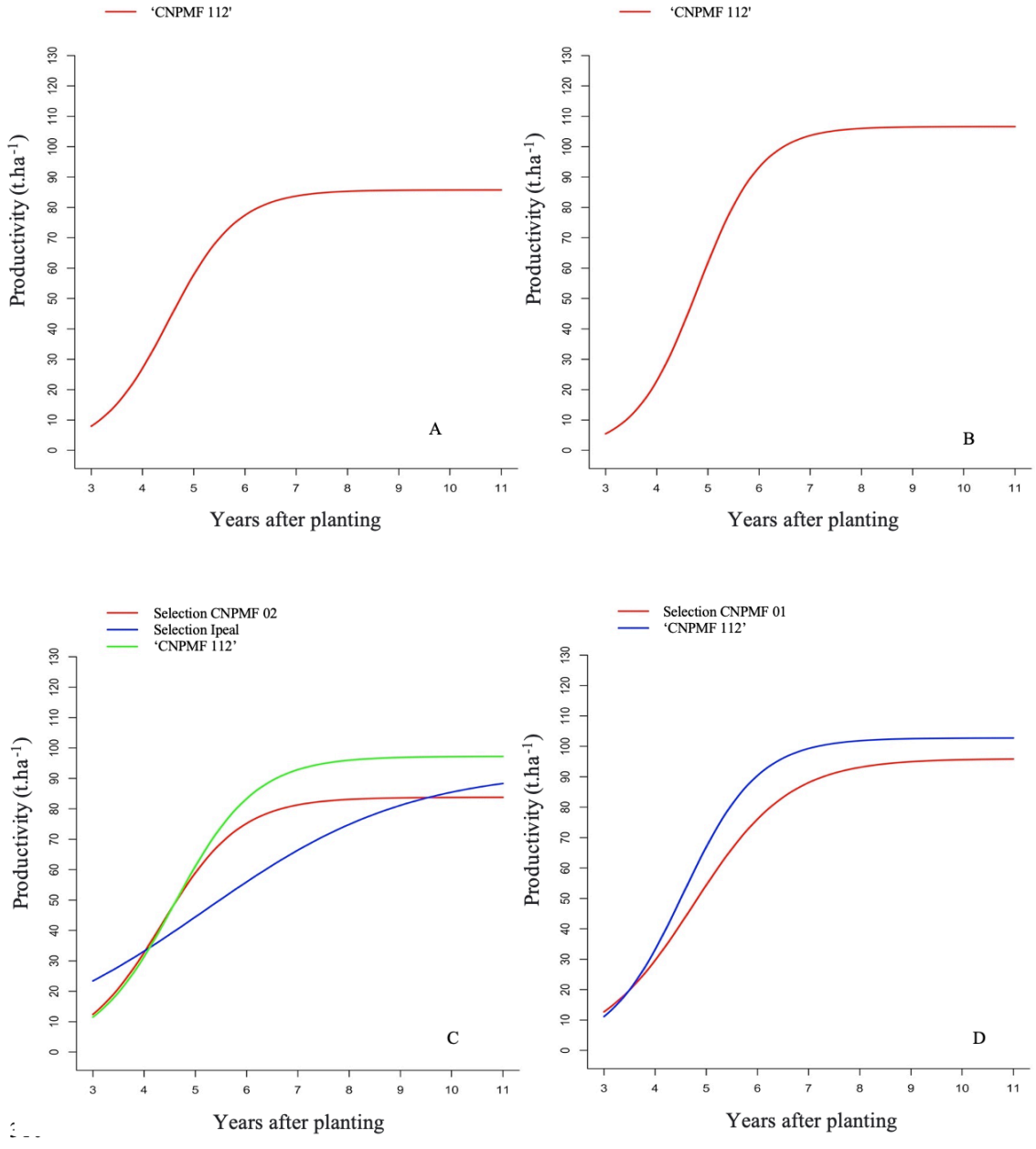

FIGURE 4. Productive performance curve obtained through logistic equations using productivity as a function of years after harvesting 'Natal' orange tree tops on the rootstock 'Sunki Tropical' (A), 'San Diego' (B), 'Riverside' (C) and 'Indio' (D).

It was possible to observe that in the group called others (Table 6 and Figure 5), the maximum productive performances were observed in the tops Selection Berna, Selection F-Menuda, 'BRS Sincorá', 'Aquiri', Selection Early Oblong, Selection Russa P.S., 'Seleta Itaborai', 'Pineapple' and 'Westin', on the rootstock 'Sunki Tropical', Selection Berna, 'Aquiri', Selection Early Oblong, 'Salustiana', 'Diva' and 'Hamlin 20', on the rootstock 'San Diego', Selection F-Menuda', 'Seleta Itaborai', 'Salustiana', 'Pineapple', 'Hamlin 20', 'MelRosa', on the rootstock 'Riverside' and Selection Berna', 'Aquiri', 'Diva' and 'Hamlin 20', on the rootstock 'Indio'. Furthermore, it is possible to note that the maximum productive performance was achieved for all cultivars between 5.32 and 10.93 years after planting, with the 'BRS Sincorá' top being the earliest among all rootstocks evaluated in this group. A fact to be mentioned is that according to Oliveira et al. (2023), evaluating the same combinations as in this study, highlighted the 'Jaffa' and 'Westin' top in all the rootstocks evaluated, as those that presented fruit characteristics with commercial quality. Furthermore, according to the same authors, the top 'BRS Sincorá' and 'Westin' on the rootstock 'Sunki Tropical', 'BRS Sincorá', 'Aquiri' and Selection Russas P.S on the rootstock 'San Diego' and ' Salustiana' and 'Westin' on 'Riverside' rootstock have shown promise for the juice production industry.

TABLE 6. Maximum productivity value (PROD) and years after planting (YAP) in which the combinations reached the maximum productivity value, obtained through logistic model equations, for tops of sweet orange trees from the other group on rootstocks 'Sunki Tropical', 'San Diego', 'Riverside' and 'Indio'

Tops/Rootstock	'Sunki Tropical'		'San Diego'		'Riverside'		'Indio'	
	PROD ($t.ha^{-1}$)	YAP (years)	PROD ($t.ha^{-1}$)	YAP (years)	PROD ($t.ha^{-1}$)	YAP (years)	PROD ($t.ha^{-1}$)	YAP (years)
Selection Berna	90.03	10.52	91.67	9.78	71.85	8.75	90.88	9.98
'Jaffa'	79.58	10.17	51.17	9.34	57.37	7.59	69.83	9.52
Selection F-Menuda	84.83	11.05	53.49	9.62	87.38	9.75	78.81	10.21
'BRS Sincorá'	81.11	6.54	71.74	6.40	52.60	5.32	73.80	5.93
'Aquiri'	86.79	9.71	82.02	9.50	77.48	8.99	97.38	9.09
Selection Early Oblong	86.42	9.76	86.85	10.70	79.39	7.28	65.14	8.62
Selection Russas P.S	90.86	10.14	77.36	9.51	66.36	8.21	45.97	8.64
'Seleta Itaborai'	106.11	10.19	50.42	7.52	85.29	9.88	71.35	9.48
'Salustiana'	75.92	9.51	90.52	9.21	86.65	9.47	57.52	9.95
'Pineapple'	99.01	10.99	73.51	8.75	82.84	7.72	70.84	8.88
Selection Rubi CN-01	45.73	10.86	32.90	9.08	52.67	9.52	43.08	10.93
'Westin'	82.47	10.93	39.94	7.36	71.85	9.85	40.36	8.12
'Diva'	64.73	9.43	91.79	10.12	77.95	8.64	98.07	10.28
'Hamlin 20'	68.24	8.29	82.14	9.30	85.96	8.65	84.24	8.90
Selection Crescent	58.26	9.34	59.66	9.03	64.09	9.48	53.14	10.57
'MelRosa'	74.31	10.19	63.70	8.87	89.25	10.45	62.11	9.70
Selection Flor Brumadinho	59.40	9.71	79.69	9.96	79.21	9.78	66.14	10.32

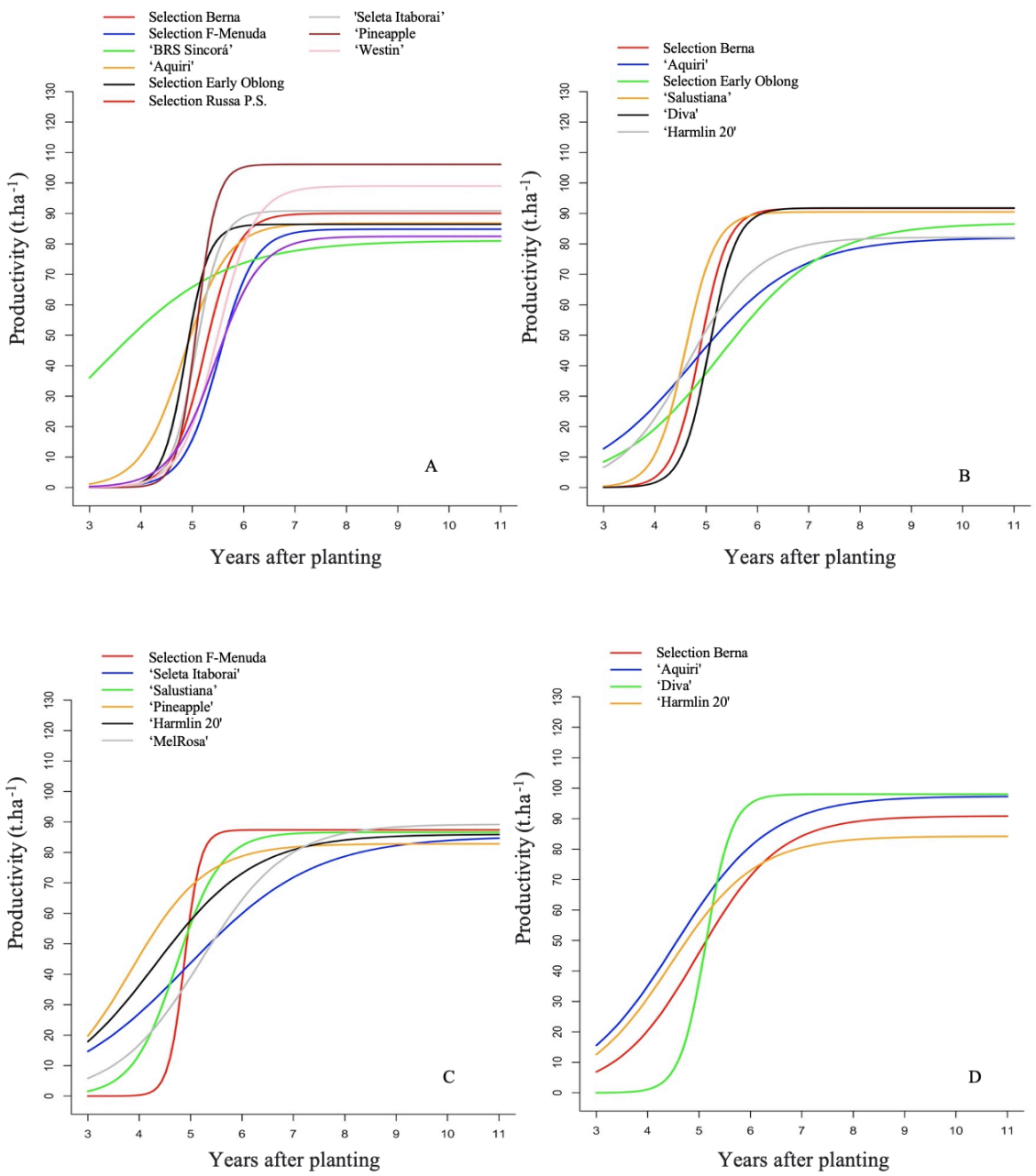

FIGURE 5. Productive performance curve obtained through logistic equations using productivity as a function of years after harvesting orange tree tops Others on the rootstock 'Sunki Tropical' (A), 'San Diego' (B), 'Riverside ' (C) and 'Indio' (D).

Among the 78 combinations that presented productivity above 80 t.ha^{-1}, 22 were on the 'Sunki Tropical' rootstock, 13 on the 'San Diego' rootstock, 23 on 'Riverside' rootstocks, and 20 on the 'Indio' rootstock. With emphasis on the rootstocks 'Riverside' and 'Indio' which, according to Carvalho et al. (2016), have a greater capacity for absorption of water and nutrients by the roots, providing canopy development and improving production performance. This can be proven mainly in the 'Natal' and 'Valencia' orange tree canopies, where 52% of the combinations evaluated showed productivity greater than 80 t.ha^{-1}. Another highlight is the rootstock 'Sunki Tropical', which presents greater rusticity, is tolerant to lack of water and with late fruit maturation (BASTOS et al., 2014), and can be an alternative for non-irrigated orchards or regions with lower rainfall regimes. Furthermore, the 'Sunki Tropical' rootstock proved to be an excellent alterna-

tive to the 'Pera' orange tree top and other cultivars, with 20 of the 35 combinations obtained showing productivity exceeding 80 t.ha^{-1} on this rootstock.

Therefore, the rootstocks 'Sunki Tropical', 'Riverside', and 'Indio' are excellent alternatives in the Brazilian production scenario, being a great option for the diversification of orchards, since around 82% of sweet orange orchards in the main producing regions in Brazil are planted using the rootstocks 'Swingle' citrumelo and 'Cravo' lemon Tree (EMBRAPA, 2022). However, it should be noted that the 'San Diego' rootstock may present desirable characteristics for certain situations, such as its reduced architecture, enabling greater density and, consequently, a greater number of plants and resulting in a greater unit of productive area (CARVALHO et al ., 2016), in addition to presenting productivity above 90 t.ha-1 in the tops Valencia Selection CNPMF 03', Valencia Selection CNPMF 36, 'Natal CNPMF 112', Selection Berna, 'Salustiana' and 'Diva'.

It should be noted that all combinations analyzed in this study presented productivity equal to or greater than 32.30 t.ha^{-1}, being higher than the average yield of Brazilian production (28.05 t.ha^{-1}) and the State of Bahia (12.08 t.ha^{-1}) (IBGE, 2023), demonstrating excellent production capacity for all combinations. This fact also highlights the lack of adoption of technologies that favor the production of orange plants in Brazilian orchards.

Among the factors that resulted in high productivity obtained in the combinations in this study, is attributed to the use of technologies and the correct implementation of cultural treatments in the orchard, such as the use of denser spacing, availability of nutrition for the plants, irrigation management, bush management to reduce competitiveness and phytosanitary monitoring and management. It is known that the use of technology is only sometimes possible due to implementation costs and the limitations of the area where the plantation is established, such as the use of irrigation, which often involves high monetary investments. However, simpler measures such as the choice of cultivars adapted to the region and the density of plants can result in significant production gains.

According to Teófilo Sobrinho et al. (2002), in denser spacings, there may be lower fruit production per plant, however, when compared to wider spacings with less plant density, in general, the yield per area is higher. According to the authors, this technique is also beneficial to avoid stress or exhaustion due to the plants producing a slightly smaller quantity of fruits. Furthermore, more spaced plants generate waste of resources, underutilizing equipment and leading to lower productive and consequently economic yields for the orchard. However, it should be noted that very dense plantings could result in competition between plants for water, light, and nutrients, which could limit plant development (SIQUEIRA; SALOMÃO, 2017).

Another fact to be mentioned is that the average temperature of the historical series in the experimental area ranged from 17 to 32 ºC, with recorded accumulated precipitation of 986 mm annually (Figure 1). These values are in the range considered ideal for the development of citrus, from 13 to 32 ºC and precipitation exceeding 700 mm (SIQUEIRA; SALOMÃO, 2017). If temperatures are very low and/or lack of water, they can interfere with the flowering of orange plants (TONET et a., 2002). At temperatures below 13 ºC and above 35 ºC, the photosynthetic rate can be impaired, severely limiting plant development and causing a reduction in productivity (SIQUEIRA; SALOMÃO, 2017). Regarding precipitation, although the region presents satisfactory amounts for the full development of the crop, the plantation has an irrigation system, which can adequately supply the amount of water demanded by the crop if necessary.

It should also be noted that the maximum productivity for all combinations under study was obtained between 4.58 and 11.18 years after planting. The production of orange fruits begins in the third year after planting, if the orchard has favorable soil and climate conditions, and production can increase up to more than 10 years after planting, depending on the cultivar. From then on, there is stability in productivity, which can last for up to 30 years when the orchard is well managed. This occurs because, at this stage of development of citrus plants, there is little vegetative growth, with the energy demand being used only for the maintenance of senescent leaves and branches and for the production of fruits (MATTOS JUNIOR et al., 2005; SIQUEIRA; SALOMÃO, 2017).

The results also indicate that, regardless of the rootstock, in general, the 'Pera' orange tops showed greater early productivity, with the combination Pera Selection Vacinada//'San Diego' being the one that achieved the highest productive performance earlier (4.58 YAP) among all the combinations evaluated. However, as observed in this study, greater productive precocity is not always related to greater productivity. This is associated with plants with greater initial biomass development, allowing better absorption of water and nutrients by the roots, thus achieving maximum productive performance earlier (RODRIGUEZ-GAMIR et al., 2010; CARVALHO et al., 2016).

It is important to highlight that to choose the best combination to be implemented in the orchard, other aspects must be considered in addition to productivity, such as maturation time, fruit quality, tops and rootstock compatibility, tolerance/resistance to main pests and diseases, adaptation to the region, availability of labor and intended market (in natural or industrial) (SIQUEIRA; SALOMÃO, 2017). These factors are essential for the success of the enterprise since the orange orchard lacks financial resources for its implementation.

Conclusions

The tops Pera Selection CNPMF A15; 'Pera C-21', Pera Selection CNPMF D3, 'Pera D25', 'Pera CNPMF E-6', Pera Selection CNPMF CE-03, Pera Selection Olímpia, 'Pera Bianchi', Pera Selection Vacinada, Pera Selection Ipeal-E3, Pera Selection Ibotirama, 'Valencia CNPMF Montemorelos', 'Natal CNPMF-112', Selection Berna, Selection F-Menuda, 'BRS Sincorá', 'Aquiri', Selection Early Oblong, Selection Russas P.S., 'Seleta Itaboraí', 'Pineapple' and 'Westin' were more productive on the rootstock 'Sunki Tropical'.

The tops Pera Selection Ibotirama, Valencia Selection CNPMF 02, Valencia Selection CNPMF 03, 'Valencia CNPMF-27', Valencia Selection CNPMF 36, Valencia Selection L. White, 'Natal CNPMF 112', Selection Berna, 'Aquiri', Selection Early Oblong, 'Salustiana', 'Diva' and 'Hamlin 20' were more productive on the rootstock 'San Diego'.

The tops Pera Selection CNPMF 02, Pera Selection CNPMF C-32, 'Pera CNPMF D-6', 'Pera D25', Pera Selection Olímpia, Valencia Selection CNPMF 01, Valencia Selection CNPMF 02, Valencia Selection CNPMF, 'Valencia CNPMF 27', Valencia Selection CNPMF 36, Valencia Selection CNPMF-F11, Valencia Selection Chapman, 'Valencia CNPMF Montemorelos', 'Valencia CNPMF Tuxpan', Natal Selection CNPMF 02, Natal Selection Ipeal, 'Natal CNPMF 112', Selection F-Menuda, 'Seleta Itaboraí', 'Salustiana', 'Pineapple', 'Hamlin 20' and 'MelRosa' were more productive on the rootstock 'Riverside'.

The tops Pera Selection CNPMF A15, 'Pera D25', Pera Selection Ipeal E3, Valencia Selection CNPMF 01, Valencia Selection CNPMF 02, Valencia Selection CNPMF, Valencia Selection CNPMF 36, Valencia Selection CNPMF-F11, Valencia Selection Delta, Valencia Selection Chapman, 'Valencia CNPMF Montemorelos', Valencia Selection Registro, 'Valencia CNPMF Tuxpan', Valencia

Selection CNPMF 21, Natal Selection CNPMF 01, 'Natal CNPMF 112', Selection Berna, 'Aquiri', 'Diva' and 'Hamlin 20' were more productive on the rootstock 'Indio'.

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