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Performance of 'Okitsu' Satsuma Mandarin on nine rootstocks

Zuleide Hissano Tazima[1]*, Carmen Silvia Vieira Janeiro Neves[2], Inês Fumiko Ubukata Yada[3], Rui Pereira Leite Júnior[4]

[1]IAPAR – Depto de Ecofisiologia, Rod. Celso Garcia Cid, km 375, C.P. 301 – 86001-970 – Londrina, PR – Brasil.
[2]UEL – Depto. de Agronomia, Campus Universitário, C.P. 10.011 – 86057-970 – Londrina, PR – Brasil.
[3]IAPAR – Depto. de Biometria.
[4]IAPAR – Depto. de Proteção de Plantas.
*Corresponding author <zuleide@iapar.br>

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ABSTRACT: Mandarins have become increasingly valued as citrus fruits for the fresh market due to the easy peeling, attractive flavor, and health and nutritional properties. Plant growth and yield, and characteristics of fruits of 'Okitsu' Satsuma mandarin (*Citrus unshiu* Marc.) trees grafted on nine rootstocks were evaluated in Londrina, northern Paraná, Brazil. The rootstocks were: 'Rangpur' lime (*Citrus limonia* Osb.); 'Cleopatra' (*Citrus reshni* hort. ex Tanaka) and 'Sunki' mandarins (*Citrus sunki* hort. ex Tanaka); 'C-13' [*Citrus sinensis* × *Poncirus trifoliata* (L.) Raf.] and 'Carrizo' citranges [*C. sinensis* × *P. trifoliata* (L.) Raf.]; 'Volkamer' lemon (*Citrus volkameriana* V. Ten. & Pasq.); trifoliate orange [*P. trifoliata* (L.) Raf.; 'Caipira DAC' sweet orange [*C. sinensis* (L.) Osb.] and 'Swingle' citrumelo [*Citrus paradisi* Macfad. cv. Duncan × *P. trifoliata* (L.) Raf.]. The highest plant growth was for the trees on 'Cleopatra' mandarin and 'Caipira DAC' sweet orange. In contrast, the smallest size was for the trees on 'Volkamer' lemon and trifoliate orange. The largest difference between the trunk diameter below and above the grafting point was induced by 'Swingle' citrumelo. Trees of 'Okitsu' Satsuma mandarin on 'Swingle' citrumelo presented the highest yield, while 'C-13', 'Carrizo', 'Sunki', and 'Swingle' induced the largest fruit masses. With regard to fruit characteristics, 'Carrizo' and trifoliate orange induced the best ratio and juice content. Based on theoretical values, 'Rangpur' lime and 'Volkamer' lemon induced the lowest yields.

Introduction

In recent years, mandarins have become increasingly valued as citrus fruits for the fresh market due to the easy peeling, attractive flavor, and health and nutritional properties. Mandarins have occupied more space than other citrus in the citrus-growing regions of California, the Mediterranean basin, and Asia. Worldwide, the citrus growing-area for oranges increased 13 % over the last ten years, while the area for mandarins increased 30 % in the same period (Neves, 2010). China is the largest producer of mandarins, representing 47 % of the world production, followed by Spain and Brazil (FAO, 2010).

In Brazil, São Paulo State is the main producer of mandarins, with 382,765 t of fruits harvested in an area of 13,664 ha. Other states with significant mandarin production are Minas Gerais, with 169,037 t in 7,614 ha, and Paraná, with 165,313 t produced in 10,077 ha for the 2011 season (IBGE, 2011). Among the cultivars of mandarins grown in Brazil, 'Ponkan' (*Citrus reticulata* Blanco) grafted on 'Rangpur' lime (*Citrus limonia* Osb.) is the most important combination. This mandarin is one of the most important fruits cultivated in Paraná state (Andrade, 2011). In São Paulo state, 'Ponkan' is also the most important mandarin cultivar, followed by 'Murcott' tangor [*Citrus reticulata* Blanco × *C. sinensis* (L.) Osb.] (Pio et al., 2005).

Due to the importance of frozen concentrated orange juice production for the citrus industry in Brazil, there is a shortage of citrus cultivars more appropriate for the fresh market. However, a trend towards specialization for the fresh fruit market has been observed in the improvement of citrus cultivars that are more suitable for this purpose (Boteon, 2011). 'Okitsu' Satsuma mandarin (*Citrus unshiu* Marc.), which is cultivated mainly in Japan, Spain, and Argentina, is a selection of Satsuma with a good quality for the fresh market, with outstanding features such as early maturing and seedless characteristics (Donadio et al., 1998). Furthermore, this cultivar is resistant to citrus canker caused by the bacterium *Xanthomonas citri* subsp. *citri* (Tazima and Leite Junior, 2002).

The rootstock can affect several characteristics of the citrus canopy, such as tree vigor, production, and fruit size, as well as juice content, fruit quality, and tolerance to pests and diseases (Pompeu Jr., 2005). It is important that the citrus rootstock used is adapted to the conditions of the region and has a good compatibility with the scion.

The objective of this work was to assess the performance of 'Okitsu' Satsuma mandarin grafted onto nine rootstocks in the northern region of the Paraná State, Brazil, in terms of plant growth, plant yield, and fruit characteristics.

Materials and Methods

The experiment was carried out in Londrina, state of Paraná, Brazil (23°21'34" S; 51°09'53" W; 585 m a.s.l.), on a Typic Hapludox (USDA, 1999). The climate is type Cfa, subtropical humid, according to Köppen's classification, with 27.3 °C mean maximum temperature and 16 °C mean minimum temperature. The total annual rainfall is 1,610 mm, and the mean relative humidity is 71 % (IAPAR, 2011).

The seedlings of the rootstocks were grown from seeds obtained at the Active Citrus Germplasm Bank, as the scion of 'Okitsu' Satsuma mandarin (*Citrus unshiu* Marc.), accession I-213. The nine rootstocks were: 'Rangpur' lime (*Citrus limonia* Osb.); 'Cleopatra' mandarin (*Cit-*

rus reshni hort. ex Tanaka); 'C-13' citrange [*Citrus sinensis* × *Poncirus trifoliata* (L.) Raf.]; 'Volkamer' lemon (*Citrus volkameriana* V. Ten. & Pasq.); 'Carrizo' citrange [*Citrus sinensis* × *Poncirus trifoliata* (L.) Raf.]; 'Sunki' mandarin (*Citrus sunki* hort. ex Tanaka); trifoliate orange [*Poncirus trifoliata* (L.) Raf.]; 'Swingle' citrumelo [*Citrus paradisi* Macfad. cv. Duncan × *Poncirus trifoliata* (L.) Raf.]; and 'Caipira DAC' orange [*Citrus sinensis* (L.) Osb.].

The experimental area was established in July 2000, with a 6.0 m × 6.5 m space between plants and rows, comprising 256 plants per hectare. Phytosanitary and fertilization treatments followed recommendations for the northern region of Paraná (IAPAR, 1992). Irrigation, pruning, and fruit thinning were not performed, and weed control was done with an ecological rotary mower. The experimental design was randomized blocks with nine treatments, six replications, and two plants per plot.

Evaluations of plant growth were carried out in July 2007 and July 2011. Two orthogonal measurements were made in the middle part of the plant with the aid of a graduated scale to determine plant canopy diameter. Plant height was determined by measuring the distance from the ground to the top of the plant. Canopy volume (V) was determined by using the equation $V = 2/3\ \pi R^2 H$ (Mendel, 1956), where R is the radius and H is the height of the plant. Trunk circumference was determined 10 cm above and below the grafting line by using a measuring tape. The diameter of the trunk below and above the grafting line was calculated based on trunk circumference. Yield was quantified by fruit number and weight. Fruits were counted and weighted with a digital scale every season during the period 2003-2011.

Samples of ten fruits were used to carry out the analysis of the fruits. Fruits were collected from the outside of the plants at 1 to 2 m high. The fruits were harvested in March of each year, from 2005 through 2011. Fruit height and diameter were determined with a digital caliper.

Juice content, expressed as a percentage, was determined by the equation = (JM/FM) × 100, where JM = juice mass (g) and FM = fruit mass (g). The juice was extracted with a juice extractor. Total soluble solids (TSS) content was determined with a digital refractometer, and the result was expressed in °Brix. The titratable acidity (TA), in percentage of citric acid, was determined by titration of 25 mL of juice with 0.1 M NaOH solution using a digital titration unit. The result was expressed as percentage (%) of citric acid (AOAC, 1990). The ratio was determined as the relationship between TSS and TA.

The technological index (TI), or amount of soluble solids in the juice from a box of fruits (40.8 kg), was calculated by using the equation TI = (juice content × TSS × 40.8)/10,000, wherein: juice content = JM/FM relation × 100; and total soluble solids = TSS (Di Giorgi et al., 1990).

The theoretical number of trees per hectare was calculated using the equation of De Negri and Blasco (1991), E = (D × 0.75) × (D + 2.5), where E = adequate theoretical spacing and D = canopy diameter. The calculation assumes a 25 % overlap of plant branches in the cultivation line and 2.5 m clear distance between the lines, which would satisfy the cultural practices of the crop. Fruit production was also estimated based on the theoretical number of trees per hectare.

For statistical analysis, values were compared using Scott-Knott test ($p < 0.05$), via SAS (SAS Institute, 2001) and SISVAR software (Ferreira, 2000).

Results and Discussion

Trees of 'Okitsu' Satsuma mandarin on 'Cleopatra' mandarin and 'Caipira DAC' sweet orange rootstocks had the largest height, canopy diameter, and canopy volume, differing from trees grafted onto other rootstocks in both years, 2007 and 2011 (Table 1). 'Sunki' mandarin and 'Swingle' citrumelo also induced large trees for the 'Okitsu' Satsuma mandarin in regard to tree size and volume, as well as trunk diameter below the graft line (Tables 1 and 2). 'Okitsu' Satsuma mandarin trees grafted on 'Volkamer' lemon and on trifoliate orange rootstock had the smallest development in both years (Table 1). Trees of 'Okitsu' Satsuma on 'Rangpur' lime did not differ from those on 'Volkamer' lemon and trifoliate orange in regard to canopy volume based on the measurements taken in 2011 (Table 1).

In a study at Bebedouro (20°53′16″ S; 48°28′11″ W), São Paulo state, Brazil, 'Okitsu' Satsuma mandarin grafted onto 'FCAV' trifoliate orange was also among the less vigorous trees (Cantuarias-Avilés et al., 2010). In contrast, plants on 'Sunki' mandarin, 'FCAV Rangpur' lime, 'Swingle' citrumelo, 'Limeira Rangpur' lime, and 'Rangpur' lime × 'Swingle' citrumelo had larger canopies with similar-sized volumes (Cantuarias-Avilés et al., 2010). The results obtained by Cantuarias-Avilés et al.

Table 1 – Tree height, canopy diameter, and canopy volume of 'Okitsu' Satsuma mandarin trees grafted onto nine rootstocks, at Londrina, PR, Brazil, for the years 2007 and 2011.

Rootstock	Tree height (m)		Canopy Size			
			Diameter (m)		Volume (m^3)	
	2007	2011	2007	2011	2007	2011
'Rangpur' lime	2.7 c[z]	3.2 c	3.7 b	4.5 c	20.0 c	33.7 d
'Cleopatra' mandarin	3.3 a	3.8 a	4.5 a	5.7 a	35.8 a	66.0 a
'C-13' citrange	2.9 b	3.2 c	4.1 a	4.9 b	27.0 b	42.0 c
'Volkamer' lemon	2.5 d	2.6 d	3.3 c	3.6 d	14.2 d	17.6 d
'Carrizo' citrange	2.9 b	3.3 c	3.9 b	4.8 b	23.1 c	39.7 c
'Sunki' mandarin	3.2 a	3.8 a	4.3 a	5.4 a	30.9 b	57.4 b
Trifoliate orange	2.5 d	2.8 d	3.5 c	4.0 d	16.7 d	23.4 d
'Swingle' citrumelo	2.9 b	3.6 b	4.4 a	5.4 a	29.5 b	54.0 b
'Caipira DAC' orange	3.3 a	4.0 a	4.6 a	5.7 a	36.8 a	67.6 a
CV (%)	5	5	8	8	19	19

[z] Mean values followed by the same letter in a column do not differ (Scott-Knott test, $p < 0.05$).

(2010) agree with those obtained in this study in regard to canopy volume of the plants on the rootstocks 'Sunki' mandarin and 'Swingle' citrumelo, which also did not differ from each other.

The performance of the nine rootstocks in regard to trunk diameter below and above the grafting line was similar in both study periods (Table 2). 'Swingle' citrumelo presented the largest trunk diameter below the grafting line, with 18.1 cm and 23.9 cm mean values in 2007 and 2011, respectively (Table 2). 'Cleopatra' and 'Sunki' mandarins, as well as 'Caipira DAC' orange, induced the largest trunk diameters above the grafting line (Table 2). In contrast, trees of 'Okistu' Satsuma mandarin on trifoliate orange had the smallest trunk diameters below and above the grafting line (Table 2).

The relationship between trunk diameter below and above the grafting line reflects the degree of compatibility between the scion and the rootstock. Plants grafted onto 'Rangpur' lime and 'Volkamer' lemon, 'Cleopatra' and 'Sunki' mandarins, and 'Caipira DAC' orange had mean values for this relationship closest to 1.0, in contrast to 'Swingle' citrumelo, which had the highest mean ratio (Table 2). Despite the apparent absence of symptoms of incompatibility between the scion of 'Okitsu' Satsuma mandarin and the rootstock 'Swingle' citrumelo, this combination should be investigated in the future, as the citrus trees get older. Barbasso et al. (2005) reported that the difference between trunk diameter below and above the grafting line is not always related to incompatibility.

'Swingle' citrumelo was the rootstock that induced the highest annual yield over the study period, from 2003 to 2011 (Table 3). In contrast, 'Okitsu' Satsuma mandarin on 'Volkamer' lemon had the lowest yield during the entire experimental period and showed a tendency to decrease production in the last three years (Table 3). Furthermore, the canopy volume of the 'Okitsu' Satsuma mandarin on the 'Volkamer' lemon rootstock was less than 50 % of that observed for trees on 'Rangpur' lime (Table 1), the most commonly used citrus rootstock in Brazil. In another study, the highest production of 'Okitsu' Satsuma mandarin was induced by the rootstocks citrandarin 'Changsha' × 'English Small' and *P. trifoliata* 'Rubidoux', followed by 'Cravo Limeira' and 'Cravo FCAV' Rangpur limes, 'Swingle' citrumelo, and 'FCAV' trifoliate (Cantuarias-Avilés et al., 2010).

Table 2 – Trunk diameter below and above the grafting line, and the ratio of the trunk diameter below and above the grafting line of 'Okitsu' Satsuma mandarin trees grafted onto nine rootstocks, at Londrina, PR, Brazil, for the years 2007 and 2011.

Rootstock	Trunk diameter 10 cm of grafting line				Trunk diameter ratio	
	Below		Above			
	2007	2011	2007	2011	2007	2011
'Rangpur' lime	13.2 d[z]	15.7 e	12.6 b	14.9 c	1.04 e	1.05 e
'Cleopatra' mandarin	16.4 b	21.7 b	15.2 a	19.3 a	1.08 e	1.12 d
'C-13' citrange	16.9 b	19.7 c	12.4 b	14.2 c	1.36 b	1.38 b
'Volkamer' lemon	12.3 d	13.7 e	12.0 b	13.7 c	1.02 e	1.00 e
'Carrizo' citrange	15.1 c	18.3 d	12.0 b	14.5 c	1.26 d	1.26 c
'Sunki' mandarin	15.4 c	21.6 b	14.7 a	19.6 a	1.05 e	1.10 d
Trifoliate orange	12.9 d	15.4 e	9.8 c	11.8 d	1.32 c	1.30 c
'Swingle' citrumelo	18.1 a	23.9 a	12.9 b	16.5 b	1.40 a	1.45 a
'Caipira DAC' orange	16.8 b	22.1 b	15.2 a	19.3 a	1.11 e	1.15 d
CV (%)	7	9	6	8	3	4

[z] Mean values followed by the same letter in a column do not differ (Scott-Knott test, $p < 0.05$).

Rootstocks influenced fruit weight and height, but not fruit diameter of 'Okitsu' Satsuma mandarin (Table 4). Fruit weight ranged from 127.2 g to 168.0 g, while fruit height varied from 60 mm to 69 mm and fruit diameter from 68 mm to 77 mm (Table 4). The largest fruit sizes were observed for trees grafted onto 'C-13' and 'Carrizo' citranges, 'Sunki' mandarin and 'Swingle' citrumelo, which differed from the other rootstocks (Table 4).

Trees of 'Okitsu' Satsuma mandarin grafted onto 'Volkamer' lemon produced fruits weighing 127.2 g, smaller than those observed for trees on the other rootstocks, which ranged from 143.7 to 168.0 g (Table 4). It is worth emphasizing the importance of this characteristic for Satsuma fruits, since fruits with larger sizes are higher priced in the fresh market (Cruz et al., 2010). Fruits of 'Okitsu' Satsuma mandarin with mean weights of 209.0 g and 150.3 g have been reported by Oliveira et al. (2005), and Borges et al. (2009), respectively. Larger 'Okitsu' Satsuma fruits were also obtained from trees on 'Carrizo' citrange, while smaller fruits were harvested from trees grafted onto trifoliates (Cantuarias-Avilés et al., 2010). Tazima and Leite Júnior (2002) also reported a mean weight of 129.2 g for fruits of 'Okitsu' Satsuma mandarin plants grafted onto 'Rangpur' lime, obtained in Londrina, Paraná state, Brazil.

The smallest height of 'Okitsu' Satsuma fruits was also induced by 'Volkamer' lemon (Table 4). However, no differences were observed in regard to fruit diameter among the rootstocks evaluated (Table 4). According to the standard of the Brazilian Group of Fresh Market Citrus Fruit, of the Brazilian Program for the Improvement of Trade and Packaging Standards of Fruit and Vegetable Producers, coordinated by the Center for Quality in Horticulture (CEAGESP, 2000), the fruits obtained in this study would be classified in Class 66 for trees on 'Volkamer' lemon, 70 for those on trifoliate orange, and 74 for those on the other rootstocks. With regard to the height vs. diameter ratio of the fruit, which indicates fruit shape, all rootstocks induced typical flattened fruits, but this characteristic was more pronounced when the plants were on 'Rangpur' lime, Carrizo' citrange, Trifoliate orange, 'Swingle' citrumelo, and 'Caipira DAC'orange (Table 4).

Table 3 – Annual production of 'Okitsu' Satsuma mandarin trees grafted onto nine rootstocks, at Londrina, PR, Brazil, for the period 2003-2011.

Rootstock	Annual production (kg tree^{-1})								
	2003	2004	2005	2006	2007	2008	2009	2010	2011
'Rangpur' lime	38.5 a[z]	42.1 a	94.0 b	100.2 c	140.4 b	161.4 a	120.0 c	142.7 b	151.4 b
'Cleopatra' mandarin	22.2 c	48.6 a	75.6 c	116.0 b	212.6 a	100.7 b	253.5 a	111.1 b	311.7 a
'C-13' citrange	32.0 b	44.9 a	105.6 a	165.5 a	203.3 a	124.0 b	189.7 b	208.5 a	254.0 a
'Volkamer' lemon	27.9 c	47.6 a	53.4 d	77.9 c	83.3 c	113.1 b	107.2 c	98.3 b	88.1 c
'Carrizo' citrange	32.5 b	33.0 b	78.6 c	123.4 b	150.3 b	129.5 b	172.9 b	222.3 a	210.3 b
'Sunki' mandarin	23.3 c	52.4 a	73.6 c	132.7 b	192.1 b	77.0 c	208.8 b	180.1 a	277.5 a
Trifoliate orange	14.5 c	26.2 b	55.4 d	110.0 b	122.6 b	175.7 a	121.6 c	181.3 a	173.9 b
'Swingle' citrumelo	44.7 a	48.2 a	122.2 a	189.7 a	239.4 a	182.0 a	241.1 a	225.8 a	275.6 a
'Caipira DAC' orange	20.0 c	43.5 a	86.9 b	99.6 c	199.4 a	64.1 c	226.9 a	94.8 b	293.3 a
CV (%)	28	28	24	20	21	33	25	27	20

[z] Mean values followed by the same letter in a column do not differ (Scott-Knott test, $p < 0.05$).

Table 4 – Fruit mass, height (H), diameter (D), H/D ratio, total soluble solids (TSS) content, titratable acidity (TA), TSS/TA (*ratio*), juice content (JC), and technological index (TI) of fruits of 'Okitsu' Satsuma mandarin trees grafted onto nine rootstocks, at Londrina, PR, Brazil, for the period 2005-2011.

Rootstock	Fruit Size				Fruit Quality				
	Weight	Height H	Diameter D	H/D	TSS	TA	Ratio	JC	TI
	g	——— mm ———			°Brix	%	TSS/TA	%	SS/cx
'Rangpur' lime	154.7 b[z]	64.0 b	75.0 a	0.86 b	9.00 b	0.71 a	12.87 c	45.0 b	1.61 b
'Cleopatra' mandarin	161.5 b	66.0 a	75.0 a	0.89 a	8.96 b	0.72 a	12.62 c	46.7 a	1.67 b
'C-13' citrange	167.4 a	69.0 a	77.0 a	0.89 a	9.00 b	0.71 a	12.85 c	44.9 b	1.61 b
'Volkamer' lemon	127.2 d	60.0 c	68.0 a	0.89 a	9.76 a	0.74 a	13.35 b	45.9 b	1.81 a
'Carrizo' citrange	168.0 a	67.0 a	77.0 a	0.88 b	9.88 a	0.68 b	14.67 a	47.4 a	1.87 a
'Sunki' mandarin	167.0 a	68.0 a	76.0 a	0.90 a	9.23 b	0.69 b	13.60 b	45.3 b	1.65 b
Trifoliate orange	143.7 c	64.0 b	72.0 a	0.88 b	9.67 a	0.69 b	14.17 a	47.2 a	1.82 a
'Swingle' citrumelo	166.0 a	67.0 a	76.0 a	0.87 b	9.02 b	0.68 b	13.26 b	46.5 a	1.67 b
'Caipira DAC' orange	161.0 b	67.0 a	77.0 a	0.88 b	8.74 b	0.69 b	12.72 c	45.1 b	1.56 b
CV (%)	5	3	17	2	3	4	4	3	4

[z] Mean values followed by the same letter in a column do not differ (Scott-Knott test, $p < 0.05$).

Regarding fruit quality, the highest values for TSS ranged from 9.67 to 9.88 °Brix (Table 4) and were observed for fruits from trees on the trifoliate orange, 'Volkamer' lemon, and 'Carrizo' citrange rootstocks (Table 4). Trifoliate orange is recognized as a rootstock which induces the best fruit quality, as also observed in research carried out in Bebedouro, São Paulo state, Brazil (Cantuarias-Avilés et al., 2010). The 'Rangpur' lime rootstock induced a value of 9.0 °Brix for sugar content of the 'Okitsu' Satsuma fruits, close to the value of 8.6 °Brix reported by Tazima and Leite Júnior (2002).

Although fruits of 'Okitsu' Satsuma mandarin on all rootstocks presented TA values lower than 1.0, fruits of trees on 'Rangpur' lime, 'Volkamer' lemon, 'Cleopatra' mandarin, and 'C-13' citrange were more acidic than those from trees on the other rootstocks (Table 4). The highest values for the ratio were induced by the 'Carrizo' citrange and trifoliate orange rootstocks, differing from fruits produced by trees on the other rootstocks (Table 4). Fruits of 'Okitsu' Satsuma mandarin on the 'Cleopatra' mandarin, 'Carrizo' citrange, trifoliate orange, and 'Swingle' citrumelo rootstocks presented the highest juice content and differed from those produced by trees on the other rootstocks (Table 4).

To determine maturation degree, the stage in which the fruit presents a minimum quality to ensure its acceptability by the consumer, parameters such as minimum juice content, TSS content, and the TSS/TA or ratio are used (Pereira et al., 2006). In relation to the group of mandarins, the Brazilian Group of Fresh Market Citrus Fruit has determined that fruits considered as acceptable for human consumption should have a juice content ranging from 35 to 42 %, sugar from 9.0 to 10.5 °Brix, and ratio from 8.5 to 9.5 (CEAGESP, 2000). Based on the values of these parameters, all fruits produced by the 'Okitsu' Satsuma mandarin trees grafted on the different rootstocks would meet the requirements of acceptability for the Brazilian fresh market, except for those produced on the 'Caipira DAC' orange and 'Cleopatra' mandarin rootstocks in regard to TSS content, although these fruits achieved a satisfactory ratio (Table 4). Similar results on the quality of the fruits of 'Okitsu' Satsuma mandarin

were obtained in other studies where the sugar content ranged from 7.8 to 8.86 ºBrix and the ratio from 11.2 to 11.3 (Borges et al., 2009; Tazima and Leite Júnior, 2002). In contrast, Oliveira et al. (2005), in Rosario do Sul (30°14'36" S; 54°55'18" W), state of Rio Grande do Sul, Brazil, obtained fruits of 'Okitsu' Satsuma mandarin with sugar content of 11.6 °Brix, titratable acidity of 0.84 %, and a ratio of 13.8, representing a regularly balanced sugar/acidity. Furthermore, in our study trees of 'Okitsu' Satsuma mandarin on the 'Volkamer' lemon, 'Carrizo' citrange, and trifoliate orange rootstocks had the highest values in regard to the technological index or sugar content per box (Table 4).

The best spacing between rows and trees, number of trees per hectare, and expected production for 'Okitsu' Satsuma mandarin were determined for each rootstock combination in order to plan the citrus orchard (Table 5), considering the theoretical values calculated based on plant growth (De Negri and Blasco, 1991). The largest tree canopies were determined for trees on the 'Cleopatra' and 'Sunki' mandarins, 'Swingle' citrumelo, and 'Caipira DAC' sweet orange rootstocks (Table 1). Thus, both line spacing and plant spacing were highest for the trees on these rootstocks, and higher than those determined for the other rootstocks (Table 5). Consequently, these rootstocks enable the smallest number of trees per area, with 287.5 to 317.8 plants ha^{-1} (Table 5). On the other hand, a total of 614.5 plants ha^{-1} was determined for the trees of 'Okitsu' Satsuma on 'Volkamer' lemon, differing from the other rootstocks (Table 5), due to the small size of the trees on this rootstock (Table 1). However, the estimated production of 'Okitsu' Satsuma mandarin grafted onto 'Volkamer' lemon was 52.0 t ha^{-1} (Table 5), but did not differ from the estimated yield for trees on 'Rangpur' lime, with 64.7 t ha^{-1} (Table 5). The yield for trees of 'Okitsu' Satsuma mandarin on both rootstocks was lower than those on other rootstocks (Table 5). For 'Okitsu' Satsuma mandarin plants on rootstocks that lead to a low number of trees per area, such as 'Cleopatra' and 'Sunki' mandarins, 'Swingle' citrumelo, and 'Caipira DAC' sweet orange, as well as to those that lead to a high number of trees per area, such as trifoliate orange, the estimated productions were higher than 87.0 t ha^{-1} (Table 5).

Table 5 – Theoretical space between rows and plants, number of trees per hectare and expected yield of 'Okitsu' Satsuma mandarin trees grafted onto nine rootstocks, at Londrina, PR, Brazil.

Rootstock	Space Between		Number of Trees	Yield
	Rows (m)	Plants (m)	ha^{-1}	t ha^{-1}
'Rangpur' lime	7.0* b[z]	3.3 c	430.0 c	64.7 b
'Cleopatra' mandarin	8.2 a	4.3 a	287.5 d	88.7 a
'C-13' citrange	7.4 b	3.7 b	385.7 c	92.9 a
'Volkamer' lemon	6.0 c	2.7 d	614.5 a	52.0 b
'Carrizo' citrange	7.3 b	3.6 b	386.5 c	87.1 a
'Sunki' mandarin	7.9 a	4.0 a	315.7 d	87.1 a
Trifoliate orange	6.5 c	3.0 d	516.5 b	89.3 a
'Swingle' citrumelo	7.8 a	4.0 a	317.8 d	87.3 a
'Caipira DAC' orange	8.2 a	4.2 a	290.0 d	84.4 a
CV (%)	5	8	14	14

[z] Mean values followed by the same letter in a column do not differ (Scott-Knott test, $p < 0.05$). *Theoretical values calculated using the equations of DeNegri and Blasco (1991).

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