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Yield efficiency for nine apple cultivars grafted on two rootstocks

Eficiência produtiva de nove cultivares de macieira sobre dois porta-enxertos

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ABSTRACT

Currently, using smaller trees is one of the most important trends in apple cultivation. It is expected that reduced size plants produce lower amount of fruit, but with high yield and yield efficiency. The aim of this study was to evaluate the yield efficiency (YE) of nine apple tree cultivars, grafted on two rootstocks, from the second to the seventh year after planting. The YE indexes oscillated from one to the other year, regardless of rootstock. Correlations between YE and yield per tree and between YE and trunk cross sectional area (TCSA) confirmed that efficiency can be increased by the production increment or by the plant's vigor reduction. The usefulness of cumulative YE (ΣYE) is highlighted to compare apple tree cultivars after the third year of production. The highest ΣYE indexes were observed for 'Royal Gala' and 'Baigent', on M-9 rootstock, and for 'Gala Real' and 'Maxi-Gala', on Marubakaido/M-9 rootstock.

Key words: ***Malus x domestica***, *M-9, Marubakaido, production, vigor*.

RESUMO

A utilização de árvores de pequeno porte é uma das mais importantes tendências na cultura da macieira na atualidade. É esperado que plantas de tamanho reduzido produzam menor quantidade de frutos, mas exibam produtividade e eficiência produtiva elevadas. O objetivo do trabalho foi avaliar a eficiência produtiva (EP) de nove cultivares de macieira, enxertadas sobre dois porta-enxertos, do segundo ao sétimo ano após o plantio. Os índices de EP oscilaram de um ano para outro, independentemente do porta-enxerto utilizado. As correlações entre EP e produção por planta e entre EP e a área da secção transversal do tronco (ATC) confirmam que a eficiência pode ser incrementada pelo aumento da produção ou pela redução do vigor da planta. É ressaltada a validade do uso da eficiência produtiva acumulada (EPA) para comparação de cultivares de macieira após o terceiro ano de produção. Os maiores índices de EPA foram determinados para 'Royal Gala' e 'Baigent', no porta-enxerto M-9, e para 'Gala Real' e 'Maxi-Gala', no porta-enxerto Marubakaido/M-9.

Palavras-chave: ***Malus x domestica***, *M-9, Marubakaido, produção, vigor*.

INTRODUCTION

Currently, planting trees grafted on dwarfing rootstock is one of the most important trends in apple orchards. Small size trees, besides facilitating orchard management and harvest, allow implantation of high density orchards, and consequently high yields even in the initial years (WEBSTER & WERTHEIM, 2003; TWORKOSKI & MILLER, 2007; VERCAMMEN & GOMAND, 2011). Therefore, preference has been on dwarfing and semi-dwarfing rootstocks, which bear plants of size similar to those obtained by using rootstock M-9 (CRASSWELLER et al., 2001; GJAMOVSKI & KIPRIJANOVSKI, 2011).

Apple trees grafted on dwarfing and semi-dwarfing rootstocks usually produce larger fruit and have better yield efficiency compared to plants grafted on vigorous rootstocks (PERRY & BYLER, 2001; GJAMOVSKI & KIPRIJANOVSKI, 2011). However, they present poorer fixation on the ground and more sensitivity to hydric stress, due to their superficial rooting (DI VAIO et al., 2009). Apple trees grafted on vigorous rootstocks show better resistance to periods of hydric deficit and better ground fixation as the main advantages; whereas, a satisfactory tree anchoring is required for locations subjected to strong winds (DI VAIO et al., 2009). It

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might be mentioned as disadvantages the insufficient control on the plant growth and the production of small and late ripe fruits (DENARDI, 2006).

In order to control excessive growth of the plants when vigorous rootstocks are used, it is possible to use interstocks that work as development reducers (VERCAMMEN et al., 2007; VERCAMMEN & GOMAND, 2011). In Brazil, the use of interstocks over Marubakaido is common, because this rootstock is easy to propagate and it is has been recommended for replanting areas, as long as the soil does not contain ***Rosellinia necatrix***, to which it is very sensitive (DENARDI, 2006).

Rootstocks, in addition to affecting plant size, influence yield. Several trials with different combinations of scion/rootstock have shown increasing of plant size providing higher yield (FERREE et al., 1995; BARRITT et al., 1996; KOSINA, 2010), but lowered yield per unit of area and yield efficiency (BARRITT et al., 1997; GJAMOVSKI & KIPRIJANOVSKI, 2011).

Yield efficiency (YE) and cumulative YE (ΣYE) indexes, both expressed in kg cm^{-2} or g cm^{-2} of the trunk cross sectional area (TCSA), are the most utilized metrics to compare plants of different sizes in trials designed to evaluate rootstocks, planting densities, training systems and growth regulators (LOMBARD et al., 1988). YE allows for comparing annual results, whereas ΣYE evaluates long term effects, such as cumulative yield over several years, depending on final TCSA. Application of such indexes in trials of cultivars competition, alongside evaluation characteristics, such as phenological performance, yield's precocity and regularity, productivity, resistance to pest and diseases and fruit quality provide subsidies to the correct screening of cultivars.

The aim of this study lies on the comparison of nine apple cultivars, grafted on rootstock M-9 and on the combination of Marubakaido/M-9, concerning to yield efficiency throughout a six-year period.

MATERIALS AND METHODS

Data used in this study were obtained from two experimental side by side orchards established in 2006 at the Temperate Fruit Experimental Station/ Embrapa Grape and Wine, in Vacaria, RS (28º33' S, 50º57' W and 955m). The region's climate is temperate (Cfb1), according to Köppen (MORENO, 1961), and the soil aluminium Cambic Red-Yellow Latosol, according to STRECK et al. (2008). It is a deep, highly weathered, well drained and with good water retention capacity soil.

The orchards were compound of 'Baigent', 'Maxi-Gala', 'Gala Real', 'Royal Gala', 'Fuji Select', 'Fuji Suprema', 'Mishima', 'Daiane' and 'Cripps Pink' cultivars in a random blocks design, with three repetitions of ten plants per experimental unit. For each orchard, which corresponds to a one trial, a specific rootstock was used along with the usually recommended spacing: on rootstock M-9 (***Malus pumila***), 3.5m x 1.0m (2.857 plants ha^{-1}); and on Marubakaido (***M. prunifolia***) with interstock of M-9, 4.0m x 1.4m (1.785 plants ha^{-1}).

The correction of soil acidity and fertility was made in pre-planting according to the results of soil analysis. They held annually maintenance fertilization based on the recommendations for apple orchards. Pruning and training system used was the same adopted in commercial orchards in the region. Trees were conducted in the central leader system. In the first two years a minimum pruning was performed. On the planting year, flowers and fruits were removed. In order to break dormancy, there was a combined application of hydrogenated cyanamide (0.20 to 0.25%) and mineral oil (3.0 to 4.0%) every year, whose concentrations varied according to chilling hours. Thinning was manual, leaving one or two fruits per inflorescence.

Each year, at the end of the winter, trunk diameter measuring of all plants in each parcel took place. For all the plants grafted on M-9 measuring was carried out 10cm above the grafting union, and in Marubakaido/M-9 planted area measuring was carried out 10cm above the interstock union with the scion. From these data, it was determined the trunk cross sectional area (TCSA), expressed in cm^2. Yield (PROD), in kg $plant^{-1}$, was obtained from six seasons - 2008 to 2013. From these primary variables, YE was calculated by plot (cultivar i and block j) and year (k) that is:

$$YE_{ijk} = \frac{PROD_{ijk}}{TCSA_{ijk}}$$

where $PROD_{ijk}$ is the average yield per plant, in kg, of variety i, block j and year k and $TCSA_{ijk}$ is the average area of the trunk cross section, in cm^2, also determined by the parcel on each season. For experiments used here, i=1 to 9; j=1, 2, 3 and k=1 to 6. By simplifying and taking into consideration that the measurement was obtained per parcel, we can have the expression above without the indexes related to cultivar, block and year, which results in

$$YE = \frac{PROD}{TCSA}$$

Therefore, YE is a synthetic variable directly proportional to PROD and inversely proportional to TCSA.

Cumulative yield efficiency (ΣYE) of each plot at the end of the period of n seasons (n≤k), expressed in kg cm^{-2} of TCSA, was obtained according to formula:

$$YE = \frac{\sum_{k=1}^{n} PROD_{(ij)k}}{TCSA_{(ij)n}}$$

which can easily be written as

$$YE = \frac{\sum PROD}{TCSA_n}$$

where ΣPROD is the sum of annual average yield, in kg, of each parcel (cultivar i and block j), until year n; and $TCSA_n$ is the average area of the trunk cross section (in cm^2), of cultivar i and block j, in year n, where n=2 to 6. Note that in the first season ΣYE=YE.

The generated variables, YE and ΣYE, associated to varieties, were obtained according to experimental scheme of original variables, that is, two trials corresponding to rootstocks, both in random outlining blocks, with repeated measures for year. A multivariate analysis of variance of YE, PROD and TCSA was carried out in the same model, in order to obtain partial correlations between index and productivity averages and plant vigor. To compare cultivars, analysis of variance (anova) of ΣYE was carried out per rootstock. A joint anova for rootstock was carried out to verify differences amongst them. ΣYE treatment averages during the last season were compared by the Scott-Knott test.

RESULTS AND DISCUSSION

The cultivars showed some fluctuations in YE throughout the six-year evaluation period (Table 1). Anova for each experiment indicated effect of variety and year, and the interaction of both (P<0.001). However, the variable YE restricts itself to attribute a measure of efficiency to each material every year. It is a point in time measure of comparison per cultivar, specific to season, which is affected by production alternation and by higher or lower trunk growth. It is not a measure that should subsidy changes in orchard management from one year to other or choosing another cultivar for a new orchard, for instance. Once anova is applied for each trial to obtain pure correlations, that is, cultivars, blocks and season effects are removed, demonstrating a strong positive correlation between YE and

Table 1 - Yield efficiency of 2008 to 2013 seasons and final ΣYE (year 2013) of nine apple tree cultivars grafted on two rootstocks (average of three repetitions). Vacaria, RS.

Cultivar	Season						ΣYE_6 (kg cm^{-2})
	2008	2009	2010	2011	2012	2013	
Rootstock M-9							
‘Royal Gala’	0.73	0.51	1.31	1.15	2.10	1.01	5.12 a*
‘Baigent’	0.72	0.56	1.57	1.19	1.79	1.06	4.81 a
‘Maxi-Gala’	0.42	0.44	1.28	1.10	1.82	1.06	4.45 b
‘Gala Real’	0.59	0.60	1.20	0.82	1.60	1.02	4.26 b
‘Cripps Pink’	0.48	1.08	1.25	1.19	1.00	1.18	4.21 b
‘Daiane’	0.71	1.16	1.32	1.35	0.80	1.11	4.05 b
‘Fuji Suprema’	0.28	0.95	0.81	1.06	0.49	1.01	3.03 c
‘Fuji Select’	0.33	0.92	1.15	0.81	0.71	0.79	2.98 c
‘Mishima’	0.36	0.92	1.06	0.82	0.61	0.74	2.78 c
Rootstock Marubakaido/M-9							
‘Gala Real’	0.50	1.02	1.64	1.16	1.49	0.88	4.09 a
‘Maxi-Gala’	0.54	0.75	1.70	1.11	1.38	0.84	3.85 a
‘Baigent’	0.47	0.63	1.52	0.87	1.20	0.79	3.41 b
‘Royal Gala’	0.49	0.89	1.61	1.10	1.26	0.81	3.36 b
‘Daiane’	0.43	1.21	1.26	1.15	0.77	0.70	3.05 b
‘Mishima’	0.20	0.60	1.07	0.88	0.67	0.79	2.52 c
‘Cripps Pink’	0.32	1.05	0.98	0.88	0.56	0.72	2.51 c
‘Fuji Select’	0.20	0.79	0.95	0.83	0.63	0.62	2.22 c
‘Fuji Suprema’	0.27	1.16	0.60	0.77	0.50	0.53	2.21 c

*Identical letters, per rootstock, indicate similar cultivars according to Scott-Knott test (P≥0.05).

PROD (P<0.001) for both rootstocks (Figure 1 left). Negative correlation between YE and TCSA showed lower significance (Figure 1 right).

The ΣYE evolution on M-9 rootstock was uniform in the first four seasons for all the cultivars (Figure 2 left and Table 1). In the fifth and sixth seasons a significant increase was verified for ΣYE in cultivars of 'Gala' group. At the end of the six seasons, three group were formed. The first one with ΣYE from 4.81 to 5.12kg cm^{-2}, including 'Baigent' and 'Royal Gala'; the second one with ΣYE from 4.05 to 4.45kg cm^{-2}, including 'Daiane', 'Gala Real', 'Maxi-Gala' and 'Cripps Pink'; and the third group with ΣYE from 2.78 to 3.03kg cm^{-2}, including 'Mishima', 'Fuji Select' and 'Fuji Supreme'. Conversely, on Marubakaido/M-9 rootstock the ΣYE evolution was uniform only in the first two seasons. From 2010 onwards, a discrimination among cultivars was observed (Figure 2 right). At the last year, three groups were formed. The first one with ΣYE from 3.85 to 4.09kg cm^{-2}, including 'Gala Real' and 'Maxi-Gala'; the second one with ΣYE from 3.95 to 3.41kg cm^{-2}, including 'Baigent', 'Daiane' and 'Royal Gala'; and the third group with ΣYE from 2.21 to 2.52kg cm^{-2}, including 'Mishima', 'Crips Pink', 'Fuji Select' and 'Fuji Suprema' (Table 1).

Cultivars of 'Gala' group showed ΣYE from 3.56 to 4.19kg cm^{-2} in the fifth season, which were higher than values from 2.29 to 3.01kg cm^{-2} determined for 'Imperial Gala'/M-9 (PERRY & BYLER, 2001). Indexes obtained for cultivars of group 'Fuji'/M-9, from 2.78kg cm^{-2} to 3.02kg cm^{-2}, were higher than those established for 'Fuji' (2.14kg cm^{-2}) by CRASSWELLER et al. (2005) and for 'Fuji Naga-fu 2' (1.72kg cm^{-2}) and 'Fuji Naga-fu 6' (1.83kg cm^{-2}) by MILATOVIĆ & DUROVIĆ (2012).

As yield efficiency is an index that depends on the plant's growth and its productivity, it is possible to observe the situation in which cultivars have satisfactory yields and high TCSA values, resulting in low values of YE. Examples of such cases are the vigorous cultivars 'Mishima', 'Fuji Select' and 'Fuji Suprema'. Conversely, situations of not so high yields can occur, which when relativized to low values of TCSA, that is, in plants with lower vigor, result in high indexes of yield efficiency. 'Galaxy', 'Royal Gala' and

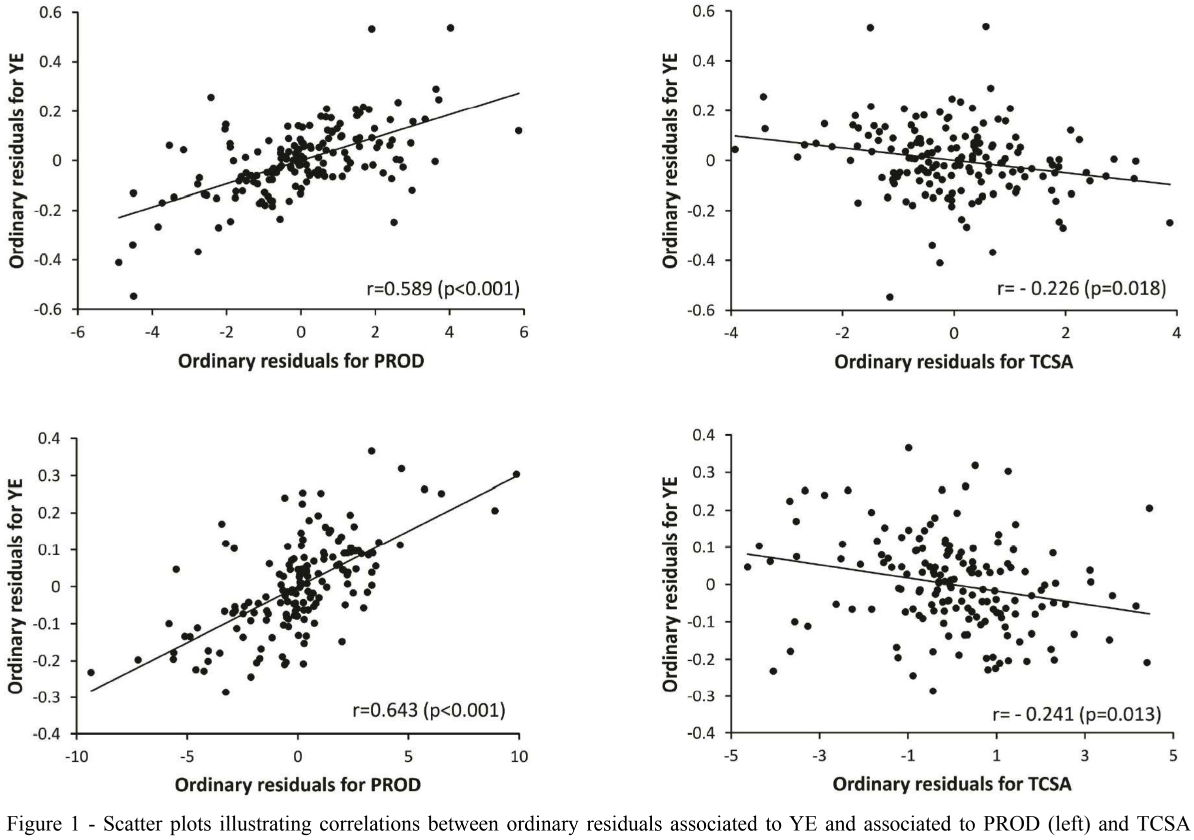

Figure 1 - Scatter plots illustrating correlations between ordinary residuals associated to YE and associated to PROD (left) and TCSA (right), based on random blocks model (nine apple cultivars and three repetitions) with repeated measurements (six seasons), on rootstock M-9 (above) and Marubakaido/M-9 (below).

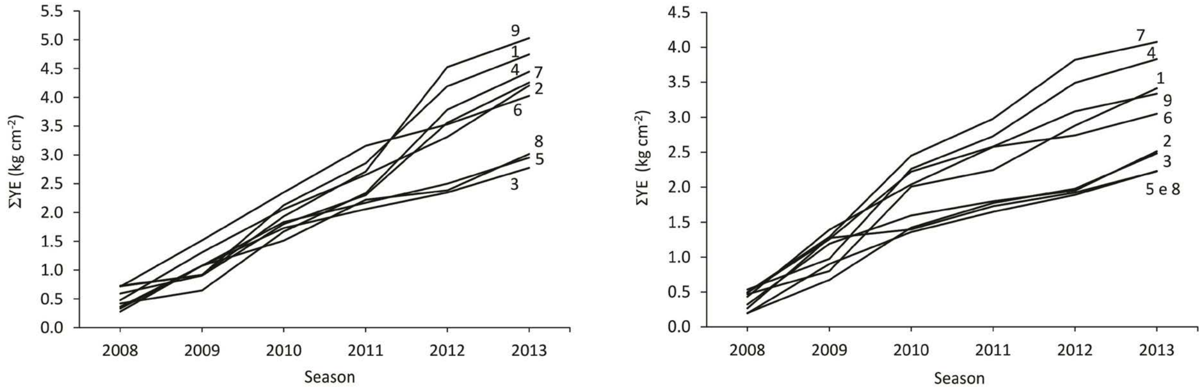

Figure 2 - ΣYE of nine apple cultivars on rootstock M-9 (left) and Marubakaido/M-9 (right), throughout six seasons. Legend: (1) ‘Baigent’, (2) ‘Cripps Pink’, (3) ‘Mishima’, (4) ‘Maxi-Gala’, (5) ‘Fuji Select’, (6) ‘Daiane’, (7) ‘Gala Real’, (8) ‘Fuji Suprema’, and (9) ‘Royal Gala’.

‘Gala Real’ can be mentioned as examples. Although it should not be used as the only evaluation criterion, the ΣYE is an important index to differentiate cultivars performance in the adult phase. In commercial orchards, ΣYE observation can help for the decision-making in at least three aspects: (1) scion and rootstock choice in new planting, (2) in specific replanting because of plants loss due to diseases or other factors, where space for the adult plant is already defined, and (3) regarding management practices in the orchard, such as fertilization, pruning and thinning.

Final ΣYE analysis (sixth season) showed high significance of cultivar effect, in both rootstocks ($p<0.001$). The discrimination of sum squares for cultivar (Table 1) showed higher efficiency for ‘Royal Gala’ and ‘Baigent’ in rootstock M-9, and ‘Gala Real’ and ‘Maxi-Gala’ in combination with Marubakaido/M-9. Cultivars of ‘Fuji’ group showed lower ΣYE values in both rootstocks. ‘Cripps Pink’ grafted on Marubakaido/M-9 showed ΣYE similar to ‘Fuji’ varieties, ascribing the low determined indexes to the plants’ high vigor. MILATOVIĆ & DUROVIĆ (2012) also determined lower efficiency in ‘Fuji’ cultivar in relation to ‘Gala’ types, whereas CRASSWELLER et al. (2005) observed the opposite.

Results show higher yield efficiency can be achieved by increasing in yield per tree or by means of vigor control, obtained by using high quality nursery trees, rootstocks with good affinity with scion cultivar, tree density adequacy and correct vegetative canopy management.

Joint anova for rootstock, showed high significance for all effects in the model ($P<0.001$): main effects rootstock and cultivar are significant; there is influence of year over rootstock and over cultivar (indicated by double interactions year x rootstock and year x cultivar) and over the interaction of two factors (triple interaction year x rootstock x cultivar). On unfolding the triple interaction effect, it was possible to observe that, at the end of the six-year period evaluation, yield efficiency was significantly higher on M-9 ($p<0.01$) for most cultivars. Exceptions were ‘Gala Real’, ‘Maxi-Gala’ and ‘Mishima’, which showed the same final efficiency on both rootstocks.

CONCLUSION

Yield efficiency indexes of apple tree cultivars oscillate from one year to the other, regardless of rootstock used, in response to production and vigor variations. ‘Royal Gala’ and ‘Baigent’, on rootstock M-9, and ‘Gala Real’ and ‘Maxi-Gala’, on rootstock Marubakaido/M-9, showed higher cumulative yield efficiency indexes amongst tested combinations. Rootstock M-9 provides higher cumulative yield efficiency.

The YE and ΣYE indexes serve as indicators for decision-making concerning orchard management in terms of yield increase or reduction of plant vigor. The YE and ΣYE are complementary indexes in comparative analysis amongst different genetic materials or for trials which treatments may influence yield or vegetative growth or plant vigor measures. These measurements, when obtained in experimental outlining conditions, meet all requisites to use analysis of variance.

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