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Substandard and Semi-Dwarfing Citrus Rootstocks for More Intensive, Higher-Density, and Sustainable Plantation Systems

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Abstract: An increasing number of intensive, dense, and sustainable citrus plantations have fostered a growing interest in addressing the future challenges of citrus crops: An increase in the world's population, climate change, and globalization. Nutrient efficiency and the absence of vigorous citrus rootstocks are required for the success of these plantation systems. The agronomic performances of the 'Lane Late' orange cultivar on three substandard or semi-dwarfing citrus rootstocks (Forner-Alcaide no.5 (FA5), Forner-Alcaide no.13 (FA13), and Forner-Alcaide no.41 (FA41)) were evaluated in Spain in comparison with more traditional Mediterranean citrus rootstocks (Carrizo citrange (CA), *Citrus macrophylla* (MP), and 'Cleopatra' mandarin (CL)) under a poor mineral fertilization program over six growing seasons. FA13 and FA41 induced the smallest 'Lane Late' trees. Although the rootstock did not induce a significant effect on the 'Lane Late' yield efficiency (kg m^{-3}), the highest values were recorded for 'Lane Late' on MP, CL and FA13. In this sense, FA13 showed a high productive potential (kg ha^{-1}), given the possibility of narrowing the tree spacing (smaller tree size). Regarding the use of soil nutrients, FA13 was the most efficient citrus rootstock. Thus, FA13 stands out as the most suitable citrus rootstock for more intensive and sustainable plantation systems of the 'Lane Late' orange under Mediterranean conditions similar to those of this study.

Keywords: alternate bearing index; leaf nutrient levels; tree size; yield efficiency

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1. Introduction

The future viability of citrus crops of the main citrus growing countries of the Mediterranean basin is seriously threatened by the increase in the world's population, climate change, and globalization [1].

Citrus fruit cultures, like agriculture in general, face the challenge of becoming more productive to feed a much larger global population under a general landscape of climate change, which threatens to increase temperature, reduce water availability, and impact soil health and quality.

On the other hand, globalization compromises the profitability of many Mediterranean citrus farms, mainly on account of competition from third countries and the onset of exogenous pest and crop diseases in terms of yield losses and higher costs involved in their inspection and control [2–4]. Moreover, Mediterranean citrus crops, highly dependent on manpower, are facing an uncertain and complex scenario regarding Covid-19, which could lead to a foreign labor shortage.

Because of this reality, it is of the highest priority to increase the citrus crop productivity from sustainable intensification. More intensive and higher-density citrus and other crop plantation systems are an interesting strategy to allow an improvement in competitiveness—earlier and higher crop yields [5–7]—and a lower environmental impact—less pressure on natural resources by production unit. The success of these plantation systems lies in the use of size-controlling citrus rootstocks, which leads to smaller and more accessible canopy trees and results in a reduction of harvesting and pruning costs, as well as easier, economical, and effective pest inspection and management. Moreover, this citrus plantation system could be aiming at super high densities and may also be useful for mechanical harvesting by over-the-row harvesters [8] for citrus production in industry, obtaining additional benefits in terms of lower harvesting costs and manpower requirements.

On the other hand, in view of the high risk of Mediterranean soil desertification, more efficient citrus rootstocks in the uptake of mineral elements of the soil are required to achieve both a greater citrus crop resilience and soil recovery by more sustainable fertilization programs. In fact, the effect of rootstocks on the performance and leaf nutrient levels of different citrus cultivars is known [9–13], as well as of other fruit crops [14,15]. This is an important aspect to consider in citrus crops, as tree growth, yield, and health, as well as fruit quality, are closely affected by its nutrition status.

Carrizo citrange (*Citrus sinensis* (L.) Osb. × *Poncirus trifoliate* (L.) Raf.) is one of the most important citrus rootstocks in Mediterranean citrus growing countries. However, in view of its susceptibility to lime-induced chlorosis and salinity [16,17], Carrizo citrange, a standard growing citrus rootstock, is unsuitable for many soils of the Mediterranean area. In addition, Carrizo citrange is susceptible to *Diaphorina citri* [18], a vector of the citrus greening, or HLB, the most devastating citrus disease worldwide [19], which threatens its possible arrival in the Mediterranean Basin. Other conventional citrus rootstocks, such as 'Cleopatra' mandarin (*Citrus reshi* Hort. ex Tan.) and *Citrus macrophylla*, which are standard growing citrus rootstocks, display other abiotic and biotic limitations, such as a higher sensibility to nematodes and root asphyxia. Moreover, 'Cleopatra' mandarin has been reported as highly susceptible to HLB [20]. Thus, the search for more interesting citrus rootstocks is the major aim in many citrus producing countries.

Different breeding programs have resulted in many interesting citrus rootstocks. This is the case for Forner-Alcaide no.5, Forner-Alcaide no.13, and Forner-Alcaide no.41, which are substandard or semi-dwarfing citrus rootstocks from a breeding program by traditional hybridization carried out at the Instituto Valenciano de Investigaciones Agrarias (IVIA) in Spain [21,22]. In addition, these three citrus rootstocks, hybrids to *Poncirus trifoliate*, could show a better response to HLB, as has been reported in *P. trifoliata* L. Raf. and some of its hybrids [20].

The purpose of this study was to identify new citrus rootstocks that are suitable for sustainable, more intensive, and higher-density plantation systems as an interesting alternative to conventional citrus plantations in the Mediterranean area. The performance of the 'Lane Late' navel orange cultivar on six citrus rootstocks (three substandard and semi-dwarfing citrus rootstocks (Forner-Alcaide no.5, Forner-Alcaide no.13, and Forner-Alcaide no.41) and three more traditional standard citrus rootstocks (Carrizo citrange, *Citrus macrophylla*, and 'Cleopatra' mandarin)) was evaluated under low fertilization conditions in Spain. The nutritional status, growth, and yield of 'Lane Late' orange trees on the six citrus rootstocks were considered in this study.

2. Materials and Methods

2.1. Plant Material and Experimental Design

The study was carried out throughout six growing seasons (2008/2009–2013/2014) in an experimental plot in Sevilla (Spain; Figure 1): Mediterranean climate, with an average temperature of 18.1 °C, annual rainfall of 586.7 mm, and reference evapotranspiration (ET_0) of 1292.4 mm; loam soil (25% of clay, 32% of sand, and 43% of silt), with an organic matter level around 1.0%, electrical conductivity of a 1:5 soil water extract of 0.12 dS m^{-1}, 4.8% of active $CaCO_3$, and pH of 8.7. The parameters related to soil fertility in the 2009/2010 growing season were 675 mg/kg of nitrogen, 23 mg/kg of phosphorus, and 18.38, 3.08, 0.15 and 0.86 meq/100 g of extractable calcium, magnesium, sodium and potassium respectively, with 0.41 mg/kg of boron.

Figure 1. Overview of the experimental plot.

Standard cultural practices were applied, with regard to drip irrigation, and were hand-pruned annually after harvest. Irrigation was applied by two drip-lines in each tree row, with 2.2 L h^{-1} of drippers every 60 cm. Seasonal water requirements were calculated based on the reference evapotranspiration (ET_0) and citrus crop coefficient (K_c) [23].

Trees were fertilized using a fertigation system. A poor fertilization program (180 g $tree^{-1}$ of N, 50 g $tree^{-1}$ of P_2O_5, and 100 g $tree^{-1}$ of K_2O) was implemented by applying about 50% of the optimum fertilizer dosage calculated according to the procedure established by Quiñones et al. [24], in order to achieve a greater understanding of the performance of the different rootstocks under restricted mineral fertilization conditions, leading to more sustainable plantation systems being established.

The experimental plot of 4800 m^2 was consistent with 'Lane Late' cultivar trees on three traditional and standard citrus rootstocks: *Citrus macrophylla* Wester (MP), Carrizo citrange (CA; *Citrus sinensis* (L.) Osb. × *Poncirus trifoliata* (L.) Raf.), and 'Cleopatra' mandarin (CL; *Citrus reshni* Hot. ex Tan.); one substandard hybrid selection: Forner-Alcaide no.5 (FA5; *Citrus reshni* Hort. ex Tan. × *Poncirus trifoliate* (L.) Raf.); and another two semi-dwarfing hybrid selections: Forner-Alcaide no.13 (FA13; *Citrus reshni* Hort. ex Tan. × *Poncirus trifoliate* (L.) Raf.) and Forner-Alcaide no.41 (FA41; *Citrus reshni* Hort. ex Tan. × *Poncirus trifoliate* (L.) Raf.).

The 'Lane Late' trees were 6 years old at the beginning of the experiment. The tree-spacing was 6 m (between tree lines) × 4 m (between trees within the same tree line). The design consisted of 4 randomized blocks, including a primary plot with 6 trees (N = 24).

2.2. Measurements

In the six growing seasons (2008/2009–2013/2014), the tree height (TH) and canopy spread (canopy diameter longitudinal to the tree line (DL) and canopy diameter transverse to the tree line (DT)] were recorded after harvest. The canopy volume (CV; m^3) was calculated according to Turrell [25]. In the 2009/2010, 2010/2011, and 2013/2014 growing seasons, the trunk diameters of the scion (Ds; at 10 cm above the level of the graft) and of the rootstock (Dr; at 10 cm below the level of the graft) were recorded as well. The rootstock–

scion affinity was determined as the rootstock/scion ratio (Dr/Ds), which became more affine as Dr/Ds approached 1.

In all six growing seasons (2008/2009–2013/2014), each tree was harvested in April and the yield per tree was recorded (kg tree^{-1}). The yield efficiency (kg m^{-3}) was estimated as the yield (kg tree^{-1})-to-canopy volume (m^3) ratio for each tree.

The alternate bearing index (ABI; %) was estimated for the six growing seasons according to the equation suggested by Pearce and Dobersek-Urbanc [26]. ABI values above 50% show an alternate bearing, while values lower than 50% are indicative of a regular bearing.

In November in the 2009/2010 and 2012/2013 growing seasons, 4–6 months-old-mature 100 leaves, from terminal and nonfruiting shoots, from all orientations on the tree were collected from three trees of each primary plot for the determination of leaf nutrient levels. These leaves were washed with tap water with a nonionic detergent solution and then rinsed with distilled water. Leaf samples were dried in a hot air oven at 60 °C for 72 h and ground at a mill Foss. The dried and ground samples, except for an aliquot part for nitrogen determination by using the Kjeldalh digestion method, were burnt to a crisp with a muffle oven. The aliquot parts for macro- and micro-nutrients were led to an acid solution and measured using an atomic absorption spectrophotometer (Perkim Elmer UV/Vis LAMBDA™) with a specific lamp for each compound [27–30].

The leaf nutrient contents of the 'Lane Late' navel orange on different citrus rootstocks were compared with threshold values given by Legaz et al. [31].

2.3. Statistical Analysis

Data were statistically analyzed using variance analysis (ANOVA) procedures. Means were separated through Tukey's multiple range test, using the STATISTICA 7.0 software package (Statsoft Inc., Tulsa, OK, USA, 2004). p values < 0.05 were considered as significant. Normality and homogeneity assumptions were tested before ANOVA, using the Kolmogorov–Smirnov and Cochran's tests, respectively. In the case of the nonobservance of the normality and homogeneity assumptions, a nonparametric Kruskal–Wallis test was adopted. The relationships among vegetative growth parameters, yield, and leaf nutrient contents were computed using Pearson's simple correlation to $p < 0.05$.

3. Results and Discussion

The success of more intensive, higher-density, and sustainable citrus plantations relies largely on the use of nonvigorous citrus rootstocks, which moreover, promote an efficient soil nutrient uptake and an optimal agronomic development of the citrus cultivar under defined soil and climate conditions.

3.1. 'Lane Late' Navel Orange Trees Size

Many studies have reported the effect of citrus rootstocks on tree growth [11,32–34]. In fact, substandard, semi-dwarfing, and dwarfing citrus rootstocks are known [35]. Substandard and semi-dwarfing citrus rootstocks established in more intensive and higher-density plantations would reduce the main cultivation costs, like pruning and harvesting, and a more efficient use of agricultural supplies, like fertilizers, would be applied.

In our results obtained on a twelve-years-old 'Lane Late' navel orange plantation, containing adult trees with a definitive tree size or close to it, statistical differences ($p < 0.05$) were found for the tree height and canopy volume among rootstocks throughout the six growing seasons (Figure 2). Thus, lower tree sizes were obtained on FA13 (2.24 m and 10.28 m^3) and FA41 (2.27 m and 11.23 m^3) in terms of tree height and canopy volume, respectively, while larger 'Lane Late' tree sizes were recorded on CA (3.34 m and 24.62 m^3) and MP (2.87 m and 20.75 m^3). The remaining rootstocks, CL and FA5, showed an intermediate behavior. In line with our results, Bassal [36] reported that the 'Marisol' clementine tree on CL recorded a lower tree height than on CA, while Forner et al. [21] reported that FA5 and FA13 were able to reduce the tree size by 25 to 50% compared with standard rootstocks.

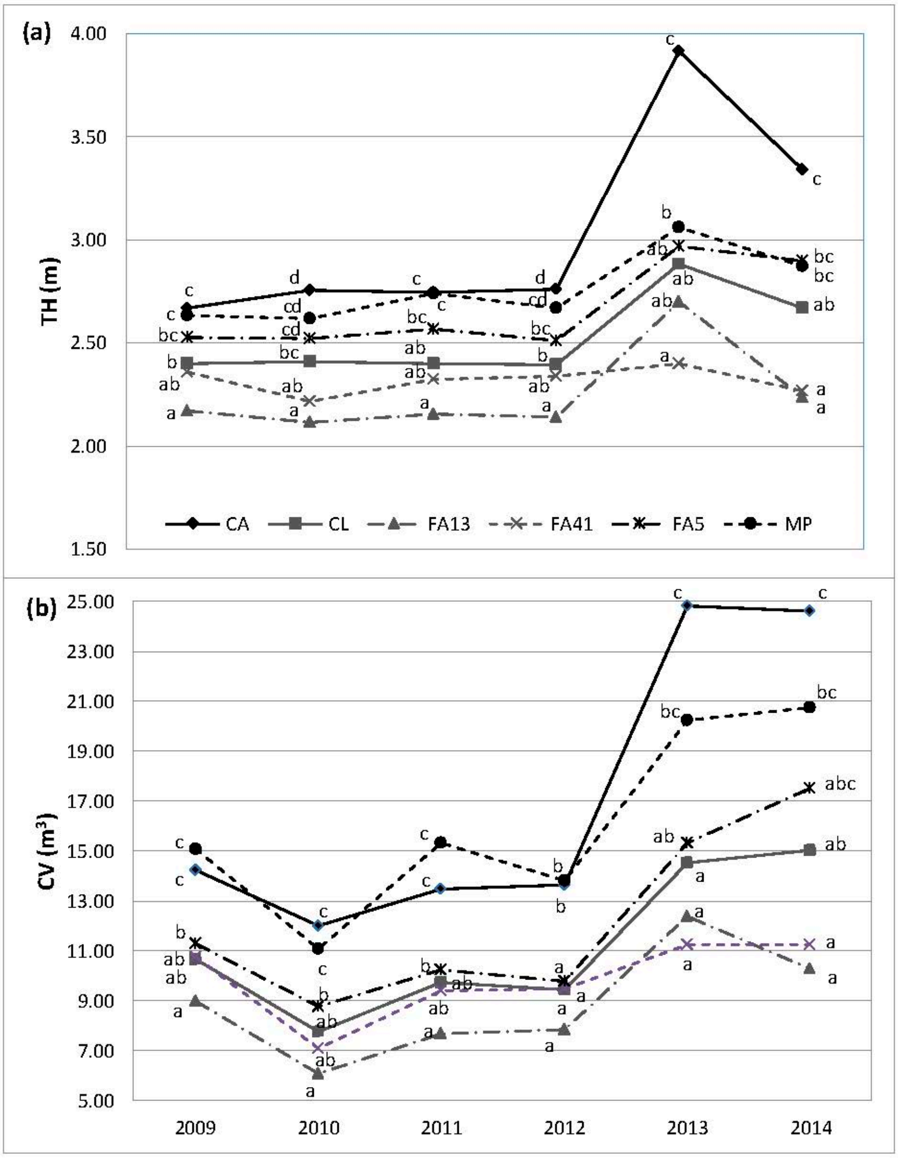

Figure 2. Effect of rootstocks on height (TH; **a**) and canopy volume (CV; **b**) in the 'Lane Late' navel orange tree over six growing seasons: 2008/2009–2013/2104. Mean values in the same growing season with different letters denote significant differences among rootstocks, based on Tukey's test ($p < 0.05$). CA: Carrizo citrange; CL: 'Cleopatra' mandarin; FA13: Forner-Alcaide no.13; FA41: Forner-Alcaide no.41; FA5: Forner-Alcaide no.5; MP: *C. macrophylla* Wester.

In the last growing season, statistical differences were found for the canopy spread (canopy diameters) among rootstocks (Table 1). Thus, 'Lane Late' trees on CA and MP had the highest longitudinal diameter (3.94 and 3.98 m, respectively; DL) and transverse diameter (3.65 and 3.50 m, respectively; DT), while trees on FA13, similar to FA41 and CL, reported the lowest values in both parameters (3.23 m DL and 3.11 m DT). FA5 induced an intermediate canopy spread.

The lower canopy spread recorded in 'Lane Late' trees on some citrus rootstocks (Table 1), especially on FA13 and FA41, reveal the possibility of using more intensive and higher-density trees than traditional plantations (417 trees ha^{-1}). Thus, more intensive and higher-density 'Lane Late' navel orange plantations could be established by adjusting the tree spacing to the tree size induced by each citrus rootstock, which in our case, would result in more than 540 trees ha^{-1} on FA13, FA41, and CL without needing to force the tree size by pruning. Other authors [33] have remarked an interest in considering the citrus tree growth induced by rootstocks in order to reduce the gap between trees and crop lines as much as possible, provided it does not affect productivity and fruit quality.

'Lane Late' trees on CA and FA5 recorded significantly ($p < 0.05$) the highest trunk diameters of the rootstock (16.29 and 16.22 cm, respectively; Table 1). Trees on FA13 and FA41 recorded the lowest means (13.57 and 12.56 cm, respectively), while CL and MP had intermediate values. Except for FA5, a similar relationship was found among rootstocks in regard to the trunk diameter of the scion (Table 1). Thus, FA5 recorded the highest trunk diameter of the rootstock and one of the lowest trunk diameters of the scion (10.70 cm), the latter being similar those of FA41 and FA13.

Table 1. Effect of rootstock on the canopy spread of 'Lane Late' navel orange trees [canopy diameter longitudinal (DL) and transverse (DT) to the tree line and average canopy diameter squared (D^2)], in the latest growing season 2013/2014, and on the trunk diameter of 'Lane Late' navel orange trees [trunk diameter of the rootstock (Dr) and of the scion (Ds)] and on rootstock-scion affinity (Dr/Ds), over three growing seasons: 2008/2009, 2010/2011 and 2012/2013.

	DL (m)		DT (m)		D^2 (m^2)		Dr (cm)		Ds (cm)		Dr/Ds	
CA	3.94	b	3.65	b	14.49	c	16.29	c	12.49	c	1.31	b
CL	3.33	a	3.32	ab	11.22	ab	13.85	b	11.93	bc	1.17	a
FA13	3.23	a	3.11	a	10.10	a	13.57	ab	9.55	a	1.45	cd
FA41	3.31	a	3.30	ab	10.98	a	12.56	a	9.47	a	1.33	bc
FA5	3.55	ab	3.36	ab	12.09	abc	16.22	c	10.70	ab	1.52	d
MP	3.98	b	3.50	ab	14.15	bc	14.44	b	11.24	bc	1.28	ab

Mean values in the same column followed by different letters denote significant differences among rootstocks, based on Tukey's test ($p < 0.05$). CA: Carrizo citrange; CL: 'Cleopatra' mandarin; FA13: Forner-Alcaide no.13; FA41: Forner-Alcaide no.41; FA5: Forner-Alcaide no.5; MP: *C. macrophylla* Wester.

The trunk diameter was negatively correlated with leaf Zn content (r = −0.42; Table 2), the latter being the only significant correlation obtained between the 'Lane Late' trees growth parameters and leaf nutrient contents, contrary to Dubey and Sharma [11], on 'Kagzi Kalan' lemon trees, which was reported to have a positive correlation of vegetative growth with leaf Ca content.

Table 2. Pearson's simple correlation among tree height (TH), tree canopy spread [canopy diameter longitudinal (DL) and transverse (DT) to the tree line], trunk diameters [trunk diameter of the rootstock (Dr) and of the scion (Ds)], rootstock–scion affinity (Dr/Ds), yield, yield efficiency, and leaf nutrient contents in 'Lane Late' navel orange trees on six citrus rootstocks over the 2009/2010 and 2011/2012 seasons.

				%					ppm		
	Kg tree^{-1}	N	P	K	Ca	Mg	B	Cu	Fe	Mn	Zn
Kg tree^{-1}	1.00	0.58 *	0.47 *	0.52 *	−0.17	−0.33	−0.32	0.24	−0.34 *	0.27	−0.14
Kg m^{-3}	0.88 *	0.61 *	0.63 *	0.48 *	−0.06	−0.30	−0.28	0.25	−0.54 *	0.16	−0.04
TH (m)	0.13	−0.18	0.11	−0.22	−0.13	−0.10	−0.19	−0.02	0.05	−0.10	−0.22
DL (m)	0.29	−0.04	0.24	0.09	−0.30	−0.21	0.11	0.03	0.16	−0.01	−0.20
DT (m)	0.13	−0.15	0.04	−0.11	−0.19	−0.15	−0.08	−0.20	0.05	−0.01	−0.24
Vc (m^3)	0.15	−0.15	0.16	−0.11	−0.23	−0.17	−0.09	−0.08	0.07	−0.07	−0.24
Dr (cm)	0.19	−0.14	0.00	−0.36	0.15	0.26	−0.21	0.16	0.17	−0.04	−0.42 *
Ds (cm)	0.28	−0.27	0.05	−0.22	0.17	0.09	−0.28	−0.17	0.02	−0.02	−0.21
Dr/Ds	−0.12	0.25	0.01	−0.07	−0.13	0.05	0.13	0.37	0.15	0.06	−0.11

* Denotes significant correlation ($p < 0.05$).

As there were no significant differences among rootstocks in leaf Zn content (Table 3), the differences found in vegetative growth should not be attributed to the efficiency of the rootstock in the uptake of nutrients. Thus, other physiological aspects must be involved in the differences found among the studied citrus rootstocks in the vegetative tree growth.

Table 3. Effect of rootstocks on 'Lane Late' navel orange leaf micro-nutrients (B, Cu, Fe, Mn, and Zn) contents over two growing seasons, 2009/2010 and 2012/2013.

	B (ppm)				**Cu (ppm)**				**Fe (ppm)**			
	2009/2010		**2012/2013**		**2009/2010**		**2012/2013**		**2009/2010**		**2012/2013**	
CA	43.33	a	59.05	a	6.33	a	5.74	a	57.00	a	107.13	bc
CL	60.67	ab	66.40	a	4.00	a	3.13	a	63.00	a	64.77	a
FA13	70.00	ab	67.78	a	6.00	a	5.20	a	58.00	a	71.46	a
FA41	89.33	b	70.15	a	6.67	a	4.10	a	65.33	a	72.03	a
FA5	53.33	a	61.19	a	5.00	a	3.99	a	58.00	a	86.43	ab
MP	44.00	b	65.90	a	5.67	a	2.05	a	66.00	a	114.20	c
Optimal range *	31–100				6–14				61–100			
	Mn (ppm)				**Zn (ppm)**							
	2009/2010		**2012/2013**		**2009/2010**		**2012/2013**					
CA	26.00	a	25.93	a	18.00	a	17.27	a				
CL	36.33	ab	28.60	a	18.00	a	17.30	a				
FA13	40.00	bc	31.51	a	24.67	a	16.15	a				
FA41	28.33	ab	29.51	a	21.67	a	15.16	a				
FA5	38.33	abc	45.38	b	17.00	a	15.41	a				
MP	49.33	c	69.61	c	16.33	a	18.98	a				
Optimal range *	26–60				26–70							

* According to Legaz et al., 1995. Mean values in the same column followed by different letters denote significant differences among rootstocks, based on Tukey's test ($p < 0.05$). CA: Carrizo citrange; CL: 'Cleopatra' mandarin; FA13: Forner-Alcaide no.13; FA41: Forner-Alcaide no.41; FA5: Forner-Alcaide no.5; MP: *C. macrophylla* Wester.

3.2. 'Lane Late' Navel Orange-Rootstock Affinity

The rootstock/scion diameter ratio is an indicator of the equality in growth rate between rootstock and scion (cultivar), so the difference among diameters may be an incompatibility measure [34].

In 'Lane Late' trees, this ratio was higher on FA5 (1.52) because, while it reported the highest rootstock trunk diameter, it induced the lowest scion trunk diameter (Table 1). On the other hand, the rootstock/scion ratio was lower (and closer to 1.00) on CL (1.17) and MP (1.28). Likewise, a good affinity in different citrus cultivars has also been found on MP [37] or CL [33,36].

In our study, a higher rootstock/scion ratio may not be understood as an incompatibility between the scions and the rootstocks, as there were no correlations of this ratio with any leaf nutrient content in the twelve-year-old 'Lane Late' trees (Table 2).

3.3. 'Lane Late' Navel Orange Trees Productivity

'Lane Late' trees did not show an alternate bearing on any rootstock (ABI < 50%; Table 4), without significant differences among rootstocks.

As in other studies [11,13,37], the results revealed an effect of citrus rootstocks on yield (kg tree^{-1}; Table 4). Thus, 'Lane Late' trees on MP recorded higher yields (60.93 kg tree^{-1}), which were statistically significant in most growing seasons, while 'Lane Late' trees on FA13 (32.44 kg tree^{-1}) and FA41 (36.85 kg tree^{-1}) had almost always the lowest yield. CA, CL, and FA5 showed an intermediate behavior, without statistical differences from FA13. Nevertheless, the low spread canopy associated with high yield efficiencies (kg m^{-3}) in more intensive plantations is the key to reaching or even exceeding the yield per hectare versus traditional system plantations (417 trees ha^{-1}).

While there was no clear correlation of yield (kg tree^{-1}) with canopy volume (Table 2), the differences obtained among rootstocks in yield (kg tree^{-1}) disappeared when it concerned canopy volume (yield efficiency; kg m^{-3}). Without statistical differences among rootstocks, 'Lane Late' trees on MP (4.10 kg m^{-3}), CL (3.94 kg m^{-3}), and FA13 (3.80 kg m^{-3}) had a higher yield efficiency than 'Lane Late' trees on the remaining rootstocks (Table 4). On the contrary, 'Lane Late' trees on CA recorded the lowest mean (2.76 kg m^{-3}). In the same way, Legua et al. [37] reported the highest yield efficiency on MP compared to other citrus rootstocks, but in this case, with significant differences.

Hence, taking into account both the spread canopy (DL and DT; m; Table 1) and yield efficiency (kg m^{-3}; Table 4) of 'Lane Late' trees on the different rootstocks, FA13, FA41, and CL would have a high potential for use in more intensive and higher-density plantations with similar or even higher yields per hectare than traditional citrus plantations on CA, which is one of the most important citrus rootstocks in Mediterranean citrus growing countries. These results become more relevant when considering the results obtained by Hervalejo et al. [38] on the same citrus rootstocks, who pointed to FA13 and CL, together with FA5, as the most interesting citrus rootstocks for the 'Lane Late' navel orange cultivar in order to obtain a more suitable harvesting time and higher internal fruit quality.

Table 4. Effect of rootstocks on the yield and average of yield (kg $tree^{-1}$), yield efficiency (kg m^{-3}), and alternate bearing index (ABI) of 'Lane Late' navel orange trees over six growing seasons (2008/2009–2013/2014).

	CA		CL		FA13		FA41		FA5		MP	
kg $tree^{-1}$												
2008/2009	52.95	ab	32.92	a	43.30	a	47.45	a	49.07	a	70.59	b
2009/2010	32.47	ab	26.25	ab	26.21	ab	22.59	a	27.54	ab	39.28	b
2010/2011	53.03	a	46.98	a	43.50	a	41.02	a	52.93	a	86.83	b
2011/2012	48.32	a	40.91	a	35.27	a	44.58	a	34.20	a	51.16	a
2012/2013	28.25	ab	27.87	ab	17.74	a	21.62	a	28.38	ab	46.03	b
2013/2014	42.99	a	69.33	a	44.83	a	46.54	a	58.88	a	70.93	a
Averages												
kg $tree^{-1}$	43.04	ab	42.05	ab	32.44	a	36.85	a	40.08	ab	60.93	b
kg m^{-3}	2.76	a	3.94	a	3.80	a	3.72	a	3.55	a	4.10	a
ABI (%)	23.36	a	31.86	a	35.48	a	32.13	a	23.30	a	15.39	a

Mean values in the same row followed by different lowercase letters denote significant differences among rootstocks, based on Tukey's test ($p < 0.05$). CA: Carrizo citrange; CL: 'Cleopatra' mandarin; FA13: Forner-Alcaide no.13; FA41: Forner-Alcaide no.41; FA5: Forner-Alcaide no.5; MP: *C. macrophylla* Wester.

There are significant positive correlations of the yield (kg $tree^{-1}$) and yield efficiency (kg m^{-3}) with leaf N (r = 0.58 and 0.61, respectively), P (r = 0.47 and r = 0.63), and K (r = 0.52 and r = 0.48) contents (Table 2). In fact, N and K are known to be among the main essential nutrients involved in yield and fruit quality [39]. This correlation was observed very clearly on MP and FA13, which recorded the highest yield efficiencies (kg m^{-3}), with their greater leaf N, P, and K contents (Table 5) being noteworthy.

On the other hand, these correlations could explain the low yields obtained in general, as leaf N and/or P contents were below the recommended optimum range by Legaz et al. [31] on all rootstocks. Nevertheless, Legua et al. [37] reported similar yields (kg $tree^{-1}$) and yield efficiencies (kg m^{-3}) in 'Lane Late' trees under no deficient fertilization conditions.

3.4. 'Lane Late' Navel Orange Trees Nutrient Status

In sustainable plantation systems, the use of citrus rootstocks with a higher ability to uptake and translocate soil nutrients could be used as an important tool to reduce the use of chemical fertilizers. Citrus rootstocks are known to have an effect on performance and plant nutrient status [9,11–13]. A significant effect of the rootstocks ($p < 0.05$) was found in certain macro-nutrients' concentrations of 'Lane Late' leaves (Table 5).

'Lane Late' trees on MP and FA13 showed a greater efficiency in N uptake than on the other citrus rootstocks, with only deficient leaf N contents in the 2012/2013 growing season by Legaz et al. [31] (Table 5). In this sense, the efficient use of N by citrus rootstocks has a particular interest in Mediterranean areas, where the nitrate contamination of ground waters is concerning.

Likewise, 'Lane Late' trees on FA13 showed a greater efficiency in P uptake (Table 5), recording the highest P accumulation in leaves in both growing seasons, within or very close to the optimum recommended range (0.12% according to Legaz et al. [31]). On the contrary, 'Lane Late' trees on FA5 had the lowest leaf P concentration in both seasons.

Leaf K, Ca, and Mg contents in 'Lane Late' trees were within the recommended optimal range on all rootstocks except CA (Table 5), which recorded a deficient leaf K in the 2012/2013 growing season, and MP, which had a deficient leaf Mg content in both growing seasons. MP and FA13 had the highest leaf K content, but with the lowest leaf Ca in the case of MP, which was statistically significant in the second growing season. Pérez-Zamora [40], in Valencia orange on MP, recorded a lower leaf Ca content than on the other citrus rootstocks, as well as a higher leaf N content than on CA or CL.

Table 5. Effect of rootstocks on 'Lane Late' navel orange leaf macro-nutrients (N, P, K, Ca and Mg) contents over two growing seasons, 2009/2010 and 2012/2013.

	N (%)				**P (%)**				**K (%)**			
	2009/2010		**2012/2013**		**2009/2010**		**2012/2013**		**2009/2010**		**2012/2013**	
CA	2.38	ab	2.29	a	0.15	a	0.12	a	0.92	a	0.68	a
CL	2.39	ab	2.23	a	0.14	a	0.09	a	1.00	a	0.75	a
FA13	2.74	b	2.27	a	0.16	a	0.12	a	1.07	a	0.75	a
FA41	2.20	a	2.37	a	0.16	a	0.11	a	0.99	a	0.75	a
FA5	2.43	ab	2.29	a	0.14	a	0.05	a	0.89	a	0.71	a
MP	2.69	b	2.25	a	0.14	a	0.10	a	1.17	a	1.14	b
Optimal range *	2.51–2.80				0.13–0.16				0.71–1.00			
	Ca (%)				**Mg (%)**							
	2009/2010		**2012/2013**		**2009/2010**		**2012/2013**					
CA	3.54	a	3.65	b	0.28	a	0.39	b				
CL	3.76	a	3.69	b	0.30	a	0.34	ab				
FA13	3.44	a	3.44	b	0.30	a	0.29	ab				
FA41	3.30	a	3.47	b	0.27	a	0.33	ab				
FA5	3.96	a	3.54	b	0.34	a	0.41	b				
MP	3.07	a	3.04	a	0.22	a	0.21	a				
Optimal range *	3.00–5.00				0.25–0.45							

* According to Legaz et al., 1995. Mean values in the same column followed by different letters denote significant differences among rootstocks, based on Tukey's test ($p < 0.05$). CA: Carrizo citrange; CL: 'Cleopatra' mandarin; FA13: Forner-Alcaide no.13; FA41: Forner-Alcaide no.41; FA5: Forner-Alcaide no.5; MP: *C. macrophylla* Wester.

As regard to leaf micro-nutrients (Table 3), a significant effect of the rootstocks was found on leaf Mn, B, and Fe contents of 'Lane Late' navel orange in at least one of the two growing seasons. 'Lane Late' trees recorded higher leaf Mn levels on MP, FA13, and FA5, while the lowest leaf Mn content was obtained on CA, which was the only citrus rootstock that showed deficient (2012/2013) or close-to-deficient leaf Mn levels (2009/2010).

In general, an optimal 'Lane Late' leaf B was recorded in both growing seasons (Table 3) on any evaluated citrus rootstock, including FA13 and FA41, which recorded the maximum values. On the contrary, a deficient leaf Zn content was recorded in both growing seasons (Table 3), which is a general problem in many citrus regions of the world [41] either from low Zn contents and/or from high carbonate content and pH [24] conditions, the latter existing in the experimental plot of the current study.

The 'Lane Late' leaf recorded a deficient Fe concentration in the 2009/2010 growing season only on CA, FA13, and FA5 (Table 3). The results obtained in leaf Fe content in 2009/2010 agree with Zekri and Obreza's statements [42], who reported that trifoliate orange and its hybrids were the least able to absorb Fe. Thus, all trifoliate orange's hybrids (CA, FA5, and FA13), except FA41, recorded a deficient leaf Fe concentration in the 2009/2010 growing season. Nevertheless, FA13 did not differ from the remaining no vigorous citrus rootstocks, which are relevant for more intensive citrus plantations. On the other hand, a deficient leaf Fe content can be effectively and sustainability corrected by synthetic iron chelates applied to foliage.

The 'Lane Late' leaf recorded a deficient Cu concentration in both growing seasons on almost all citrus rootstocks (Table 3), except on FA13, FA41, and CA.

'Lane Late' trees on CA showed the lowest efficiency in the uptake of soil nutrients, as opposed to FA13, which appears to be the citrus rootstock with better behavior in reference to leaf N, P, and K contents, nutrients mainly linked to the 'Lane Late' tree yields (Table 5). Moreover, FA13 has received particular interest in some Mediterranean areas due to its excellent resistance to salinity [22], unlike CA. Nevertheless, FA13, similar to CA, is sensitive to lime-induced chlorosis, requiring special attention to the active limestone of the soils.

4. Conclusions

There are considerable differences in the tree vegetative growth, yield, and efficiency in macro- and micro-nutrient uptakes among citrus rootstocks in 'Lane Late' navel orange. The tree size of the 'Lane Late' navel orange was not related to plant nutrient status in this study, while the yield (kg tree^{-1}) and yield efficiency (kg m^{-3}) was linked to plant nutrient status (or ability to uptake the soil nutrients), more specifically, N, P, and K leaf contents.

Forner-Alcaide no.13 (FA13) and Forner-Alcaide no.41 induced the smallest 'Lane Late' trees, while the largest trees were obtained on *Citrus macrohylla* and Carrizo citrange (CA). Forner-Alcaide no.5 and 'Cleopatra' mandarin (CL) induced an intermediate tree size. The higher yield efficiency (kg m^{-3}) recorded in 'Lane Late' trees on CL and FA13, along with the smaller tree size induced by them, revealed the high potential of these two citrus rootstocks to be used in more intensive and higher-density plantations, reaching similar or even higher yields per hectare than traditional citrus plantations on CA, one of the most important citrus rootstocks in the Mediterranean citrus growing countries.

Finally, FA13 was the most efficient citrus rootstock in the use of soil nutrients under poor mineral fertilization conditions, recording higher leaf N, P, K, Zn, and Cu contents in 'Lane Late' trees. FA13 showed only less efficiency in the uptake of Fe than other citrus rootstocks, but similar to the other nonvigorous citrus rootstocks, which can be easily and sustainably compensated by synthetic iron chelates applied to foliage.

Taking an overall view of the results, FA13 appeared to be the most promising rootstock for a more intensive, higher-density, and sustainable plantation system of the 'Lane Late' navel orange cultivar for regions with similar ecological conditions to this survey.

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