INFLUENCE OF DIFFERENT ROOTSTOCKS ON THE VEGETATIVE AND REPRODUCTIVE PERFORMANCE OF *VITIS VINIFERA* L. MALBEC UNDER IRRIGATED CONDITIONS

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Abstract

Aims: A trial of cv. Malbec grafted to six different rootstocks (Harmony, SO4, 1103 P, 140 Ru, 3309 C and Cereza) and own rooted cv. Malbec (ORMa) was carried out with the aim to study the influence of rootstock on the vegetative and reproductive performance of cv. Malbec. Another objective was to study the relationship between below ground (i.e., rootstock) and above ground (i.e., scion) growth under irrigated conditions, typical of Argentine viticulture.

Methods and results: Four groups of rootstocks could be distinguished according to their vegetative and reproductive performance. The first group (Cereza and 3309 C, as ORMa) showed intermediate yield and high vegetative expression (VE). The second group (SO4 and 1103 P) was characterized by high yield and intermediate VE. The third group (140 Ru) displayed intermediate yield and low VE. Finally, the fourth group (Harmony) showed low yield and low VE. 140 Ru showed the highest number of roots, while 1103 P, SO4 and Harmony showed the lowest number. Harmony showed a greater skin to berry ratio than 1103 P and a lower berry weight (1.56 g) than the rest of the treatments (1.7 g on average).

Conclusion: Rootstocks influenced the biomass partitioning between leaves, grapes and roots: 140 Ru promoted root and reproductive development; Cereza, 3309 C and ORMa promoted vegetative development; SO4 and 1103 P promoted grape yield; and Harmony promoted root development.

Significance and impact of the study: The absence of a general behavior pattern highlights the need to accurately assess the performance of each rootstock for each zone and each *Vitis* variety, in order to choose the most appropriate scion-rootstock combination.

Keywords: root density, source-sink relations, vegetative expression, vigor, yield

Résumé

Objectif de l'étude: Afin d'étudier l'influence du porte-greffe sur le comportement végétatif et reproductif du Malbec, un essai de Malbec greffé sur différents porte-greffes (Harmony, SO4, 1103 P, 140 Ru, 3309 C et Cereza) et sur ses propres racines (ORMa) a été établi. De plus, les relations entre la partie aérienne (i. e., greffon) et la partie racinaire (i. e., porte-greffe) ont été étudiées dans une situation d'irrigation, typique de la viticulture argentine.

Méthodes et résultats: Quatre groupes de porte-greffe ont été distingués selon leur comportement végétatif et reproductif. Le premier groupe (Cereza et 3309 C, ainsi que ORMa) s'est caractérisé par une expression végétative (VE) élevée et un rendement intermédiaire. Le deuxième (SO4 et 1103 P) s'est caractérisé par un rendement élevé et une VE intermédiaire. Le troisième (140 Ru) a montré un rendement intermédiaire et une VE basse. Le quatrième (Harmony) a montré un rendement et une VE bas. 140 Ru a eu le plus grand nombre de racines et 1103 P, SO4 et Harmony ont eu le plus petit. Harmony a eu un plus grand rapport pellicule/pulpe que 1103 P et un poids des baies plus petit (1,56 g) que le reste des traitements (1,7 g en moyenne).

Conclusion: Les porte-greffes influencent la partition de biomasse entre feuilles, baies et racines. 140 Ru a privilégié le développement du système racinaire et reproductif; Cereza, 3309 C et ORMa ont privilégié le développement végétatif; SO4 et 1103 P ont favorisé la production de raisin; et Harmony a privilégié le développement du système racinaire.

Significativité et impact de cette étude: L'absence d'un modèle général de comportement souligne la nécessité de connaître avec précision le comportement de chaque porte-greffe pour chaque région et chaque variété de *Vitis*, pour ainsi pouvoir choisir la meilleure combinaison porte-greffe/greffon.

Mots-clés: densité racinaire, relation source puits, expression végétative, vigueur, rendement

Abbreviations: ORMa: own rooted cv. Malbec; VE: vegetative expression; PW: pruning weight; LA: leaf area; RI: Ravaz index

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INTRODUCTION

Traditionally, grapevine rootstocks have been used to control phylloxera (*Dactylosphaera vitifoliae*). Since the outbreak of this pest in Europe at the end of the XIX[th] century, growth of *Vitis vinifera* was only possible by grafting the scion onto resistant rootstocks.

Later studies showed that particular scion-rootstock combinations modify the source-sink relations, influencing vegetative expression, vigor, yield and vegetative-reproductive balance of the vines (Mattii *et al.*, 2005; Sampaio and Vasconcelos, 2005; Pouget, 1987). These factors are important because they correlate with fruit quality and crop sustainability. Specifically, vegetative-reproductive balance, e.g., leaf area to yield ratio, is associated with berry quality (Kliewer and Dokoozlian, 2005). An optimum level of this relationship ensures a higher berry quality (i.e., higher sugar and polyphenolic concentrations). On the other hand, Tandonnet *et al.* (2005) showed a relationship between above and below ground growth. By studying cv. Cabernet-Sauvignon grafted to several rootstocks, it was observed that a larger root system confers a greater above ground development (i.e., leaf area, pruning weight and yield). Therefore, in addition to conferring resistance to some biotic factors, rootstocks could also be used to control vegetative expression and yield, thus optimizing berry composition.

Published works about rootstocks mainly refer to phylloxera-infested vineyards under non irrigated conditions. However, in Argentine, vineyards are irrigated and phylloxera is not an immediate threat. An evidence of this is that 95% of the vineyards are planted with ungrafted (own rooted) vines (INV, 2007). Because of this, there is a marked lack of local research on rootstock performance under irrigated conditions. Rodriguez *et al.* (1998) showed that SO4 induces higher yield and 1103 P induces higher vigor than 110 R, when they are grafted to cv. Cabernet-Sauvignon. In another study, it was observed that cv. Cabernet-Sauvignon vines grafted to Salt-Creek, SO4 and ungrafted vines were more vigorous than those grafted to 1613 C, Freedom and Harmony (Andreoni, 2005). In this context, no experiments were conducted on rootstock performance with cv. Malbec, which represents the main Argentinean red wine variety in terms of cultivated surface and wine volume exported (INV, 2005).

The aim of this work was to study the performance of cv. Malbec grafted to different rootstocks, with respect to vegetative-reproductive parameters and berry composition, under irrigated conditions in Argentine. Moreover, we aimed to study the relationship between below ground (i.e., rootstock) and above ground (i.e., scion) growth. The study was conducted in Lujan de Cuyo, Mendoza, for being the core zone of cv. Malbec. American hybrid rootstocks (3309 C, 1103 P, 140 Ru, SO4 and Harmony) were tested because they were the most locally spread at that time. *Vitis vinifera* cv. Cereza, empirically considered as resistant to nematodes and high salinity, was also studied. Considering that most of the Argentinean vineyards are planted with ungrafted vines, a control with own rooted cv. Malbec (ORMa) was also included in the study.

MATERIALS AND METHODS

I - Plant material and experimental design

A trial of cv. Malbec scions grafted onto different rootstocks was carried out in the Agricultural Experiment Station of INTA Mendoza, Lujan de Cuyo, Argentine (33° S; 68° O; 924 m above sea level) during the growing seasons 2006-2007 and 2007-2008. The treatments were Harmony, SO4, 1103 Paulsen (1103 P), 140 Ruggeri (140 Ru), 3309 Couderc (3309 C), cv. Cereza (*Vitis vinifera*) and own rooted cv. Malbec (ORMa). The rootstock material was from the California Certified Grape Stock (University of California-Davis, CA, USA) and the cv. Malbec material was from a bulk selection of Mendoza vineyards. The scions were grafted to rootstocks using the « omega » technique and the grafted plants were planted in 1999.

The experimental design was a 7 x 7 Latin square. Each of the 49 experimental units was composed of 4 vines (the 2 central ones were used for sampling).

The experimental plot was established on a deep Typic Torrifluvent soil (>1.50 m) with textures varying from sandy loam (clay 10%, silt 20%) to clay loam (clay 16%, silt 32%). It had medium to low salinity content, low levels of N and P and high levels of K. Prior to the evaluation of the trial, soil and root samples from each treatments were tested for nematode and phylloxera infestation.

The vines were trained to a vertical shoot-positionned trellis system, with row and vine spacing of 2.5 m and 1.5 m, respectively. The pruning system was a spur-pruned cordon. For all treatments, vines were pruned to 20 buds per kg of pruning weight, leaving between 16 and 24 buds per vine. The canopy was covered with an anti-hail net in order to prevent hail damage already observed in the previous season. The experimental plot was flood irrigated to field capacity whenever the midday leaf water potential (æMD) reached -1.1 MPa from budbreak to veraison and -1.4 MPa from veraison to harvest, taking into account the average æMD of all the treatments. Therefore, in each season, the field was irrigated nine times and a total of 675 mm of water was applied. Shoots were not trimmed in order to assess the « real » vegetative growth potential of the vines. For each season, all rootstocks were harvested on a single date.

Due to lack of vigor, measurements could not be done on the first row of the experimental plot during the first season (2006-2007), resulting in an unbalanced design that year (see data analysis).

2. Measured variables

a) Vegetative expression and vigor

Winter pruning weight per vine (PW) was used as an indicator of vegetative expression. Mean shoot weight per vine, calculated by dividing the PW by the number of shoots, was used as an indicator of vigor. In order to obtain total shoot length per vine, the length of the main and lateral shoots of each vine was measured during pruning. To obtain total leaf area per vine (LA), a sample of shoots was first collected from the border vines of all treatments. Then, the length of the main and lateral shoots was measured and the leaves were processed with a leaf area meter (C1-203/C1-203CA; CID, Wa, USA) to obtain their leaf area. Based on these measures, a regression model between LA and total shoot length (R^2= 0.84; data not shown) was calculated. Using this model, LA per vine could then be predicted from the total shoot length measured during pruning.

b) Yield and yield components

Shoots per vine and clusters per vine were counted before harvest. A sample of two clusters per vine was collected in order to get berry and stalk weights. Yield per vine (total berry weight) was measured during harvest. Clusters per shoot, cluster weight and berries per cluster were obtained by calculations.

c) Vegetative and reproductive balance

Ravaz index (yield to pruning weight ratio; RI) and crop load (LA to yield ratio) were calculated.

d) Root density and distribution

Roots were plotted using the profile wall method proposed by Bohn (Smart *et al.*, 2006). Trenches were dug at a distance of 0.1 m from the trunk. Two trenches (1 m x 1 m, 1 m deep) were dug per treatment, at both ends of the rows. Observations were done on the walls parallel and perpendicular to the vine row. After removing a thin layer of soil (4 mm) to uncover the roots, a grid composed of 9 squares of 10 cm x 10 cm was placed onto the walls to analyze. The number of roots of the different diameter classes (0-1 mm; 1-2 mm; 2-4 mm; 4-6 mm; > 6 mm) within each square was counted. Then, the total number of roots per square meter and for each diameter class was calculated. In order to analyze root distribution, the profile was divided in three levels (0-30, 30-60 and 60-90 cm deep) and the percentage of total roots and of each diameter class, for each level, was calculated.

e) Berry composition

Samples of 200 berries per plot were randomly collected during harvest to be analyzed. Berries were separated by diameter classes with a combination of sieves (7 to 17 mm with intervals of 2 mm). Mean berry weight was determined and the berries from the modal class were kept to measure the rest of the variables. Berries were divided into their components -skin, pulp, seeds-. Soluble solids (Brix) were measured with a refractometer (ATC-1E, ATAGO, Japan) and pH was measured with a potentiometer (ph 330/SET -1 WTW, Germany) from the milled pulp. Anthocyanins and total phenolics of the skins were measured by spectrophotometry UV-VIS (Riou and Asselin, 1996). Results of anthocyanins were expressed in mg kg-1 and in mg berry-1.

3. Data analysis

Variables were individually analyzed by analysis of variance (ANOVA). Due to the unbalanced design during the first year, ANOVA was performed by PROC MIXED program. Comparison between individual means was done by Tukey's test with a confidence level of 95%. When it was considered unnecessary to minimize type 1 error, LSD test (95% of confidence) was used. Only variables with homogeneity and normality assumption were analyzed by these procedures. The rest of the variables were analyzed with Friedman non parametric test at a confidence level of 95%. Additionally, variables were analyzed in pool by principal components analysis (PCA). For the PROC MIXED program, the statistic software SAS (v. 6.12; SAS Institute, Inc.) was used. The rest of the analyses were done by the statistic software InfoStat v.2007 p (InfoStat Group, Argentine).

RESULTS

1. Vegetative and reproductive performance of the vines

Rootstocks showed differences in vegetative, reproductive and balance features during both seasons. In general, as vines were not trimmed, all treatments showed high levels of LA and PW. In 2006-07, two groups were observed: one of large vines (ORMa, Cereza, 3309 C, 1103 P and SO4) with greater LA and PW, and one of small vines (Harmony) (Table 1). 140 Ru showed an intermediate position. In 2007-08, similar differences were observed.

With respect to grape yield, a more productive group (1103 P and SO4) and a less productive one (3309 C and Harmony) were observed in 2006-07 (Table 1). The other rootstocks showed intermediate yield (140 Ru> ORMa> Cereza) although ORMa and 140 Ru did not significantly differ from the high-yield group. In 2007-08, differences

Table 1 - Vegetative, reproductive and balance features of Malbec grafted to six rootstocks and own rooted, during two seasons: 2006-07 (n = 6) and 2007-08 (n = 7).

Rootstock	Leaf area (m^2 $vine^{-1}$)	Pruning weight (kg vine-1)	Yield (kg vine-1)	Ravaz index (Yield:Pruning weight)	Average shoot weight (g)
2006-2007					
ORMa	7.70 a	1.48 a	2.01 abc	1.28 bcd	80 a
Cereza	8.59 a	1.65 a	1.95 bcd	1.23 cd	84 ab
3309 C	7.12 a	1.37 a	1.55 cd	1.11 d	74 ab
1103 P	7.11 a	1.32 a	2.65 ab	2.12 a	63 abc
SO4	6.91 a	1.25 a	2.50 a	1.93 a	61 bcd
140 Ru	5.17 ab	0.91 ab	2.34 abc	2.35 a	56 cd
Harmony	4.49 b	0.79 b	1.29 d	1.79 abc	46 d
p value	0,0001	0,0001	0,0212	0,0011	0,0029
2007-2008					
ORMa	6.55 a	1.54 a	2.13 bc	1.52 ab	80 a
Cereza	6.70 a	1.57 a	1.57 c	1.20 b	71 a
3309 C	5.96 ab	1.32 a	2.13 bc	1.92 ab	62 ab
1103 P	6.63 a	1.46 a	2.90 ab	2.21 ab	64 ab
SO4	6.14 a	1.39 a	3.38 a	2.73 a	65 ab
140 Ru	4.62 bc	0.94 ab	2.27 abc	2.51 ab	50 bc
Harmony	4.00 c	0.77 b	1.22 c	1.88 ab	41 c
p value	0,0001	0,0001	0,0000	0,0219	0,0000

Different letters denote significant differences in Friedman test at $p \leq 0.05$, excepting yield, Ravaz index and average shoot weight in the 2007-08 season, which indicate differences in ANOVA and Tukey's test at $p \leq 0.05$.

between high-yield 1103 P and S04 and low-yield Harmony were the same as in the previous season, but the previously low-yield 3309 C was now significantly similar to 1103 P. On the other hand, ORMa differed from the high-yield group (it produced less than SO4) and Cereza joined the low yield group. 140 Ru showed an intermediate performance between the high and low yield groups.

Regarding vegetative-reproductive balance, all treatments showed low RI, explained in part by the high LA and the low yields (Table 1). In 2006-07, 1103 P, SO4 and 140 Ru promoted a more balanced vine than ORMa, Cereza and 3309 C. Harmony showed an intermediate position but with a better balance than 3309 C. In 2007-08, differences in vine balance occurred between SO4 (higher) and Cereza (lower), while the rest of the rootstocks showed an intermediate position. All rootstocks had values of crop load higher than 2 m^2 kg^{-1}. Differences in this variable were similar to those of RI, because both variables were highly correlated (R= -0.97).

Concerning vines' vigor (i.e., average shoot weight), in 2006-07, Harmony induced lower vigor than ORMa, Cereza, 3309 C and 1103 P. Besides, ORMa, Cereza and 3309 C induced higher vigor than 140 Ru. On the other side, ORMa's vigor was higher than the one induced by SO4. In 2007-08, Harmony promoted lower vigor than the rest of the rootstocks, except for 140 Ru. On the other hand, 140 Ru promoted lower vigor than ORMa and Cereza.

All treatments had low yields, probably due to hail damage from the previous season. Low yields could be explained by the low number of clusters per shoot (1.43 clusters per shoot on average) and the low number of berries per cluster (43 berries per cluster on average) (Table 2). Harmony showed the lowest yield, which could be explained, in part, by a low number of shoots per vine (as compared with Cereza, 1103 P and SO4), a low cluster weight (as compared with 1103 P, SO4 and 140 Ru), and a low berry weight.

The vegetative and reproductive features of each treatment could be better visualized by principal components analysis (PCA, Figure 1). In this analysis, the first two components explained 85% of the total variability. Component 1 (which explained 53% of

Table 2 - Malbec yield components over six rootstocks and own rooted. Average values of the two seasons (2006-07 and 2007-08), n = 13.

Rootstock	Shoots per vine	Clusters per shoot	Cluster weight (g)	Berries per cluster	Berry weight (g)
ORMa	19 bcd	1,37	72.97 bcd	41.62 abc	1.71 abc
Cereza	20 abc	1,34	61.44 d	34.55 c	1.69 abc
3309 C	20 abcd	1,5	65.65 cd	38.60 bc	1.66 bc
1103 P	22 a	1,45	92.63 ab	50.28 a	1.76 a
SO4	21 ab	1,57	93.52 a	51.62 a	1.75 a
140 Ru	18 cd	1,45	83.95 abc	49.31 ab	1.64 c
Harmony	17 d	1,3	57.07 d	36.33 c	1.56 d
p value Rootstock	0,0000	0,0913	0,0000	0,0000	0,0001
p value Rootstock. x Year	0,963	0,4552	0,0658	0,1134	

Different letters denote significant differences in ANOVA and Tukey's test at p ≤ 0.05, excepting berry weight, which denotes differences in Friedman test at p ≤ 0.05.

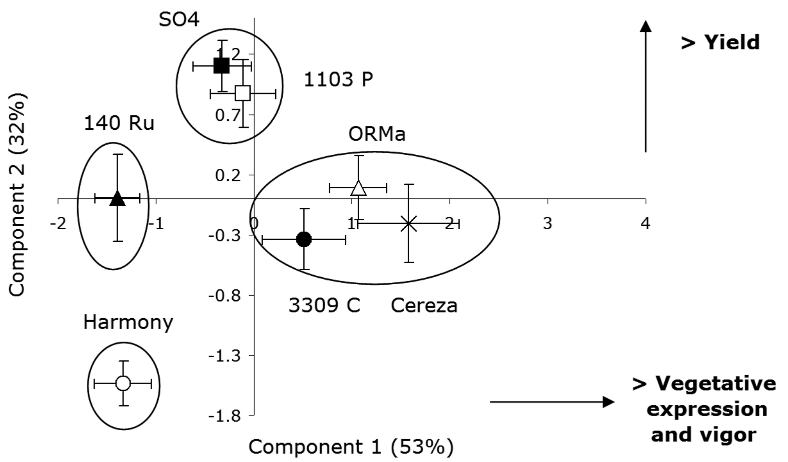

Figure 1 - Principal components analysis for vegetative and reproductive variables of Malbec grafted to six rootstocks and own rooted.
Arrows show main gradients. Bars mean standard errors. Average values of the two seasons (2006-07 and 2007-08), n = 13.

variability) was positively associated to LA, PW, total shoot length and average shoot weight; and was negatively associated to RI, representing mainly vine vegetative expression and vigor. Component 2 (which explained 32% of variability) was positively associated to yield and cluster weight; and was negatively correlated to crop load, representing mainly vine productivity.

PCA allowed to distinguish four groups of rootstocks according to their vegetative and reproductive performance. The first group was composed of ORMa, Cereza and 3309 C, with high vegetative expression and intermediate yield. The second group was composed of SO4 and 1103 P, with high yield and intermediate vegetative expression. The third group was composed of 140 Ru, with intermediate yield and low vegetative expression. Finally, the fourth group was composed of Harmony, with low yield and low vegetative expression (Figure 1). 1103 P and SO4 showed a trend toward a reproductive behavior, whereas ORMa, Cereza and 3309 C showed a trend toward a vegetative behavior.

With respect to nematodes, ORMa showed higher Meloidogyne sp. density in both roots and soil as compared with the hybrid rootstocks. On average, 7.5 larvaes were found in 10 g of roots in ORMa compared to 0.25 in rootstocks (p value = 0.0423). In the soil, 18 larvaes per kilo were found, on average, in ORMa, whereas 2 were found in rootstocks (p value = 0.0049). Phylloxera infestation was not detected.

When the root system of the vines was analyzed, 140 Ru showed the highest number of roots, while 1103 P, SO4 and Harmony showed the lowest number (Table 3).

Table 3 - Total root number and thinner roots (< 1 mm) of Malbec grafted to six rootstocks and own rooted. n = 2.

Rootstock	Total root number (roots m^{-2} soil profile)	Roots <1 mm (roots m^{-2} soil profile)
ORMa	661 abc	585 abc
Cereza	688 ab	615 ab
3309 C	687 ab	623 a
1103 P	575 c	508 cd
SO4	578 c	484 d
140 Ru	734 a	646 a
Harmony	595 bc	522 bcd
p value	0,0432	0,0309

Different letters denote significant differences in LSD test at p ≤ 0.05.

ORMa, Cereza and 3309 C did not differ from 140 Ru or Harmony. At the same time, ORMa did not differ from 1103 P or SO4. Observed differences in total roots were especially due to differences in thinner roots (0-1 mm). There were differences in total root number between rootstocks, but not in root distribution. For all rootstocks, most of the total roots (50.2%) were found in the first 30 cm of the soil. The second (30 to 60 cm) and third stratum (60 to 90 cm) contained 28.8% and 21% of total roots, respectively. This pattern was observed with few variations for all diameter classes (data not shown).

When yield:LA (i.e., the inverse of crop load) and roots:LA relations were calculated on the basis of standardized values (each value divided by the standard deviation), four groups of rootstocks could be established according to their performance (Figure 2): a first group composed of ORMa, Cereza and 3309, corresponding to large vines with few roots and few grapes in relation to their LA; a second group composed of 1103 P and SO4, similar to the first one regarding vine size and root number, but showing a more reproductive character (i.e., more grapes in relation to their LA); a third group composed of 140 Ru, promoting small vines with a high number of roots and grapes in relation to its LA; and a fourth group composed of Harmony, similar to the previous one with respect to vine size and root number, but with a lower yield with respect to its LA.

When expressing the vegetative and reproductive variables of each rootstock as relative difference with respect to ORMa, it was observed that Cereza was the only one that promoted a greater vegetative expression (+ 7% LA and PW), whereas all the American hybrid rootstocks produced lower vegetative expression than ORMa (Figure 3). 1103 P, SO4 and 140 Ru had higher yields than ORMa (+34%, +42% and 11%, respectively),

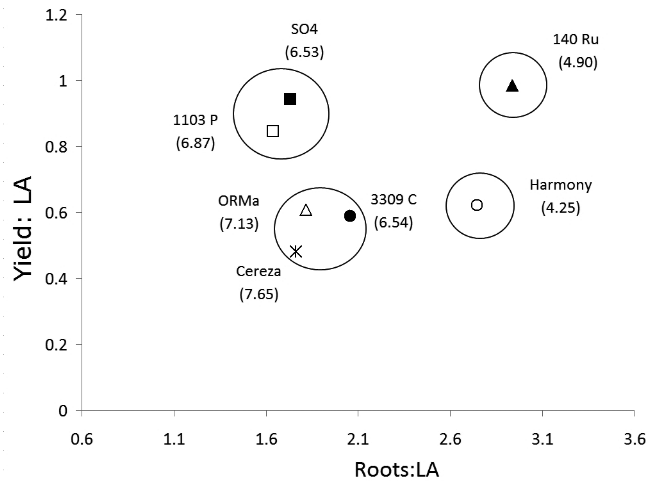

Figure 2 - Yield:LA vs. Roots:LA of Malbec grafted to six rootstocks and own rooted (relations were calculated with standardized values for each variable).
Average values of the two seasons (2006-07 and 2007-08), n = 13. Circle surfaces represent scaled LA. Numbers between parentheses show LA values.

but 1103 P and SO4 had a lower number of roots (-13%). On the contrary, 140 Ru had a higher number of roots (+11%) and produced less LA and PW (-31% and -39%, respectively) than ORMa. Rootstocks that had a lower yield as compared with ORMa were Cereza, 3309 C and Harmony (-15%, -11% and -39%, respectively). Cereza and 3309 C also had little more roots than ORMa (+4%). Harmony had lower LA, PW and root number than ORMa (-40% LA, -48% PW and -10% roots).

2. Berry composition

In 2006-07, differences in the skin to berry ratio were observed between 1103 P (78) and Harmony (91) (Table 4). The rest of the rootstocks showed an

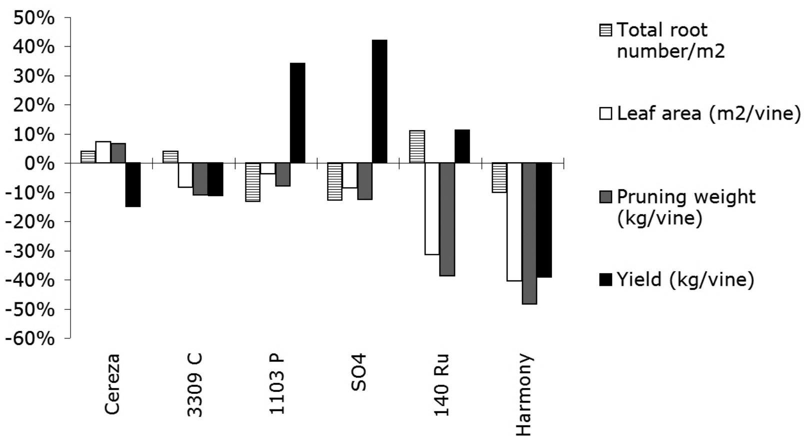

Figure 3 - Relative differences of the vegetative and reproductive variables of each rootstock compared with Malbec own rooted. Average values of the two seasons (2006-07 and 2007-08), n = 13.

intermediate position. The Brix values measured in Cereza were smaller than those of 3309 C, SO4, 140 Ru and Harmony. There were no differences in pH, anthocyanins and total polyphenols between the different treatments. The absence of differences in anthocyanin concentration could be due to a lack of differences in their biosynthesis (1.54 mg per berry in average, data not shown).

In 2007-08, the observed difference in the skin to berry ratio between 1103 P and Harmony was similar to that of the previous season (Table 4). Besides, 1103 P showed a lower skin to berry ratio as compared with ORMa, Cereza and 3309 C. Differences in Brix values were found between 3309 C (24.3) and 1103 P, SO4, 140 Ru and Harmony (23.7 on average). Harmony's pH value was higher than those of ORMa, Cereza, 3309 C and SO4, but these differences were minimal. As in the previous season, no differences in anthocyanins were found between the different rootstocks. Similarly, no differences were observed with respect to anthocyanin biosynthesis (data not shown). Harmony's total polyphenols were higher than those of Cereza, 1103 P and 140 Ru.

With respect to seeds, there were no differences in the seed to berry ratio in any of the two seasons (Table 4).

Different letters denote significant differences in ANOVA and Tukey's test at $p \leq 0.05$ for skin-berry ratio, °Brix 2007-08, pH 2006-07, anthocyanins and total polyphenols 2007-08. Seed-berry ratio, °Brix 2006-07, pH 2007-08, anthocyanins and total polyphenols 2006-07 denote differences in Friedman test at $p \leq 0.05$.

DISCUSSION

Observed differences between different rootstocks in terms of vegetative expression, vigor and biomass partitioning (between leaves, grapes and roots) are in agreement with the observations of several authors in different scion-rootstock combinations (Andrade *et al.*, 2005; Agut *et al.*, 2005; Tandonnet *et al.*, 2005). This finding reaffirms that rootstocks modify source-sink relations, influencing vines' vegetative and reproductive performance. On the other hand, results showed that American hybrid rootstocks displayed a higher control on vines' vegetative expression and vigor than Cereza (*Vitis vinifera*) or own rooted. This agrees with the results of Soar *et al.* (2006), who found a higher vegetative expression in ungrafted cv. Syrah vines as compared with grafted vines to different rootstocks, under no water deficit. Therefore, the use of rootstocks could be useful as an agronomic tool, if the aim is to improve the vegetative-reproductive balance of vines.

Some of the tested rootstocks did not perform as cited in literature: e.g., 1103 P, one of the most reproductive rootstock with cv. Malbec in this study, showed lower yield than other rootstocks when it was grafted to cv. Ruby Seedless (Ezzahouani and Williams, 1995). This outcome could suggest that there is an actual scion-rootstock interaction, which was previously observed by other authors (Clímaco *et al.*, 1999; Tandonnet *et al.*, 2005). Differences could also be due to interactions between environment and rootstock, since soil, weather and agronomic management conditions differed in the different studies. It should be pointed out that most of the literature refers to non irrigated conditions in the presence of phylloxera, while this study was done under irrigated conditions in the absence of the pest. This could explain why 3309 C showed an intermediate yield and high vigor, while it is considered as low yield and low vigor in Europe (Pouget, 1987). The same happened with Harmony, which showed low vigor with cv. Malbec in this study, while in South Australia it displayed an intermediate to high vigor when it was grafted to cv. Syrah and Chardonnay (Cirami *et al.*, 1984; McCarthy and Cirami, 1990). These differences in Harmony's behavior could be explained

Table 4 - Berry composition of Malbec grafted to six rootstocks and own rooted, during two seasons: 2006-07 (n = 6) and 2007-08 (n = 7).

Rootstock	Skin-berry ratio (g kg^{-1})	Seed-berry ratio (g kg^{-1})	Brix	pH	Anthocyanins (mg kg^{-1})	Total polyphenols (A_{280})
2006-2007						
ORMa	82 ab	32	23.5 cd	3,76	831	43
Cereza	82 ab	26	23.1 d	3,77	752	40
3309 C	89 ab	27	24.0 abc	3,87	892	44
1103 P	78 b	34	23.5 bcd	3,8	788	41
SO4	85 ab	30	24.0 abc	3,76	839	43
140 Ru	79 ab	30	24.1 a	3,89	844	43
Harmony	91 a	27	23.8 abc	3,84	808	47
p value	0,0001	0,1402	0,0135	0,168	0,0745	0,492
2007-2008						
ORMa	84 a	36	24.0 ab	3.98 e	1514	79 ab
Cereza	84 ab	41	24.0 ab	3.90 bcde	1347	72 bc
3309 C	80 bc	34	24.3 a	4.03 cde	1517	78 abc
1103 P	76 d	37	23.6 c	4.09 abcd	1327	71 bc
SO4	78 cd	35	23.8 bc	4.02 de	1409	73 ac
140 Ru	76 d	34	23.9 bc	4.08 ab	1327	70 c
Harmony	84 ab	36	23.6 c	4.14 a	1510	82 a
p value	0,0000	0,4148	0,0000	0,0052	0,1854	0,0003

by variation in the soil texture, as in this study the soil was heterogeneous, from sandy loam to clay loam, while in South Australia it was a sandy soil. Due to the lack of homogeneity of variance for some of the vegetative and reproductive variables in this study, a statistical analysis of the interactions between rootstocks (genotypes) and year (environment) could not be done. However, results analyzed by non parametric tests indicate that vine size (LA and PW) is a more steady character, with regard to environment, as compared to yield. The same was observed during eight seasons for Syrah grafted to 12 rootstocks (Agut *et al.*, 2005).

Low RI values in all treatments could be explained by a low yield and a high level of LA and PW. Hail damage from the previous season could be the cause of the low yield. This causal link was reported by other authors (Candolfi-Vasconcelos and Koblet, 1990), who concluded that defoliation reduced bud fertility in the following season. Besides, Argentinean vine-growers empirically observed that the damage caused by a hail storm may affect yield for more than a season. On the other hand, the absence of shoot topping could explain the high level of LA and PW.

With respect to root system, differences in root density between rootstocks, but not in their distribution, coincided with the observations of several authors (Williams and Smith, 1991; Smart *et al.*, 2006). 140 Ru had the highest root density in this study, as previously observed by Southey and Archer (1988) under water deficit conditions. However, under no water deficit conditions, 140 Ru had a small root density (Swanepoel and Southey, 1989), showing again an interaction between genotype and environment.

140 Ru promoted small vines with a high number of roots and grapes in relation to its LA. Its higher root system and its lower vegetative development could be related to its better adaptation to drought conditions (Carbonneau 1985; McCarthy *et al.*, 1997; Novello and de Palma, 1997; Clímaco *et al.*, 1998). Its higher root density would allow a better soil exploration and water uptake, and its lower LA would induce a lower transpiration rate of the vine, influencing on water use.

The relationship between above ground and below ground previously shown by Tandonnet *et al.* (2005) indicated that a higher root system confers a higher above ground development (i.e., leaf area, pruning weight and yield); however, this relationship was not observed for any of the rootstocks in this study. The later could suggest that the root system is not the only element that influences vine development and production. Other variables not analyzed in this trial could have had influence. For example, it was observed that the presence of wider xylem vessels in SO4 produced a higher hydraulic conductance and a higher vegetative development of the vine (Giorgessi *et al.*, 1996). In the present work, SO4 showed a similar performance (low root but high vegetative development).

The observed influence of rootstocks over berry composition partially agrees with other authors (i.e., skin to berry ratio, Brix, pH and total phenols; Agut *et al.*, 2005; Sampaio and Vasconcellos, 2005). The lack of differences in anthocyanin concentration or biosynthesis could be due to the fact that all rootstocks, even those of low vegetative expression, had a very high crop load (> 2 m^2 kg^{-1}). Kliewer and Dokoozlian (2005) observed that over 1.2 m^2 kg^{-1}, pigment concentration in berry does not increase. However, when qualitative differences appeared, they were insignificant, except for Harmony. This rootstock consistently yielded smaller berries, which were associated with smaller vines. This could have enological implications, because a higher skin to berry ratio is required to produce more concentrated red wines.

CONCLUSIONS

Grapevine rootstocks influenced biomass partitioning between leaves, grapes and roots, showing differences in both vegetative and reproductive performance. Some rootstocks promoted root and reproductive development over vegetative development (140 Ru), while others promoted the opposite (Cereza and 3309 C, the same as ORMa). On the other side, some as SO4 and 1103 P promoted grape yield over vegetative and root development. Others as Harmony promoted root over vegetative or grape yield. The absence of a general behavior pattern highlights the need to accurately assess the performance of each rootstock for each zone and each Vitis variety, in order to choose the most appropriate scion-rootstock combination.

The results obtained in this study allow us to give some preliminary rootstock use recommendations for cv. Malbec, under similar conditions of soil, weather and agronomical management. Harmony (i.e., low vegetative expression, low yield and small berries) can be interesting if the goal is a balanced crop, a high skin to berry ratio and concentrated wines. SO4 and 1103 P (i.e., high yield and low root density) can be recommended when the aim is high yields and water is not a limiting factor. Finally, 140 Ru (i.e., high root density and low LA) can be recommended as a potential rootstock to be used in water deficit conditions.

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