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Leaf nutrient content of ‘Jade’ peach grafted on 22 clonal rootstock and in own-rooted trees

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Abstract

The objective of this research was to evaluate the effects of 22 clonal rootstocks and own-rooted scion trees (without rootstock) on leaf nutrient contents (N, P, K, Ca, Mg, Mn, Fe, Zn, Cu and B) of the ‘Jade’ scion peach growing in a no-irrigated area, as well as their effects on nutrient agronomic interpretation. Macronutrient (N, P, K, Ca and Mg) and micronutrient contents (B, Cu, Fe, Mn and Zn) were determined in the first and second years after tree planting, in Pelotas-RS, Brazil. We conclude that leaf contents of P, K, Ca, Mg, B, Cu, Mn and Zn are influenced by the scion/rootstock combinations and own-rooted trees tested. Treatments changed agronomic interpretation classes of all macro and micronutrients. For macronutrients, ‘Flordaguard’, De Guia, Tardio-01 rootstocks and the own-rooted trees stood out, with leaf nutrient contents similar or even higher than trees grafted on ‘Capdeboscq’ and ‘Aldrighi’. For micronutrients, trees on GxN.9, ‘Ishtara’ and ‘Santa Rosa’ plum stood out. From a nutritional point of view, own-rooted ‘Jade’ peach trees did not present any limitations.

Keywords: cutting propagation, intraspecific budding, interspecific budding, nutrition, Prunus

Introduction

The peach tree [*Prunus persica* (L.) Batsch] has notable economic importance among temperate climate fruit in the world (Mestre et al., 2015). In Brazil, 201,880 tons of peaches were produced in the 2020 harvest (IBGE, 2022). The peach, nectarine and plum represent the stone fruit trees of commercial importance in Brazil (Mayer et al., 2017; Mayer et al., 2018), with relevance in family farming (Severo et al., 2020) and positive economic and social impact on producing areas (De Paula et al., 2020).

In commercial stone fruit orchards, trees are formed by a two different genotypes combination (scion/rootstock), which can markedly affect some morpho-physiological characteristics, such as tree vigor, tree nutrient uptake, precocity and fruit yield (Comiotto et al., 2013; Shahkoomahally et al., 2020; Yahmed et al., 2020; Mayer et al., 2021), adaptability to different soil conditions such as fertility, salinity and moisture (Jiménez et al., 2011; Kuçukyumuk et al., 2015) and pathogen resistance (Reighard & Loreti, 2008).

Peach rootstock propagation in Southern Brazil is predominantly by seed germination, generally by not suitable seeds of scion variety with high segregation (Mayer et a., 2014; Mayer et al., 2017). If seeds of segregating genotypes and not selected for rootstock purpose are used, rootstocks will be genetically different from each other and, therefore, undesirable in modern fruit production. Alternatively, propagation of *Prunus* spp. by softwood cuttings is technically feasible and produces trees genetically identical to the original mother tree, in addition of optimizing several nursery activities through an alternative system of potted tree production (Mayer et al., 2014; Mayer et al., 2015b; Mayer et al., 2021).

Peach quality is mainly determined by the scion/rootstock combination, soil and climate conditions,

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irrigation and fertilization. However, the rootstock represents an important component (Galarça et al., 2012; Reighard et al., 2013; Mayer et al., 2015a.; Jimenez et al., 2018; Mayer et al., 2021), because it is related to all physical, chemical and biological soil conditions, it is responsible for nutrients and water uptake from the soil and, consequently, for the adequate tree nutrition (Reighard & Loreti, 2008; Shahkoomahally et al., 2020). Specifically in the Rio Grande do Sul State, the Peach Tree Short Live (PTSL) syndrome is one of the main agronomic problems, which is related to susceptible rootstocks with no defined genetic identity (Mayer & Ueno, 2021).

Research involving peach tree nutrition in different scion/rootstock combinations can help recommendation of genotypes most suitable for soil and climate conditions of a region, in addition to enabling more specific fertilizers recommendation (Rombolà et al., 2012). Therefore, one of the most effective ways of evaluating scion nutrition is to identify rootstock efficiency in nutrient uptake and translocation, as well as to observe graft incompatibility symptoms (Reighard et al., 2013; Huang et al., 2016; Neves et al., 2017; Jimenes et al., 2018; Shahkoomahally et al., 2020; De Paula et al., 2021).

The rootstock selection for a given peach producing area is a long and important research, since characteristics such as scion/rootstock adaptation, yield, vigor, fruit quality and reaction to pests and diseases, including the PTSL, interfere in the orchard management and activity sustainability. The objective of this research was to evaluate the effects of 22 clonal rootstocks and own-rooted scion trees (without rootstock) on leaf nutrient contents (N, P, K, Ca, Mg, Mn, Fe, Zn, Cu and B) of the 'Jade' scion peach growing in a no-irrigated area with Peach Tree Short Life (PTSL) history, as well as their effects on nutrient agronomic interpretation.

Material and methods

Germplasm and trial conditions

For the nursery tree production, several cultivars and genotypes of interest to be tested as rootstocks were vegetatively propagated, which consisted of 22 genotypes (selections, public domain rootstock cultivars, species or interspecific hybrids of *Prunus* spp.). Softwood shoots were collected from mother trees of the "*Prunus* Rootstock Block" at Embrapa Clima Temperado (Pelotas, Rio Grande do Sul State, Brazil), which were managed for this purpose, through drastic winter pruning to stimulate new and intense new shoots. Softwood cuttings 15 cm-long were prepared, with 3 to 8 half-leaves at the top 3 nodes, treated with indolbutyric acid at 3,000 mg.L^{-1} and conditioned in fine vermiculite for rooting under an intermittent mist system (Mayer et al., 2013). Identification, species, characteristics of interest and bibliographic sources of studied genotypes as rootstocks, as well as the own-rooted 'Jade' trees (without rootstock), are described in (**Table 1**).

The rooted cuttings classified as suitable were transplanted into perforated plastic bags (30cm x 18cm) containing commercial substrate based on pine bark and peat. Rootstocks were then conducted on a single stem until the following summer, when they were grafted with 'Jade', a peach [*Prunus persica* (L.) Batsch] scion variety for processing, by the "T-inverted" grafting method. Own-rooted nursery trees of 'Jade' (without rootstock), were also propagated by softwood cuttings (Mayer et al., 2013; Mayer et al., 2015b).

The experimental area is located on a typical peach farm in Colônia Santa Áurea, 7th district of Pelotas-RS, Brazil, with 205-208 m of altitude a.s.l. and with a PTSL history. In March, 2014, a soil sample (0-20cm) was collected for chemical analyzes and interpretations (**Table 2**, Cqfs-RS/SC, 2004), which helped to correct soil pH and pre-plant fertilization. Soil profile samples were also collected for the physical characterization (**Table 3**).

'Jade' nursery peach trees were planted in August, 2014, under a spacing of 5.5 x 3.0 m, preserving intact the substrate surrounding roots. Trees were conducted in the "open-vase system", through annual winter pruning. The experimental design was in randomized blocks, with four replications of one tree per plot. Treatments were composed of 'Jade'/22 clonal rootstocks and by the own-rooted 'Jade' trees (without rootstock), totaling 23 treatments (Table 1) and 92 experimental units.

Soil and leaf chemical analysis

Leaf sampling for chemical analysis were carried out on November, 23th, 2015 and November, 8th, 2016, that is, between the 13th and 15th weeks after full bloom. Approximately 100 complete leaves (blade + petiole) were sampled around each tree, in the middle new shoot portion, according to Freire and Magnani (2005). Leaf samples were placed in identified paper bags and immediately sent to the Laboratory of Vegetal Nutrition of Embrapa Clima Temperado for chemical analysis. Leaf macronutrient contents nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg), expressed in %, and leaf micronutrients contents iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and boron (B), expressed in mg kg^{-1}, according to the methodologies defined by the Official Network of Soil and Plant Tissue Analysis Laboratories of Rio Grande do Sul and Santa Catarina State - ROLAS (Cqfs-RS/SC, 2016). Soil samples

Table 1. Twenty-two *Prunus* spp. genotypes as a clonal rootstock for ‘Jade’ peach, and own-rooted ‘Jade’ trees, with main features and references. Embrapa Clima Temperado, Pelotas-RS, Brazil

Rootstocks and own-rooted ‘Jade’	Species	Main features	References
Barrier	*P. persica* x *P. davidiana*	Waterlogging tolerance; drought tolerance better than peach seedlings.	Reighard & Loreti (2008)
Cadaman	*P. persica* x *P. davidiana*	Waterlogging tolerance; resistant to *M. incognita*, *M. arenaria* and *M. hispanica*; drought tolerance; suitable for replanting peach areas.	Reighard & Loreti (2008)
GF 677	*P. persica* x *P. amygdalus*	Adaptation to poor soils and arid climate.	Loreti & Massai (2002)
G x N.9	*P. persica* x *P. dulcis*	Resistant to *M. javanica* and *M. incognita* race 2; red leaf.	Rossi et al. (2002)
Capdeboscq	*P. persica*	Adaptation to climate and soil conditions of Rio Grande do Sul State.	Finardi (1998); Mayer et al. (2014)
Genovesa	*P. salicina*	Increase genetic variability tested as rootstock	No information
Rigitano	*P. mume*	Easy propagation by softwood cuttings; resistance to *M. javanica* and *M. incognita*; less vigor than ‘Okinawa’; induces greater fruit weight, size and soluble solids.	Pereira et al. (2007)
Clone 15	*P. mume*	Easy propagation by softwood cuttings; resistance to *M. javanica* and *M. incognita*; induces greater fruit weight, size and soluble solids for ‘Aurora-1’ peach.	Pereira et al. (2007)
México F1	*P. persica*	Low chill requirement; produces very homogeneous trees.	No information
Tsukuba-1	*P. persica*	Waterlogging tolerance; resistance to *M. incognita* race 2 and *M. javanica*; red leaf.	Rossi et al. (2002); Reighard & Loreti (2008)
Tsukuba-2	*P. persica*	Waterlogging tolerance; resistance to *M. incognita* race 2 and *M. javanica*; red leaf.	Rossi et al. (2002); Reighard & Loreti (2008)
Tsukuba-3	*P. persica*	Waterlogging tolerance; resistance to *M. incognita* race 2 and *M. javanica*; red leaf.	Rossi et al. (2002); Reighard & Loreti (2008)
Okinawa	*P. persica*	Easy propagation by softwood cuttings; freestone and good seed germination; low chill requirement; resistance to *M. incognita* and *M. javanica*; tolerant to *M. floridensis*.	Rossi et al. (2002); Mayer et al. (2014); Sarkhosh et al. (2018); Shahkoomahally et al. (2020)
Flordaguard	*P. persica*	Resistant to *M. javanica*, *M. floridensis* and *M. incognita* races 1 and 3; low chill requirement; freestone; red leaf; high vigor.	Sherman et al. (1991); Sarkhosh et al. (2018); Shahkoomahally et al. (2020)
Nemared	*P. persica*	Resistant to root-knot nematodes; red leaf; vigorous growth; good anchorage.	Ramming & Tanner (1983)
Ishtara	(*P. cerasifera* x *P. salicina*) x (*P. cerasifera* x *P. persica*)	Resistant to *M. incognita*, *M. javanica*, *M. arenaria*, *M. hapla* and *M. hispanica*; less vigor than GF 677; waterlogging tolerance; resistant to *Armillaria mellea*.	Loreti & Massai (2002); Reighard & Loreti (2008)
Aldrighi	*P. persica*	Adaptation to the edaphoclimatic conditions of Rio Grande do Sul State.	Finardi (1998); Mayer et al. (2014)
Tardio-01	*P. persica*	Longevity of the original tree (over 40 years); adaptation to the edaphoclimatic conditions of the Pelotas region.	No information
De Guia	*P. persica*	Decumbent growth habit.	No information
Rosaflor	*P. persica*	Increase genetic variability tested as rootstock; is an ornamental peach cultivar.	Embrapa Clima Temperado (2004)
P. mandshurica	*P. mandshurica*	Source of cold resistance; increase genetic variability tested as rootstock.	Das et al. (2011)
Santa Rosa	*P. salicina*	To increase variability tested as rootstock	Guerra et al. (1992)
Own-rooted ‘Jade’	*P. persica*	To check the technical feasibility of nursery peach trees without rootstock; high vigor.	Mayer et al. (2013); Neves et al. (2017); Mayer et al. (2021)

Table 2. Results and interpretation of soil chemical analysis of the experimental area in pre-planting (2014) and in each experimental block (0-20cm) in 2015 and 2016 years. Embrapa Clima Temperado, Pelotas-RS, Brazil

Year/ sample	pH water 1:1	Organic matter (%)	Clay (%)	P	K	Ca	Mg	Saturation (%)		CEC pH 7	B	Cu	Zn	Mn	Fe
				mg dm^3		cmol$_c$ dm^3		Al	Bases		mg dm^3				g dm^3
2014 (pre-planting)	5.3 (L)	2.1 (L)	16	7.0 (Vl)	111 (H)	2.4(M)	0.4 (L)	8.3(L)	45 (L)	7.9 (M)	0.2(M)	1.7 (H)	5.6 (H)	11.0(H)	0.6
2015 Block 1	7.0 (H)	2.0 (L)	13	35.3 (H)	82 (H)	4.6 (H)	1.2 (H)	0.0(Vl)	81 (H)	7.4 (M)	0.5 (H)	0.6 (H)	3.1 (H)	1.6 (L)	0.1
2015 Block 2	6.8 (H)	1.7 (L)	15	29.5 (H)	102 (H)	3.7(M)	1.0 (M)	0.0(Vl)	71 (M)	7.0 (M)	0.4 (H)	0.7 (H)	5.6 (H)	2.9(M)	0.2
2015 Block 3	6.1 (H)	2.7 (M)	15	36.4 (H)	108 (H)	5.1 (H)	1.2 (H)	0.0(Vl)	72 (M)	9.2 (M)	0.4 (H)	0.6 (H)	5.3 (H)	3.9(M)	0.3
2015 Block 4	6.1 (H)	3.2 (M)	21	30.8(Vh)	134 (Vh)	5.2 (H)	1.9 (H)	0.0(Vl)	75 (M)	9.9 (M)	0.5 (H)	1.1 (H)	6.0 (H)	4.9(M)	1.1
2016 Block 1	6.9 (H)	2.5 (L)	16	70.7 (Vh)	85 (H)	4.9 (H)	1.3 (H)	0.0(Vl)	83 (H)	7.7 (M)	0.2(M)	0.5 (H)	4.2 (H)	2.9(M)	0.5
2016 Block 2	7.0 (H)	2.6 (M)	15	56.7 (Vh)	104 (H)	5.1 (H)	1.6 (H)	0.0(Vl)	84 (H)	8.3 (M)	0.2(M)	0.5(H)	3.0 (H)	4.3(M)	0.4
2016 Block 3	6.5 (H)	2.7 (M)	13	53.1 (Vh)	85 (H)	4.3 (H)	1.3 (H)	0.0(Vl)	77 (M)	7.5 (M)	0.2(M)	0.3 (M)	5.0 (H)	5.4 (H)	0.2
2016 Block 4	6.5 (H)	3.2 (M)	15	51.6 (Vh)	87 (H)	3.2(M)	1.8 (H)	0.(Vl)	79 (M)	6.6 (M)	0.3(M)	0.7(H)	4.8 (H)	5.8 (H)	1.1

Interpretation of chemical analysis (CQFS-RS/SC, 2004): Vl= very low; L= low; M= medium; H= high; Vh= very high.

Table 3. Soil physical analysis of layers in the experimental area. Embrapa Clima Temperado, Pelotas-RS, Brazil

Soil layer	Clay (%)	Silt (%)	Silt/clay ratio	Sand (%)			Disperse clay (%)	Flocculation degree (%)	Dispersion degree (%)	Particle density (g cm^{-3})
				Total	Coarse	Fine				
A1 (0-20cm)	6.1	19.6	3.2	74.3	3.6	3.8	2.2	65.1	34.9	2.52
A2 (20-47cm)	6.0	25.0	4.2	69.1	3.4	3.5	1.8	70.7	29.3	2.52
A3 (47-67cm)	9.0	17.6	2.0	73.4	5.1	2.2	2.7	70.2	29.8	2.50
Bt1 (67-82cm)	8.3	33.7	4.0	58.0	2.9	2.9	5.0	39.9	60.1	2.50

were also collected to evaluate pH, organic matter (%), clay contents (%), P and K (mg dm^3), Ca and Mg (cmol$_c$ dm^3), saturation by bases and by aluminum (%), cation exchange capacity (CEC pH 7), boron, copper, zinc, manganese (mg dm^3) and iron (g cm^3) (Table 2), to assist interpretation of leaf nutrient data (Freire & Magnani, 2005).

Statistical analysis

Leaf nutrient content data were submitted to analysis of variance by F test and the means were compared by the Scott-knott test, at 5 % error probability, using the SASM - Agri software. To carry out a joint statistical analysis of relationship among treatments for all 10 nutrients, considering the average of two years of evaluation (2015 and 2016), a cluster analysis was adopted (Mingoti, 2005) using Euclidean distance and the Complete Linkage method. A similarity level of 59.79 % was established for discussion of the obtained groups. Analyzes were performed using Minitab Release 14 software (Minitab, 2003).

Results and Discussion

The results of leaf nutrient contents of ‘Jade’/22 clonal rootstocks and own-rooted trees are shown in (**Tables 4** and **5**). It was observed that most nutrients were significantly influenced by treatments, regardless of the year evaluated. In both evaluated years, leaf N content did not present significant differences among tested treatments (Table 4). However, differences were observed for the agronomic interpetation of leaf N contents, according to Cqfs-RS/SC (2004). Considering all 23 treatments tested, ten had leaf N contents below normal in at least one cycle. Trees grafted on ‘Tsukuba-3’ were classified as below normal in both evaluation years (3.16 and 3.25 % respectively). For trees grafted on ‘Genovesa’ plum, it was not possible to collect leaf samples in the second cycle due to graft incompatibility, which led to the death of all repetitions of this treatment.

Regarding leaf P contents, trees grafted on ‘Ishtara’, ‘Aldrighi’ and Tardio-01 selection showed higher levels in both years. ‘Rigitano’ rootstock gave normal leaf P contents in both years. For the other treatments tested, leaf P contents were above normal or excessive in at least one cycle.

Trees on *Prunus mandshurica* showed normal leaf K contents in both years (1.65 and 2.01 %, respectively) and, for trees on ‘Rosaflor’, only in the first cycle. Other treatments presented leaf K contents classified as above normal, for both evaluated years. Statistically, trees on *P. mandshurica*, ‘Rosaflor’ and ‘Rigitano’ were inferior to all the others, however, they still presented sufficient values of leaf K contents.

Leaf Ca contents was below normal in all treatments in the first cycle, and normal in nine treatments in the second cycle. Trees on ‘GF 677’, ‘Capdeboscq’, Clone 15, México F1, ‘Flordaguard’, Tardio-01, ‘De Guia’, *P. mandshurica* and the own-rooted trees, were superior in both years in terms of leaf Ca contents.

In all treatments and evaluated years, leaf Mg contents were classified as below normal, however, trees on México F1, ‘Flordaguard’, Tardio-01 and *P. mandshurica*, were superior in both evaluated years, compared to the other treatments.

For leaf B contents (Table 5), trees on ‘Rigitano’ presented levels below normal and, as soon as trees on Clone 15, were lower than the other treatments, in both evaluated years. Leaf Cu contents were classified as normal in both years for trees on ‘Tsukuba-3’, ‘Ishtara’, ‘Rosaflor’ and ‘Santa Rosa’. For the other treatments, leaf Cu contents were below normal in at least one cycle. Trees on ‘Ishtara’, ‘Rosaflor’ and ‘Santa Rosa’ were superior in terms of leaf Cu contents.

All treatments showed insufficient leaf Fe contents in the first cycle, according to the classification of Cqfs-RS/SC (2004). When compared to each other, 13 treatments had leaf Fe contents higher in both years. For leaf Mn contents, trees on México F1, ‘Aldrighi’ and ‘De Guia’ were below normal in the first cycle. All other treatments had leaf Mn contents classified as normal in both years, and four treatments had leaf Mn contents above normal in the second cycle. When compared to each other, stood out trees on ‘GF 677’, ‘Ishtara’, *P. mandshurica* and ‘Santa Rosa’.

Leaf Zn contents were classified as normal in only four rootstocks (‘Cadaman’, ‘GF 677’, GxN.9 and ‘Ishtara’) in both years. There were also three treatments that showed insufficient leaf Zn contents (México F1, ‘Tsukuba-2’ and ‘Aldrighi’). Comparing treatments, trees on ‘Cadaman’, ‘GF 677’ and GxN.9 were superior to the others tested, in both years.

Cluster analysis was applied to share 23 treatments (22 clonal rootstocks and own-rooted ‘Jade’ trees) according to their effects on leaf macro and micronutrient contents of the ‘Jade’ scion. (**Figure 1**). Considering the acceptable level of 59.79 % similarity, twelve groups were formed, being composed of only one or up to four treatments per cluster. Some clusters were composed of rootstocks genetically similar to each other, such as ‘Rigitano’ and Clone 15 (both *P. mume*) in the same group and the three rootstocks of ‘Tsukuba’ Series

Table 4. Effects of clonal rootstocks used for ‘Jade’ peach and own-rooted ‘Jade’ trees in leaf macronutrient contents (%) in 2nd and 3rd years after tree planting (2015 and 2016). Embrapa Clima Temperado, Pelotas-RS, Brazil

Rootstocks and own-rooted scion	N (%)		P (%)		K (%)		Ca (%)		Mg (%)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Barrier	3.62 a	3.35 a	0.30 c	0.33 a	2.21 a	2.35 a	1.49 a	1.30 b	0.41 a	0.36 c
Cadaman	3.53 a	3.82 a	0.28 c	0.37 a	2.42 a	2.65 a	1.56 a	1.43 b	0.39 a	0.34 c
GF 677	3.63 a	3.66 a	0.27 c	0.32 a	2.44 a	2.43 a	1.42 a	1.61 a	0.31 b	0.34 c
GxN.9	3.56 a	3.51 a	0.30 c	0.37 a	2.20 a	2.62 a	1.20 b	1.44 b	0.35 b	0.36 c
Capdeboscq	3.48 a	3.43 a	0.30 c	0.35 a	2.48 a	2.61 a	1.46 a	1.64 a	0.40 a	0.43 b
Genovesa	3.83 a	--	0.29 c	--	2.43 a	--	1.35 a	--	0.33 b	--
Rigitano	3.25 a	3.40 a	0.28 c	0.27 b	2.34 a	2.14 b	1.33 a	1.57 b	0.27 b	0.35 c
Clone 15	3.37 a	3.20 a	0.33 c	0.28 b	2.34 a	2.44 a	1.43 a	1.90 a	0.29 b	0.36 c
México F1	3.37 a	3.09 a	0.37 b	0.28 b	2.34 a	2.45 a	1.46 a	1.85 a	0.41 a	0.49 a
Tsukuba-1	3.02 a	3.36 a	0.34 c	0.30 b	2.37 a	2.60 a	1.08 b	1.44 b	0.34 b	0.42 b
Tsukuba-2	2.97 a	3.59 a	0.35 c	0.29 b	2.38 a	2.73 a	0.97 b	1.53 b	0.31 b	0.38 c
Tsukuba-3	3.16 a	3.25 a	0.37 b	0.30 b	2.20 a	2.49 a	0.96 b	1.51 b	0.32 b	0.41 b
Okinawa	2.97 a	3.28 a	0.37 b	0.29 b	2.18 a	2.37 a	1.12 b	1.66 a	0.30 b	0.40 b
Flordaguard	3.27 a	3.51 a	0.45 a	0.31 b	2.46 a	2.59 a	1.28 a	1.87 a	0.38 a	0.48 a
Nemared	3.40 a	3.49 a	0.43 a	0.29 b	2.31 a	2.63 a	1.11 b	1.49 b	0.33 b	0.35 c
Ishtara	3.38 a	3.56 a	0.44 a	0.32 a	2.35 a	2.42 a	1.43 a	1.38 b	0.33 b	0.30 c
Aldrighi	3.21 a	3.38 a	0.41 a	0.33 a	2.43 a	2.70 a	1.07 b	1.46 b	0.35 b	0.42 b
Tardio-01	3.29 a	3.88 a	0.46 a	0.34 a	2.24 a	2.56 a	1.30 a	1.74 a	0.44 a	0.51 a
De Guia	3.21 a	3.30 a	0.44 a	0.29 b	2.30 a	2.60 a	1.24 a	1.74 a	0.39 a	0.42 b
Rosaflor	3.46 a	3.64 a	0.40 b	0.30 b	2.01 b	2.51 a	1.13 b	1.42 b	0.35 b	0.40 b
P.mandshurica	3.46 a	3.56 a	0.38 b	0.31 b	1.65 c	2.01 b	1.35 a	1.76 a	0.37 a	0.45 a
Santa Rosa	3.75 a	3.03 a	0.45 a	0.29 b	2.23 a	2.58 a	1.31 a	1.06 b	0.34 b	0.29 c
Own-rooted ‘Jade’	3.66 a	3.49 a	0.46 a	0.30 b	2.17 a	2.61 a	1.36 a	1.74 a	0.29 b	0.48 a
$F_{rootstocks}$	1.2255^{ns}	1.4023^{ns}	8.0218**	2.6890**	3.8362**	2.5363**	2.9584**	3.7921**	3.6183**	4.4278**
F_{block}	26.9088**	0.7407^{ns}	16.3921**	8.4149**	8.7306**	2.1814^{ns}	7.5337**	17.1417**	4.0107*	15.8899**
CV (%)	12.37	10.19	12.50	11.02	7.98	8.29	15.45	13.17	13.30	14.29

Means followed by different letters in the column differ from each other by Scott-knott test. * Significant at 95 % confidence; ** significant at 99 % confidence; ^{ns} not significant. Agronomic interpretation of leaf nutrient contents, according to Cqfs-RS/SC (2004):

Below normal | Normal | Above normal | Excessive

Table 5. Effects of clonal rootstocks used for 'Jade' peach and own-rooted 'Jade' trees in leaf micronutrient contents (mg kg^{-1}) in 2nd and 3rd years after tree planting (2015 and 2016). Embrapa Clima Temperado, Pelotas-RS, Brazil

Rootstocks and own-rooted scion	B (mg kg^{-1})		Cu (mg kg^{-1})		Fe (mg kg^{-1})		Mn (mg kg^{-1})		Zn (mg kg^{-1})	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Barrier	42.0 a	35.0 a	4.0 d	5.5 b	40.5 a	80.0 a	67.0 a	128.3 b	24.3 b	21.5 a
Cadaman	41.3 a	39.5 a	5.5 c	6.8 a	41.5 a	104.0 a	52.0 b	111.5 b	30.8 a	25.5 a
GF 677	37.3 b	36.3 a	4.0 d	7.0 a	39.5 a	87.5 a	100.3 a	186.0 a	28.0 a	25.8 a
GxN.9	46.3 a	39.5 a	5.3 c	6.5 a	42.0 a	84.3 a	79.8 a	129.5 b	34.3 a	25.3 a
Capdeboscq	40.0 a	36.5 a	4.5 d	5.3 b	36.3 b	80.5 a	35.8 b	107.8 b	21.5 b	14.0 b
Genovesa	43.4 a	--	5.8 c	--	31.8 b	--	69.5 a	--	21.8 b	--
Rigitano	31.3 b	29.3 b	3.8 d	4.3 b	34.0 b	80.3 a	44.8 b	137.0 b	16.8 c	18.0 b
Clone 15	34.5 b	30.8 b	4.3 d	4.8 b	30.8 b	77.0 a	32.8 b	97.8 b	14.8 c	16.5 b
México F1	42.5 a	38.7 a	4.9 c	5.8 b	32.9 b	75.4 a	24.2 b	59.5 b	11.7 c	8.4 b
Tsukuba-1	37.5 b	35.0 a	7.8 b	5.5 b	38.8 a	83.0 a	43.0 b	94.8 b	15.8 c	16.5 b
Tsukuba-2	41.3 a	36.5 a	7.0 b	5.8 b	31.3 b	85.8 a	30.8 b	88.0 b	9.8 c	14.3 b
Tsukuba-3	41.0 a	34.3 a	7.8 b	6.5 a	35.8 b	82.8 a	42.5 b	88.3 b	13.3 c	14.3 b
Okinawa	43.3 a	35.8 a	8.0 b	5.3 b	41.0 a	82.8 a	36.5 b	110.0 b	14.3 c	20.5 a
Flordaguard	46.0 a	42.0 a	8.8 b	5.5 b	38.5 a	78.3 a	39.3 b	110.0 b	13.8 c	12.8 b
Nemared	42.0 a	32.3 b	6.0 c	4.5 b	31.3 b	103.3 a	32.0 b	122.3 b	13.8 c	15.8 b
Ishtara	43.5 a	32.8 b	10.8 a	6.5 a	37.8 a	104.3 a	74.3 a	194.8 a	24.5 b	34.5 a
Aldrighi	42.3 a	36.0 a	7.8 b	4.5 b	30.5 b	102.8 a	23.8 b	83.3 b	7.8 c	14.0 b
Tardio-01	43.5 a	39.0 a	8.5 b	4.8 b	43.3 a	104.3 a	32.8 b	122.8 b	16.5 c	23.5 a
De Guia	47.0 a	38.0 a	9.8 a	5.5 b	47.0 a	110.3 a	25.0 b	84.0 b	10.8 c	15.0 b
Rosaflor	41.5 a	34.3 a	9.3 a	6.3 a	47.5 a	108.3 a	50.3 b	118.5 b	15.0 c	20.5 a
P.mandshurica	42.5 a	27.1 b	9.3 a	4.8 b	45.3 a	104.4 a	80.8 a	213.9 a	14.3 c	26.3 a
Santa Rosa	48.0 a	38.5 a	10.8 a	7.0 a	38.3 a	101.8 a	70.5 a	192.3 a	22.0 b	23.3 a
Own-rooted 'Jade'	36.8 b	36.3 a	7.8 b	4.8 b	34.8 b	110.3 a	31.5 b	111.0 b	12.8 c	20.8 a
$F_{rootstocks}$	2.1706**	3.1543**	14.0944**	1.9125*	3.2901**	0.9549^{ns}	2.5493**	4.6878**	6.4311**	2.2462**
F_{block}	2.7104^{ns}	9.9827**	3.7455*	17.7579**	3.4775*	82.8175**	9.8289**	6.9869**	10.7386**	25.8845**
CV (%)	12.96	10.91	16.80	22.09	14.98	27.56	54.83	29.11	30.64	40.14

Means followed by different letters in the column differ from each other by Scott-knott test. * Significant at 95 % confidence; ** significant at 99 % confidence; ^{ns} not significant. Agronomic interpretation of leaf nutrient contents, according to Cqfs-RS/SC (2004):

Insufficient Below normal Normal Above normal

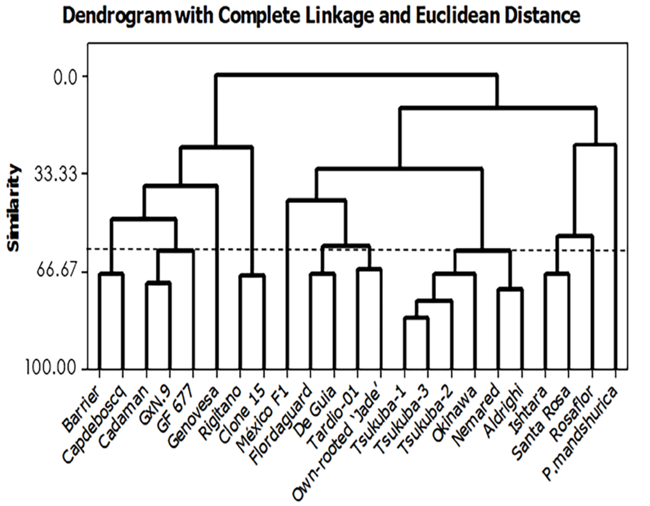

Figure 1. Dendrogram with Complete Linkage Method and Euclidian Distance illustrating the relationship among peach clonal rootstocks and own-rooted trees for leaf nutrient content of ‘Jade’ scion (dashed line = 59.79 % of similarity level).

and ‘Okinawa’ (all *P. persica*, of Japanese origin), joining another group. On the other hand, other treatments belonging to the same species (i.e., ‘Genovesa’ and ‘Santa Rosa’, belonging to *P. salicina*; or ‘Barrier’ and ‘Cadaman’, which are hybrids of *P. persica* x *P. davidiana*) were in different clusters in the dendrogram.

The influence of *Prunus* rootstocks on leaf nutrient contents has been evidenced in several studies (Jiménez et al., 2011; Reighard et al., 2013; Mayer et al., 2015a; Mestre et al., 2015; Jimenes et al., 2018), which may be related to factors such as absorption, translocation of nutrients, scion/rootstock affinity and rootstock root morphology.

Although there were no statistically differences among treatments and most rootstocks had leaf N contents considered normal, some treatments had low levels of N in both evaluated years (Table 4). Such results can be attributed to formation and growth of root system and their inability to absorb and translocate N in a manner compatible with tree scion growth. Nitrogen has the characteristic of being the unique nutrient indicated for the growth fertilization (up to the 3rd year) (Rombolà et al., 2012; Cqfs-RS/SC, 2016), with this, these genotypes, with lower N absorption capacity, can require greater amounts of N in the first years at field for adequate tree growth, due to this nutrient is related to vigor (Nava et al., 2010).

Regarding leaf P contents, trees on ‘Ishtara’, ‘Aldrighi’ and Tardio-01 proved to be rootstocks with the highest efficiency in absorption and translocation of this nutrient. However, the fact that all treatments had leaf P contents in the normal range or above normal (Cqfs-RS/SC, 2004), indicates that leaf P will hardly be observed at deficient levels in peach trees, when they are available in the soil, corroborating what occurs in pear (Brunetto et al., 2015), apple (Nava et al., 2017) and also in peach (Navroski et al., 2019). The fact that some treatments reduced leaf P contents when they were in excessive concentrations in the first year can be explained by the tree growth and the consequent dilution of this nutrient in their tissues. Trees on ‘Rigitano’, despite being the only rootstock to present normal leaf P contents in both years evaluated, does not characterize it as inferior to the others, considering that its levels were satisfactory, however, there is a reduced P absorption capacity. According to the Cqfs-RS/SC (2016), there is no response of peach trees to phosphate fertilizer in the Southern Brazil, when leaf P content is greater than 0.09 %. Therefore, based on chemical leaf analyzes carried out, it was found that phosphate fertilization is unnecessary when soil P content is above the critical level (Navroski et al., 2019), a situation observed in both evaluated years and treatments tested.

Leaf K contents showed concentrations above normal for peach trees (Cqfs-RS/SC, 2004). Such results possibly occurred due to tested genotypes as a rootstocks are efficient in K absorption. In addition, high leaf K content can also be related to the high soil K levels (Table 2) and its low exportation due to the absence or very low fruit number per tree in the first two years, a fact already proven in other studies carried out in Rio Grande do Sul (Mayer et al., 2015a). The importance of adopting efficient rootstocks in K absorption is justified, since higher K levels are usually associated with more colorful fruits and with higher sugar content (Nava et al., 2007). In addition, K promotes translocation of sugars produced in the leaves by photosynthesis to the fruits (Taiz et al., 2017), also influencing fruit size and yield. However, Rombolà et al. (2012) emphasize that fruit K excess can impair fruit conservation, which may be relevant for fresh consumption.

The high leaf K contents in peach may explain the low levels of leaf Ca contents, due to the occurrence of a cationic imbalance, as these ions compete for the same absorption site, a fact that was also observed by Reighard et al. (2013) in a nutritional research with *Prunus* rootstocks. As young trees, preferential allocation of Ca occurs in root formation, since the presence of this nutrient in the soil solution helps in a greater capacity to exploit soil volume (Havlin et al., 2014; Nava et al., 2016; Benati et al., 2021). This positive effect is known because the absorption of soil Ca occurs only in the youngest and not yet suberized root parts (Marschner, 2012), thus there is a need for continuous absorption of this nutrient to ensure adequate development of tree meristematic areas (Tagliavini & Scandellari 2013; Taiz et al., 2017).

Despite Mg being at high levels in the soil in both evaluated years, leaf Mg contents showed insufficient amounts. Such results may be related to the irregular distribution of rainfall, as the low soil moisture reduces the Mg supply through the mass flow to the root system (Taiz et al., 2017), which can induce deficiency, even with good availability of the soil nutrient, since there was no irrigation in the orchard. Also, as for Ca, possibly the competition for cations, mainly K, may have inhibited the absorption of Mg (Gransee & Führs, 2013).

For leaf Fe and Zn contents, most treatments showed levels below normal or insufficient, in both evaluated years (Cqfs-RS/SC, 2004), which may be related to the increase in pH in the soil surface, generally higher than 6.5 (Table 1), which tends to decrease the availability of these micronutrients (Abreu et al., 2007; Ernani 2016). According to Johnson (2008) and Marschner (2012), the main function of Fe in the tree is transfer energy during the photosynthesis and respiration process, while Zn acts in the auxins synthesis, however, the deficiency of both micronutrient becomes a problem in alkaline soils (pH between 7.0 and 8.5). Therefore, it is emphasized that insufficient leaf Fe contents found in this study may be related to the young tree stage, which possibly did not form a root system capable of exploring deeper soil layers where pH is lower. As for the leaf Mn levels, some treatments showed concentrations above normal, probably due to the greater efficiency of this nutrient uptake by the trees. Furthermore, it is possible that the use of fungicides containing Mn, commonly applied in peach orchards, may have contributed to obtaining sufficient Mn levels for most treatments, in both years of evaluation.

In both evaluated years, ‘Rigitano’ rootstock proved to be less efficient in B absorption, where its contents were classified as below normal. Boron has several functions in fruit trees, such as tissue lignification, sugar transport, cell wall structure, carbohydrate metabolism, among others (Marschner, 2012). The “cascade effect” of B deficiency on essential cellular processes leads to disruption of several metabolic pathways. In the second year, trees grafted on Clone 15, ‘Nemared’, ‘Ishtara’ and *P. mandshurica* showed lower than normal leaf B contents, that is, these genotypes may also have a lower B absorption capacity when soil B levels are lower, as was the case in the second year. For comparison among treatments (Table 5), trees on ‘Rigitano’ and Clone 15 selection stood out negatively in both consecutive years. ‘BRS-Kampai’ peach trees grafted onto these two rootstocks have low vigor, compact tree shape and shorter shoot internodes, characteristics influenced by the interspecific graft combination (Mayer et al., 2021), a fact that may be related to the lower capacity of these rootstocks to absorb and/or translocate B, possibly due to some degree of interspecific graft incompatibility.

Trees on ‘Tsukuba-3’, ‘Ishtara’, ‘Rosaflor’ and ‘Santa Rosa’ showed greater efficiency in Cu absorption, and the last three stood out compared to the other treatments evaluated. Jimenes et al. (2018) highlighted the ‘Sunraycer’/‘Ishtara’ combination with a high capacity for Cu absorption. However, for the soil conditions of Southern Brazil, temperate fruit trees rarely show symptoms of Cu deficiency, because soils present characteristics of high acidity, mainly in deep layer no corrected with lime and, consequently, greater availability of this nutrient, especially in the deeper soil layers that do not receive lime, but that can also be exploited by the deeper root system of fruit trees.

Finally, for this trial, cluster analysis was efficient and allowed separation of treatments in twelve groups. Some of these groups were composed of treatments genetically close to each other, however, other groups were formed by treatments that were distant or with different origins. Four groups were formed by a single treatment (‘Genovesa’, México F1, ‘Rosaflor’ and *P. mandshurica*). Surprisingly, ‘Capdeboscq’, ‘Aldrighi’ and Tardio-01 selection (all *P. persica*, being ancient genotypes from southern Brazil), were found in three completely different clusters. Therefore, it can be seen that cluster analysis of rootstocks considering variables measured in the scion can be useful in some cases, but it should not be the only way to analyse similar rootstocks.

Conclusions

Leaf contents of P, K, Ca, Mg, B, Cu, Mn and Zn are influenced by the scion/rootstock combinations and own-rooted ‘Jade’ trees tested, in both evaluated years.

The tested treatments changed agronomic interpretation classes of all macro and micronutrients evaluated.

In general, for macronutrients, ‘Flordaguard’, De Guia, Tardio-01 selection as rootstocks and the own-rooted ‘Jade’ trees stood out, with leaf contents similar or even higher than trees grafted on ‘Capdeboscq’ and ‘Aldrighi’; for micronutrients, trees on the interspecific hybrids GxN.9, ‘Ishtara’ and ‘Santa Rosa’ plum stood out, which presented higher leaf contents.

From a nutritional point of view, own-rooted

‘Jade’ peach trees did not present any limitations.

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