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Performance of 'Sunburst' sweet cherry grafted on different rootstocks

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SUMMARY
The field performance of CAB 6P, CAB 11E, 'Colt', GM 9 ('Inmil'), GM 61/1 ('Damil'), GM 79 ('Camil'), Masto de Montañana 9 (MM 9), MaxMa 14, MaxMa 97 and Sainte Lucie GF 64 (SL 64) rootstocks grafted with one sweet cherry cultivar (*P. avium* 'Sunburst'), were compared for the first nine years after planting. The orchard was located on a calcareous clay-loam soil, which was level-basin irrigated. While no trees of CAB 6P, 'Colt', 'Damil', MM 9, and MaxMa 97 rootstocks died, most of the trees on 'Inmil' and 'Camil' did die. 'Damil' proved to be the most dwarfing and low-yielding rootstock, whilst 'Colt', MM 9 and CAB 6P were the most invigorating rootstocks, although differences with CAB 11E and SL 64 by the ninth year after planting were not significant. An intermediate level of vigour, shown on MaxMa rootstocks, could indicate a semi-dwarfing potential for these selections. In general, *P. cerasus* rootstocks (CAB 6P, CAB 11E and MM 9) promoted greater cumulative yields and better yield efficiency than the other rootstocks. Leaf mineral analysis of trees showed element concentrations close to the optimum for the trees grafted on *P. cerasus* rootstocks, and they were better than for trees on 'Damil' and 'Colt'. Leaf chlorophyll concentration, estimated by SPAD readings, was also generally higher for the trees on *P. cerasus* rootstocks. According to our results, the *P. cerasus* selections seem to be the best adapted rootstocks for cherry cultivars in heavy and calcareous soil conditions, under flood irrigation. However, they had the highest number of root suckers. The growing conditions were not favourable for the cherry rootstocks 'Camil', 'Damil' and 'Inmil'.

The primary cherry rootstocks in use throughout the world have been, and still are, seedlings or clonal selections of *P. avium* L. and *P. mahaleb* L. The excess of vigour induced by these rootstocks, especially *P. avium*, has encouraged fruit breeders to produce a range of dwarfing rootstocks for cherries from within closely allied *Prunus* species or from hybrids between these species (Webster, 1981; Gruppe, 1985; Trefois, 1985; Edin, 1989). 'Colt', a hybrid rootstock (*P. avium* L. × *P. pseudocerasus* Lindl.), was produced at East Malling. It was released in the early 1970s, because scions grafted on it where shown to be slightly less vigourous and more precocious than trees on clones of *P. avium* such as F 12/1 (Webster, 1981). More recently, breeding and selection in Belgium has produced three dwarfing rootstocks, 'Inmil' (GM 9), 'Damil' (GM 69/1) and 'Camil' (GM 79), which are much more dwarfing than F 12/1 (Trefois, 1985).

Important objectives for breeders of cherry rootstocks have also included the adaptation to different soil types, good graft compatibility and more precocious and consistent cropping of high quality fruits. Soil is one of the most important factor affecting successful production in cherry-growing areas. Generally, *P. mahaleb*, *P. avium*, and *P. cerasus* are better adapted to light and well-drained soils, loam to clay loam soils, and heavy clay soils, respectively (Perry, 1987). In Spain and other Mediterranean countries, *P. mahaleb* (St. Lucie) and the clonal selection SL 64, are widely used as cherry rootstocks in gravelly, well-drained, droughty and calcareous soils. However, *P. mahaleb* is unsuitable on heavy soils or where waterlogging occurs (Breton *et al.*, 1972; Perry, 1987). In these conditions, selections derived with wild types of sour cherry (*P. cerasus* L.) could offer a better choice. Clones such as CAB 6P and CAB 11E have been selected at the University of Bologna from wild sour cherry populations growing in the Emilia-Romagna area of Italy (Loreti, 1994). Similarly, MM 9 was selected from a local sour cherry, named Masto de Montañana, traditionally used as a rootstock for sweet cherry at Zaragoza (Spain). This rootstock is propapagated by *in vitro* techniques and has a wide range of compatibility with sweet cherry scion cultivars (Cambra, 1979; Gella and Marín, 1990).

The rootstocks MaxMa 14 and MaxMa 97, presumed to be *P. avium* × *P. mahaleb* hybrids, were also selected by researchers and nurserymen searching for a good agronomic adaptation to different cherry growing areas and the control of tree vigour (Stebbins *et al.*, 1978; Stebbins and Cameron, 1984; Perry, 1987).

In this study, we report on the performance of the *Prunus* species and hybrid clones above-mentioned, as potential rootstocks for sweet cherry production in calcareous and heavy soil conditions. Rootstock behaviour was assessed in terms of survivability, vigour and yield characteristics, as well as influences on leaf mineral status, in the climatic conditions of Zaragoza, Spain.

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MATERIALS AND METHODS

Plant material

Eight clonal rootstocks were compared with 'Colt' (*P. avium* × *P. pseudocerasus*) and the selection of *P. mahaleb*: Sainte Lucie GF.64 (SL.64), as controls, in one trial planted in the winter of 1988–1989. They were grafted *in situ* with 'Sunburst' sweet cherry during the summer of 1989.

The rootstocks under evaluation included three sour cherry (*P. cerasus*) selections: CAB 6P, CAB 11E, and Masto de Montañana 9 (MM 9); one selection each of *P. dawyckensis*: GM 61/1 ('Damil') and *P. canescens*: GM 79 ('Camil'); a *P. incisa* × *P. serrula* hybrid: GM 9 ('Inmil'), and two other selections considered to be of *P. mahaleb* × *P. avium* parentage: MaxMa 14 and MaxMa 97.

Trial characteristics

The trial was carried out at the Estación Experimental de Aula Dei (Zaragoza, Spain) on calcareous soil, with 35% total calcium carbonate, 8% active lime, pH in water 8.0, and a clay-loam texture.

Trees were planted at 5.0 × 4.5 m, and allowed to develop naturally with minimum pruning throughout the experiment. The orchard was managed following the usual local procedures. The plot was level-basin irrigated every 12 d during the peak of the summer. The experiment was designed as randomized blocks with five single-tree replications for each scion/stock combination. Guard rows were used to preclude edge effects.

Tree survival and growth measurements

Tree health and survival were monitored throughout the trial and the incidence of rootstock suckering recorded in several seasons. Trunk girths were measured during the dormant season at 20 cm above the graft union, and the trunk cross-sectional area (TCA) was calculated. In 1997, tree vigour was also estimated based on tree height and canopy volume to assess the correlation with TCA. Tree crown volume was calculated using measurements of tree height and lateral spread.

Yield and fruit characteristics

For all the cropping years, starting in 1992, date of flowering, yield, and mean fruit weight per tree were recorded. Cumulative yield per tree and yield efficiency (cumulative yield in kilograms per tree per final TCA) of each scion/stock combination were computed from the harvest data.

In 1997, yield was much more abundant. During harvest, 50 mature fruits were sampled from each of five trees per combination, and the quality variables colour, soluble solids content (SS) and titratable acidity (TA) recorded. Concentration of SS (°Brix) was measured using an Atago digital refractometer from free-run fruit juice from each fruit of the 50 fruit sample. TA was determined on a homogenized sample of juice from the fruits and analysed according to A.O.A.C. (1990).

Chlorophyll analysis

The chlorophyll (Chl) concentration per unit leaf area was estimated in the field, using a SPAD 502 meter (Minolta Co., Osaka, Japan). After calibration, SPAD measurements were converted into Chl concentration per unit of leaf area (nmol Chl cm^{-2}). Thirty leaves per tree, from extension shoots located all around the crown, were measured with the SPAD to obtain an average leaf Chl concentration representative of the leaves belonging to the outer part of the tree canopy. Measurements were carried out at 30, 70, 110 and 140 d after full bloom (DAFB) in 1997. In addition, leaf dry weight per unit area (W/LA) was determined from samples of undamaged adult leaves from extension shoots of the scion that were collected at 30 and 110 DAFB. Fifty leaves per tree were sampled and their area and percentage moisture content recorded.

Mineral analysis

Leaf mineral element concentrations were determined in 1997 and 1998, i.e. in years 8 and 9 after grafting. Sampling was done at 110 DAFB (approximately six weeks after harvest). Leaf samples were collected from extension shoots of trees of five blocks, i.e. five single-tree replications of each graft combination. The mineral elements of the dried samples were measured using the methods of C.I.I. (1969) and C.I.I. *et al.* (1975). Total N was determined by Kjeldahl analysis; P was analysed by the phospho vanadate colorimetric method; K by atomic emission spectroscopy; and Ca, Mg, Fe, Mn, Cu and Zn by atomic absorption spectroscopy (Pye Unicam SP9).

Analysis of data

Data were evaluated by analysis of variance. When the F test was significant, means were separated by Duncan's test ($P \leq 0.05$). Values from dead trees were considered as missing data.

RESULTS AND DISCUSSION

Mortality and anomalous behaviour of trees

While no trees of CAB 6P, MM 9, MaxMa 97, 'Damil' and 'Colt' rootstocks died, most of the trees on 'Inmil' and 'Camil' died in the trial. In SL 64, CAB 11E and MaxMa 14, only one tree per rootstock was lost. Tree losses were distributed throughout the life of the trial, with the exception of 'Camil', where four trees died in 1990. Poor adaptation of some of the Grand Manil selections have also been reported in the cherry growing areas of Italy (De Salvador and Albertini, 1995). Substantial tree losses on *P. mahaleb*, SL 64, 'Colt' and other rootstocks have been reported for cherries grown on some sites (Mircetich *et al.*, 1976; Larsen *et al.*, 1987; Bononad *et al.*, 1988). For 'Colt', tree mortality has been attributed to its sensitivity to root asphyxia (Bononad *et al.*, 1988), although Claverie *et al.* (1985) achieved good results in heavy and wet soils using this rootstock. In the case of *P. mahaleb* and the clone SL 64, tree mortality has also been related to the sensitivity to root asphyxia and susceptibility to various root rot pathogens such as *Phytophthora* sp. or to 'Silver Leaf Disease' *Stereum purpureum* (Mircetich and Matheron, 1976; Bauman and Engel, 1986; Moreno *et al.*, 1996). In our work, the presence or absence of these pathogens was not evaluated.

For 'Damil', although death was not immediate, abnormal scion behaviour was observed, including

symptoms such as small leaves and fruits, yellowing leaves, early leaf fall and the senescence and death of shoots and branches. These symptoms recall the ill-health signs related by Herrero (1951) and Mosse (1962) with the "translocated" graft incompatibility. In contrast, good graft-compatibility of 'Sunburst' on 'Damil' has been reported in Belgium (Druart *et al.*, 1997). It is known that incompatibility problems can occur more frequently in warmer areas.

The tree lost on CAB 11E was broken off at the point of union during the first year of growth. Sometimes, the excessive growth rate of the scion during the year after grafting can cause breakage at the point of union. However, lack of graft-compatibility may also occur when sweet cherry is grafted on sour cherry (Feucht *et al.*, 1983).

Tree vigour

Due to their high mortality, vigour comparisons for trees on 'Camil' and 'Inmil' were discontinued after the second year of scion growth in the orchard.

Tree growth, as measured by TCA, was significantly affected by the rootstock (Figure 1). From 1995, TCA was always significantly greater on 'Colt', CAB 6P and MM 9, although differences were not significant when compared with CAB 11E and SL 64. The MaxMa 97 and MaxMa 14 rootstocks were intermediate in vigour, the latter not differing from CAB 11E and SL 64. From the TCA and canopy volume determinations (Table I), Maxma selections appear to have a semi-dwarfing potential. This behaviour is in accordance with the results of Stebbins and Cameron (1984) and Edin *et al.* (1989).

Damil was the most dwarfing rootstock. As mentioned, this is probably due to poor adaptation to the growing conditions and/or to some form of stress-exacerbated delayed graft incompatibility, as reported by Herrero (1976) and Webster and Lucas (1997) when different species are used as rootstock for sweet cherry.

In this trial, 'Colt' has proved to be among the most invigorating rootstocks. This is in contrast with the results of Perry (1987) and Bononad *et al.* (1988), who

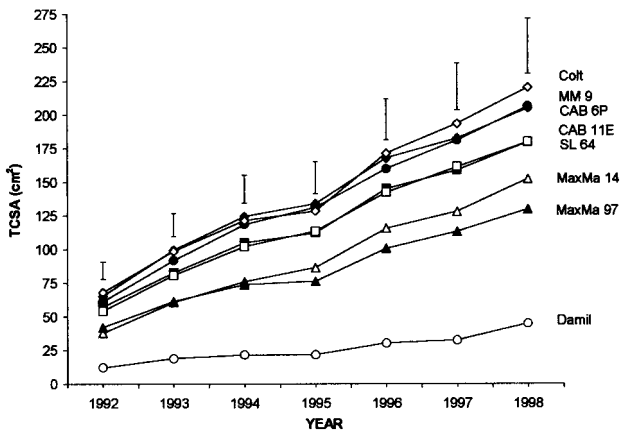

Fig. 1
Rootstock effects on trunk cross-sectional area (TCA) of 'Sunburst' sweet cherry from the third (1992) to the ninth (1998) year after grafting. Vertical lines indicate LSD ($P \leq 0.05$).

Table I
Tree height and canopy volume of 'Sunburst' sweet cherry trees, in the eight year after grafting

Rootstock	Tree height (m)	Canopy volume (m^3)
CAB 6P	3.9 c	13.5 d
CAB 11E	3.7 bc	11.8 cd
MM 9	4.0 c	12.2 cd
MaxMa 14	3.5 bc	9.1 bc
MaxMa 97	3.3 b	6.8 b
Damil	2.3 a	1.6 a
Colt	3.4 b	12.0 cd
SL 64	3.3 b	8.8 bc
SED	0.23	1.38

Mean separation within columns by Duncan's multiple range test at $P \leq 0.05$.

indicated that trees on 'Colt' are greatly reduced in vigour when grown in heavy and calcareous soils.

Positive correlations were found between TCA and tree height ($r = 0.79$, $P \leq 0.001$), as well as between TCA and canopy volume ($r = 0.88$, $P \leq 0.001$) in 1997, when different methods were applied to estimate tree vigour.

Fruit yield and quality

The number of flowers per tree was usually greatest on *P. cerasus* rootstocks, intermediate on the MaxMa selections or SL 64 and least on the scions grafted on 'Damil' and 'Colt' (data not shown). The date of full flowering was slightly affected by rootstocks. In general, *P. cerasus* and SL 64 advanced flowering 1 d in comparison with MaxMa selections and 2 d in comparison with 'Colt' and 'Damil' (data not shown).

In the first year of cropping, 1992, yields were insignificant, and there were no statistically significant treatment differences ($P \leq 0.05$). However, in the next cropping years, differences in precocity among rootstocks became evident, 'Damil' being the least efficient rootstock.

Most combinations bore their highest annual yields in 1997, and fruits were slightly smaller than in the first two cropping years or in the previous low-yielding year of 1996. In 1997, yields were highest on MM 9 (average of 80 kg per tree) and CAB 6P, although they did not differ significantly from CAB 11E. An intermediate level of yield was recorded on 'Colt' (53 kg per tree), SL 64 and the MaxMa selections.

The cumulative yields by year 9 after planting (Table II), were greatest on the *P. cerasus* rootstocks, especially MM 9 and CAB 6P. On the contrary, the lowest yields in most of the cropping years, and the lowest cumulative

Table II
Cumulative production and yield efficiency (cumulative yield per unit TCA) of 'Sunburst' sweet cherry grafted on different rootstocks, in the ninth year after grafting

Rootstock	Cumulative yield (kg/tree)	Yield efficiency (kg cm^{-2})
CAB 6P	169 d	0.84 cd
CAB 11E	158 cd	0.84 cd
MM 9	185 d	0.90 d
MaxMa 14	103 b	0.67 bc
MaxMa 97	101 b	0.77 cd
Damil	14 a	0.35 a
Colt	127 bc	0.59 b
SL 64	133 bc	0.74 bcd
SED	14.9	0.07

Mean separation within columns by Duncan's multiple range test at ($P \leq 0.05$).

TABLE III
Mean fruit weight (g) of 'Sunburst' sweet cherry grafted on different rootstocks

Rootstock	1992	1993	1994	Year 1995	1996	1997	1998
CAB 6P	12.2	11.0	8.6	8.1 bc	12.2	8.5 c	9.4 b
CAB 11E	12.3	10.8	8.0	7.0 ab	11.9	8.3 cb	9.5 b
MM 9	11.7	10.5	8.8	8.1 bc	11.2	8.0 cb	9.3 b
MaxMa 14	12.2	11.2	7.8	9.2 c	12.3	6.7 ab	9.6 b
MaxMa 97	11.6	11.1	7.2	6.4 a	12.3	6.6 ab	9.3 b
Damil	10.6	10.4	8.0	7.2 ab	11.8	5.2 a	9.6 b
Colt	12.2	11.3	7.6	8.1 bc	12.7	8.6 c	9.2 b
SL 64	12.0	10.7	7.7	8.0 bc	11.8	6.9 abc	7.5 a
SED	0.45	0.44	0.64	0.56	0.56	0.74	0.42

Mean separation within columns by Duncan's multiple range test at $P \leq 0.05$.

yield by the year 9 after planting, were recorded on 'Damil'. Cumulative yields were intermediate on SL 64, 'Colt' and the MaxMa selections, the first two not differing significantly from CAB 11E.

Yield efficiency was higher on MM 9, although differences were not significant when compared with CAB 6P, CAB 11E, MaxMa 97 and SL 64. Yield efficiency was significantly lower on 'Damil'. Also, yield efficiency was low on 'Colt', although this did not differ significantly from SL 64 and MaxMa 14.

Mean fruit weight was significantly affected by rootstock in 1995, 1997, and 1998 (Table III), when, in general, yields increased. In 1995, mean fruit weight was greater on MaxMa 14 than on all of the other roostocks, although differences were not significantly greater than MM 9, CAB 6P, SL 64 and 'Colt'. In this year, MaxMa 14 was one of the lowest yielding rootstocks. In 1997, the largest fruits were picked from the trees on 'Colt' and CAB 6P, although the differences were not statistically significant when compared with MM 9, CAB 11E and SL 64. The relatively high yielding trees on *P. cerasus* rootstocks (MM 9, CAB 6P and CAB 11E) had some of the largest fruits. That year, the lowest mean fruit weight was shown on 'Damil' although differences were not significant when compared with MaxMa 97, MaxMa 14 and SL 64. In 1998, the lowest mean fruit weight was shown on SL 64; while no significant differences were found among all the other rootstocks.

The highest fruit weight induced by the *P. cerasus* and 'Colt' rootstocks, especially for the high yielding years, is a desirable marketable trait since thinning is not usually practised in cherry production and attractive large fruits are an important component of sweet cherry fruit quality.

TABLE IV
Soluble solid content, pH and titratable acidity of fruits at harvest of 'Sunburst' sweet cherry grafted on different rootstocks, in the eighth year after grafting

Rootstock	Soluble solid content (°Brix)	pH	Titratable acidity (g malic acid/100ml)
CAB 6P	14.9 a	3.77	67.1 e
CAB 11E	15.1 a	3.75	67.8 e
MM 9	14.8 a	3.80	64.7 e
MaxMa 14	15.0 a	3.74	55.2 bc
MaxMa 97	15.1 a	3.79	52.1 b
Damil	14.8 a	3.74	48.2 a
Colt	15.8 b	3.72	58.3 cd
SL 64	15.0 a	3.76	60.7 d
SED	0.23	0.03	1.67

Mean separation within columns by Duncan's multiple range test at $P \leq 0.05$.

In 1997, complementary analyses of fruit characteristics revealed that roostock also had an effect on soluble solid content (SS) and titratable acidity (TA) of fruits (Table IV). Although the pH was not significantly affected ($P \leq 0.05$), the SS values were slightly greater on 'Colt' rootstock, whereas significant differences were not found among the other rootstocks. TA was highest on *P. cerasus* rootstocks. It was followed by SL.64 and 'Colt', but the TA of the latter did not differ from that on MaxMa 14. The least TA was found in fruits from trees on 'Damil', followed by those on the MaxMa selections. It will be interesting to confirm the influence of *P. cerasus* on TA since it could be related with their greater level of cropping for this year, or perhaps an effect of the sour cherry species per se. Nevertheless, all the values were considered as adequate, according to accepted quality criteria.

Root suckering

MM 9 consistently had the highest number of root suckers. 'Camil' was the next highest followed by CAB 11E, CAB 6P and 'Colt', whereas very few or no root suckers were observed from MaxMa rootstocks or SL 64 (data not shown). Excessive rootstock suckering is a common drawback observed with *P. cerasus* and hybrids with this species (Franken-Benbenek and Gruppe, 1985). The high level of suckering of 'Camil' was also mentioned by De Salvador and Albertini (1995).

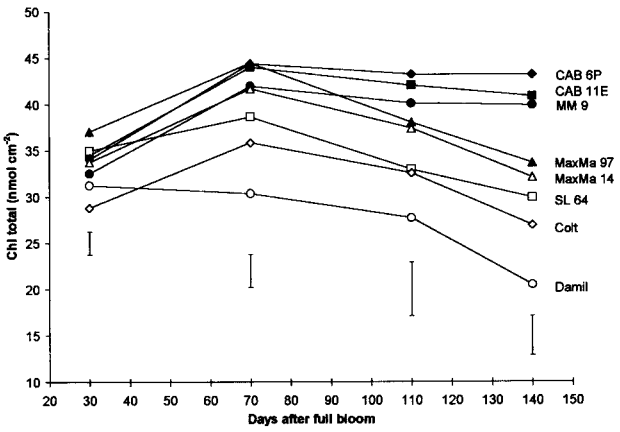

FIG. 2
Rootstock effects on the total chlorophyll concentration of 'Sunburst' sweet cherry leaves, at the 8th year after grafting. Vertical lines indicate LSD ($P \leq 0.05$).

Table V

Rootstock effects on leaf mineral element concentrations of 'Sunburst' sweet cherry 110 days after full bloom, at the eighth and ninth years after grafting. Results for N, P, K, Ca and Mg are expressed as percentage of dry matter and for Fe, Mn, and Zn, as mg kg^{-1}

	N		P		K		Ca		Mg	
Rootstock	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998
CAB 6P	1.90 bc	2.13 b	0.35 abc	0.46 b	2.02 b	2.15 de	2.45 ab	2.51 ab	0.38 ab	0.46 bc
CAB 11E	1.98 bcd	1.71 ab	0.38 bc	0.47 b	2.13 bc	2.04 d	2.54 abc	2.80 bc	0.42 ab	0.44 ab
MM 9	2.03 cd	2.11 b	0.41 c	0.49 b	2.42 c	2.32 e	2.77 bcd	2.60 ab	0.36 ab	0.40 ab
MaxMa 14	2.01 bcd	1.89 ab	0.42 c	0.47 b	1.87 b	2.15 de	2.94 cd	2.55 ab	0.63 cd	0.47 bcd
MaxMa 97	2.09 d	2.01 b	0.39 c	0.46 b	2.15 bc	2.33 e	2.17 a	2.11 a	0.33 a	0.36 a
Damil	2.00 bc	1.98 b	0.27 a	0.33 a	1.69 ab	1.53 b	2.74 bcd	2.47 ab	0.58 c	0.53 c
Colt	1.61 a	1.54 a	0.29 ab	0.31 a	1.11 a	1.20 a	3.67 e	3.65 d	0.73 d	0.70 e
SL 64	1.83 b	1.88 ab	0.42 c	0.51 b	1.99 bc	1.81 c	3.03 d	3.34 cd	0.50 bc	0.56 d
SED	0.08	0.19	0.04	0.03	0.29	0.10	0.19	0.24	0.07	0.04

Mean separation within columns by Duncan's multiple range test at $P \leqslant 0.05$.

	Fe		Mn		Zn	
Rootstock	1997	1998	1997	1998	1997	1998
CAB 6P	121.4	79.8	56.0 cd	59.2 c	23.4	36.8
CAB 11E	117.0	74.0	59.0 d	74.3 d	22.3	24.0
MM 9	110.6	74.2	51.0 cd	63.0 cd	22.8	29.6
MaxMa 14	127.0	73.5	48.8 c	44.8 ab	24.8	33.0
MaxMa 97	113.0	80.4	26.2 a	32.0 a	17.0	29.0
Damil	85.7	71.8	50.2 cd	64.2 cd	20.0	43.4
Colt	105.0	67.4	38.8 b	45.4 b	25.9	32.6
SL 64	108.0	75.0	53.3 cd	57.3 bc	17.5	29.3
SED	12.8	6.1	3.75	6.2	3.57	11.7

Mean separation within columns by Duncan's multiple range test at $P \leqslant 0.05$.

Leaf characteristics

Leaf yellowing was particularly observed when 'Sunburst' was grafted on 'Colt' and 'Damil'. In some years, less acute symptoms were observed when scions were grafted on SL 64 and MaxMa selections.

In 1997, to determine differences in the leaf chlorophyll concentration among rootstocks, SPAD readings in leaves of the cultivar were obtained (Figure 2). Leaf SPAD readings were generally higher for CAB 11E, CAB 6P and MM 9; intermediate for MaxMa rootstocks and lower for SL 64, 'Colt' and 'Damil'. These differences were more noticeable as the growing season advanced. In accordance with these SPAD readings, the leaves of trees on *P. cerasus* rootstocks remained dark green, late in the season.

The specific weight of leaves (W/LA) (gm^{-2}) and the percentage of leaf water content were not significantly ($P \leqslant 0.05$) influenced by the rootstock. Nevertheless, the mean fresh and dry leaf weight and the mean leaf area were lowest on 'Damil' trees, intermediate on MaxMa and SL.64 selections and highest on trees on 'Colt' and *P. cerasus* rootstocks (data not shown).

Mineral element concentration of leaves

To determine differences among rootstocks in the efficiency of nutrient uptake, the concentration of macro- and micronutrients in leaves of the cultivar were obtained in 1997 and 1998 (Table V). The results showed that most mineral elements were affected by the choice of rootstock.

Leaf N concentrations were significantly lower on 'Colt' trees and they showed deficiency, according to reference value (Leece, 1975). Nevertheless, the other rootstocks also had values slightly lower than optimum. Since yield and yield efficiency for 'Colt' trees was smaller or similar to SL 64 and *P. cerasus* rootstocks, the low leaf N concentration for trees on 'Colt' implies that this rootstock could be more susceptible to N deficiency in these conditions, as previously reported (Moreno *et al.*, 1996).

For both years, leaf P concentrations were higher than normal for all rootstocks, in relation to the values reported by Leece (1975). Soil P content analysis reflected that P fertilization might have been excessive in this soil (data not shown).

The lowest leaf K concentration was shown on 'Colt' and 'Damil' trees, showing values lower than optimum (Leece, 1975). Leaf K concentrations were considered to be adequate for the other rootstocks. In 1997 and 1998, 'Damil' was the lowest-yielding rootstock and 'Colt' yield was intermediate, implying that factors other than crop load were affecting leaf K. As previously reported (Moreno *et al.*, 1996; Neilsen and Kappel, 1996), the low K concentrations on 'Damil' and 'Colt' rootstocks might indicate that they could be susceptible to K deficiency, especially on sites with lower soil supplies of K.

Leaf Ca and Mg concentrations were in general highest on 'Colt' trees, especially when compared with MaxMa 97, *P. cerasus* rootstocks, 'Damil', and, to a lesser degree, with SL 64 and MaxMa 14. Nevertheless, most rootstocks showed values slightly higher than normal. This behaviour was more acute in 'Colt' trees showing values associated with an excessive concentration range (Leece, 1975). The tendency of trees on 'Colt' to higher leaf Ca concentrations has been previously reported (Moreno *et al.*, 1996; Neilsen and Kappel, 1996). Leaf Mg concentrations were consistently adequate for all rootstocks in both years.

Leaf Mn concentrations were generally lower for MaxMa 97, showing values lower than optimum (Leece, 1975). Similar tendency was observed for Colt and MaxMa 14. In addition, visual symptoms that indicate Mn deficiency were found on these rootstocks. It could be due to poor uptake of ths element in this type of soils. Manganese deficiency has been also reported for

cherry grown in calcareous soils (Moreno *et al.*, 1996; Akillioglu, 1997).

Leaf Na and Cu concentrations were consistently adequate (Leece, 1975) for all rootstocks both years (data not shown).

In 1997, leaf Fe concentration for 'Damil' was lower than normal (Leece, 1975) whereas the other rootstocks showed adequate values. Lower leaf Fe on 'Damil' trees were also reported by Neilsen and Kappel (1996) when comparing various rootstocks. In 1998, differences among rootstocks were not significant and leaf Fe concentrations were close to deficiency (Leece, 1975) for all rootstocks. Although Fe chlorosis can occur on cherry, there is little relationship between the disorder and leaf Fe concentration (Shear and Faust, 1980).

Although differences between rootstocks were not significant, leaf Zn concentrations of SL 64 and MaxMa 97 were close to deficiency values in 1997 (Leece, 1975). It is interesting to note the low Zn concentrations found on the SL 64 rootstock, as *P. mahaleb* had been reported to be less prone to Zn deficiency than other rootstocks (Breton *et al.*, 1972).

Trees on 'Damil', the most dwarfing rootstock, had lower leaf concentrations of most measured nutrients. These results are in good agreement with Neilsen and Kappel (1996) who suggested the possibility that inadequate nutrition was, in part, the cause of smaller tree size.

CONCLUSION

In our experiment, *P. cerasus* rootstocks showed a better adaptation to heavy and calcareous soils under flood irrigation conditions than the other rootstocks tested, since trees on these stocks showed a healthy appearance and an adequate level of growth. Moreover, the *P. cerasus* rootstocks profoundly and positively influenced the fruiting response of 'Sunburst' sweet cherry compared with the other rootstocks studied. Thus, the good adaptation of these rootstocks to the growing conditions probably favoured higher yields, vigour, yield efficiency and fruit weight. In addition, the levels of most minerals found in the leaves of 'Sunburst' trees growing on them were, in general terms, close to those considered optimum for the diagnosis of cherry tree nutrient status. However, the excessive number of root suckers is a strong drawback of these rootstocks.

The semi-dwarfing habit of MaxMa rootstocks may be of interest for reducing excessive growth of cherry cultivars and for increasing tree density when planting on more fertile, deep, and well-irrigated soils.

The growing conditions prevailing in this trial were not favourable for the Grand Manil rootstock selections, due to the high level of mortality showed by the trees grafted on 'Camil' and 'Inmil'. In addition, 'Damil' appears to dwarf excessively, probably due to its poor adaptation to the growing conditions and to inadequate uptake of mineral elements. This may also be due to some form of delayed graft-incompatibility, which could also be related to the soil conditions.

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