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Rootstock evaluation in intensive sweet cherry (*Prunus avium* L.) orchard

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Summary: During 2000 and 2007, rootstocks of different vigor have been tested in a high density sweet cherry orchard with 'Vera'® and 'Axel'® cultivars at 4 × 2 meter row and plant distance. Trees are trained to Hungarian Spindle with permanent basal branches; in the alley way naturally grown grass is managed by mowing. The first considerable fruiting was in 2004. Every year we measured trunk and canopy parameters of the trees, productivity and fruit size. Our conclusion is that the rootstocks considerably affected the growth, precocity, as well as tree and orchard productivity, fruit weight of sweet cherry cultivars, but these rootstock effects are modified by cultivars, except for growth vigor. According to our results Cema, SL 64, and Bogdány are vigorous rootstocks, moderate vigorous are MaxMa 97, Pi-Ku 1, and Tabel® Edabriz, Gisela® 5 and Prob are dwarfing rootstocks. Besides the precocious Gisela® 5 also mahaleb rootstocks CEMA, Bogdany and SL 64 showed considerable precocity, which can be explained by the larger bearing surface to the time of turning to bearing, and a similar or relative large density of burse shoots on fruiting branches. Cumulative yield of 'Axel'® was the highest on Bogdány and on Cema, contrary to Gisela® 5, which produced only 50% of the previous ones. Cumulative yield of 'Vera'® was the highest on SL 64, and no significant difference was found, compared to trees on rootstocks Cema, Bogdány and Pi-Ku 1. Cumulative yield production of trees was smaller on Gisela® 5, Prob, MaxMa 97 and Tabel® Edabriz rootstocks. Corresponding to the literature data of yield efficiency calculated on TCSA basis was highest on Gisela® 5 rootstock, but the efficiency calculated on canopy volume of 'Axel'® trees was similarly high on CEMA and Bogdány, and that of 'Vera'® trees relatively high on CEMA, Bogdány, SL 64 and PiKu 1 rootstocks. When calculating orchard efficiency at spacing 4 × 2 meters (1250 tree/ha), we received highest yield values on Bogdány, CEMA, SL 64, and PiKu 1 rootstocks, with large fruit weight. Rootstocks also affect fruit weight. We measured the largest fruit weight on trees on Bogdány.

Key words: bearing surface, clonal mahaleb rootstocks, fruit weight, growth vigor, orchard efficiency, precocity, *Prunus mahaleb* L. seedlings, *Prunus* hybrids, yield efficiency

Introduction

Over decades there was a common belief of sweet cherry growers and rootstock breeders that the lack of dwarfing rootstocks hindered the development of intensive orchards. So the main breeding objective was to produce dwarfing rootstocks (*Webster,* 1980, 1998; *Gruppe,* 1984; *Callesen,* 1998). In contrary *Zahn* (1990, 1996) recommended in his high density orchard system for sweet cherry both vigorous and dwarfing rootstocks.

Now we have a complete scale of growth vigor of cherry rootstocks. There are also high density orchards on different vigor of rootstocks, from dwarfing ones to standard rootstocks. Authors from North- and North-West-Europe and partly from North-America for high density orchard systems recommend dwarfing rootstocks like Weiroot 154, 158, Gisela® 5 or P-HL-A or Tabel® Edabriz (*Vogel,* 1995; *Walther & Franken-Bembenek,* 1998; *Balmer & Blanke,* 2005; *Franken–Bembenek,* 2005; *Stehr,* 2005; *Charlot* et al., 2005; *Robinson,* 2005; *Grzyb* et al., 2005; *Usenik* et al., 2008), while in South- and South-East-Europe these rootstocks usually failed under dry and hot summer conditions (*Negueroles,* 2005; *Salvador* et al., 2005; *Bujdosó & Hrotkó,* 2005; *Iglesias & Peris,* 2008). A large number of new promising dwarf rootstocks are known from the literature (*Callesen,* 1998), but besides vigor, the adaptability to the local environmental conditions, as well as precocity, their effect on fruiting branch formation, renewal capacity and rootstock effect on fruit size also should be tested for each production area (*Lang,* 2005; *Hrotkó,* 2007; *Quarteri* et al., 2008).

In Hungary the sweet cherry growing is located in a region with continental climatic influence and on soils with high lime content and pH level, partly on light sandy soils. In these conditions, traditionally seedling mahaleb rootstocks have been used for sweet cherries. In Hungary the rootstock breeding resulted both seedlings (CEMA, *Nyujtó,* 1987) as well as clonal mahaleb (*Bogdany, Magyar, Egervár*) rootstocks (*Hrotkó & Magyar,* 2004). These rootstocks haven't been tested yet in high density conditions. On the other hand, we have developed a special training system for cherry orchards, the so-called Hungarian Spindle (*Hrotkó* et al., 2007), which is a central leader type with basal branches combined with adequate pruning technique. Moderate vigorous and dwarfing rootstocks (M×M 14, M×M 97, Colt, Weiroot 154, 158 and Gisela® 5) have already been tested in Hungary in semi-intensive orchard conditions (*Hrotkó* et al., 1999; *Bujdosó & Hrotkó,* 2005), but there is no enough information about the value of these rootstocks in high density orchard. That is the reason why we started to test rootstocks of a wide vigor range in high density conditions.

Materials and methods

In spring 2000 there are planted 'Vera'® sweet cherry on eight, and 'Axel'® on five different rootstocks in Szigetcsép Experimental Station of Corvinus University, Budapest with the aim of rootstock evaluation in intensive orchard conditions. The soil is sandy loam, with high lime content (11.1%), humus is low (0.8%) and pH: 7.7. Meteorological characteristics in the average of the last fifteen years (1991–2004): average yearly temperature is 11.3 C, total sunshine is 2079 hours in a year, rainfall is 560 mm year^{-1}. Data of years of the trial show similar weather conditions *(Table 1)*. Trees were budded on rootstocks in 1998, one-year-old trees were lifted in the nursery 1999 autumn and planted into the orchard in spring 2000.

Table 1. Meteorological data in the orchard site during the trial (Szigetcsép 2000–2007)

Year	Average temperature °C	Precipitation mm	Sum of sunshine hours
2000	12.5	393.5	2198.2
2001	11.2	619.1	1769.4
2002	12.2	548.1	1721.0
2003	11.3	379.0	2394.0
2004	10.8	590.0	1979.0
2005	11.0	718.5	2017.0
2006	11.6	515.2	2035.2
2007	13.1	557.1	2306.6
Average	11.7	540.1	2052.6

The following rootstocks are involved in the trial:

GiSelA® 5: (*Prunus canescens* × *P. cerasus* Gi 148/2), dwarfing clonal rootstock, precocious and highly productive, widespread planted in intensive orchards in Germany (*Franken Bembenek,* 2005; *Balmer & Blanke,* 2005; *Stehr,* 2005; *Hilsendegen,* 2005);

Tabel® Edabriz: (*Prunus cerasus*) dwarfing clonal rootstock, precocious and highly productive, widespread planted in intensive orchards in France (*Charlot* et al., 2005);

Prob: *P. fruticosa* hybrid, selected in Hungary, dwarfing clonal rootstock (*Hrotkó,* 2004);

PiKu 1: *P. avium* × *(P. canescens* × *P. tomentosa)*, moderate vigorous clonal rootstock (*Wolfram,* 1996; *Hilsendegen,* 2005; *Stehr,* 2005);

Brokgrow (M×M 97): *P. mahaleb* × *P. avium*, moderate vigorous clonal rootstock (*Westwood,* 1978), in previous test proved to be promising in semi-intensive orchard (*Hrotkó* et al., 1999);

SL 64: *Prunus mahaleb*, vigorous clonal rootstock, in previous test proved to be promising in semi-intensive orchard (*Hrotkó* et al., 1999);

Bogdany: *Prunus mahaleb*, vigorous clonal rootstock selected in Hungary (*Hrotkó,* 2004)

CEMA: *Prunus mahaleb*, vigorous seedling population of C 500 pollinated by C 2753 and Érdi V. Registered rootstock in Hungary (*Nyujtó,* 1987).

Sweet cherry cultivars 'Vera'® and 'Axel'® are recently registered and protected. Both are promising in Hungary; 'Vera'® needs pollinator, ripes early, 'Axel'® is self fertile and late ripening (*Apostol,* 2005).

The trees were planted at a spacing of 4 × 2 m, 1250 trees ha^{-1} density. In one plot there are three trees planted, plots from each rootstock/scion combination are six times repeated and randomized. Thee trees are trained to Hungarian Cherry Spindle (*Hrotkó* et al., 2007); in the alley way naturally grown grass is managed by mowing. Drip irrigation was installed in the orchard, giving 60–120 mm water during the fruit growing until ripening, the amount of water varied depending on the actual rainfall.

Our purpose was to examine the value of eight different rootstocks with the above mentioned two cherry cultivars in Hungarian site conditions. The following data were measured annually: trunk and canopy size of trees, yield from each tree, fruit weight (of 50 fruits from each tree). In the year 2003 length of one-year-old terminal shoot as well as length of two-year-old or older branches were measured on four sample branches on each tree. Shoot number, node number of shoots and number of burse shoots (spurs) on branches were counted also.

The first considerable fruiting was in 2004. From the collected data, the followings are calculated: trunk cross-sectional area (TCSA, cm^2), canopy volume (CV, m^3), cumulative yield and cumulative yield efficiency CYE (total cumulative yield divided by final TCSA or canopy volume), orchard efficiency (t ha^{-1}), annual yield average of 2004–2007, and fruit weight in grams from 2005 to 2007.

Data are tabulated and statistically analyzed; means are separated using the Duncan's Multiple range test of Statgraphics software. Means differing significantly are displayed in tables using different letters.

Results and Discussion

Eight years after planting the growth characteristics of Vera and Axel cherry trees showed significant differences on various rootstocks *(Table 2)*. Largest trunk cross-sectional area of Vera trees was produced on Bogdány; compared to this, trees on rootstock SL 64 and CEMA did not show any significant differences. Smallest TCSA was measured on Gisela® 5 rootstock, but Tabel® Edabriz, Prob and PiKU 1 rootstocks also produced similarly thin trunk without any significant differences, compared to trees on Gisela® 5. Intermediate TCSA was produced on Brokgrow. The TCSA of Axel trees performed similarly, but trees of this cultivar on CEMA seedlings formed an intermediate group. By the canopy volume Vera trees can be classified into two groups only: Large canopy is produced on Bogdany, SL64, CEMA, Brokgrow, PiKu1 and Prob rootstocks while on Gisela® 5 and Tabel® Edabriz rootstocks the canopy volume is smaller, within the two groups

Table 2. Effect of rootstocks on growth of cherry cultivars 'Vera'® and 'Axel'® in 2007 (8th leaf)

	TCSA (cm²)				Canopy volume (m³)				Tree height (m)			
Rootstocks	'Vera'®		'Axel'®		'Vera'®		'Axel'®		'Vera'®		'Axel'®	
Gisela 5	53.0	a	34.6	a	8.3	a	5.1	a	3.60	a	3.05	a
Edabriz	64.0	a	52.4	a	9.8	ab	9.0	b	4.03	ab	3.68	b
Prob	77.1	a	31.6	a	11.9	bc	4.1	a	4.10	b	2.95	a
Piku 1	86.3	a			12.6	bc			4.60	c		
Brokgrow	123.2	b			13.8	c			4.66	c		
Cema	143.4	bc	110.1	b	13.4	c	9.4	b	4.79	c	4.66	c
SL 64	147.6	bc			12.9	c			4.78	c		
Bogdány	166.4	c	140.7	c	14.0	c	11.6	b	4.88	c	4.74	c

Means are separated by Duncan's Multiple Range test at P<0.05

there are no significant differences. Rootstocks Prob and Tabel® Edabriz performed differently with Axel, Tabel® Edabriz produced larger, while Prob smaller canopy. Based on trunk cross-sectional area (TCSA) and canopy volume we classified rootstocks into three groups, which corresponds to the literature data (*Nyujtó,* 1987; *Hrotkó* et al., 1999; *Hrotkó & Magyar,* 2004; *Charlot* et al., 2005; *Franken & Bembenek,* 2005). Cema, SL 64, and Bogdány are vigorous rootstocks, moderate vigorous are MaxMa 97, Pi-Ku 1, while Tabel® Edabriz, Gisela® 5 and Prob are dwarfing rootstocks.

The canopy volume of trees on different rootstocks showed less difference, possibly caused by the plant distance as limiting factor and by the pruning as restricting effect. Also the tree height is restricted by heading, carried out in 2006 only on trees on vigorous rootstocks. The significant smaller trees on Gisela® 5, Tabel® Edabriz and Prob did not reach the height of heading (3.8–4 m). Also the branching on central leader in upper section is poor, which considerably affects the bearing surface in vertical dimension of the orchard.

The growth characteristics measured in 2003 *(Table 3)*, one year before turning to bearing showed more or less similar performance compared to the tree size in 2007. The only difference is that smallest tree sizes of 'Vera'® were found on Tabel® Edabriz rootstock. The canopy volume of 'Vera'® trees on vigorous rootstocks was about double large compared to those on Gisela® 5 or on other dwarfing rootstocks. This data suggest that trees on vigorous rootstocks until turning to bearing produced around double large bearing surface compared to dwarfing ones.

Considering the differences in total length of one-year-old shoot growth in 2003 can be stated that significantly reduced growth was produced on 'Vera'® trees on Tabel® Edabriz, PiKu1 and Brokgrow rootstocks, while 'Axel'® trees produced less shoot growth on Gisela® 5. Also the reduced shoot growth of this year influenced the bearing surface development. On trees of 'Axel'® trees this reduced growth is linked with shorter internodes on dwarfing rootstocks, while on 'Vera'® trees the shorter internodes on dwarfing Gisela® 5 and Tabel® Edabriz seems to be just a tendency without significant differences *(Table 3)*.

Burse shoots (spurs) are valuable fruiting branches in the sweet cherry bearing surface (*Laurie & Claverie,* 2005; *Lang,* 2005). Formation of burse shoots is an important sign of precocity and can be affected by rootstocks (*Flore* et al., 1996; *Đurić* et al., 1998; *Lang,* 2005). Our data confirm this statement but show interesting performance on different rootstocks *(Table 4)*. Comparing the two cultivars, 'Axel'® forms larger number of burse shoots in the whole tree as well as larger density on one meter shoot length or on trunk cross-sectional area unit. Total number of burse shoots of 'Vera'® trees is the largest on Cema rootstock, and the smallest on Tabel® Edabriz and Brokgrow, while intermediate group is formed by Gisela® 5, Bogdány, Prob, SL 64 and PiKu1 rootstocks. On 'Axel'® trees there are no considerable differences in the total number of burse shoots. The burse shoot density compared to TCSA (cm²) is largest on Gisela® 5 rootstock on trees of both cultivar, albeit statistically proved differences were found at 'Axel'® only. Burse shoot density on one meter length of branches at 'Vera'® cultivar is largest on Prob rootstock, smallest on SL 64, while in intermediate group are rootstocks such as Gisela® 5, Cema,

Table 3. Growth characteristics in 2003 (fourth leaf) of cherry trees on different rootstocks

Rootstocks	TCSA cm²		Tree height m		Canopy volume m³		Total shoot length m		Average internode length cm	
					'Vera'®					
Gisela 5	19.3	ab	2.53	a	2.93	ab	3.10	ab	2.0	a
Edabriz	14.2	a	2.23	a	1.42	a	1.36	a	2.2	a
Prob	20.6	ab	2.73	a	4.07	ab	2.76	ab	2.4	a
Piku1	17.4	ab	2.64	a	3.42	ab	2.29	a	2.0	a
Brokgrow	19.7	ab	3.03	a	3.59	ab	2.06	a	2.2	a
Cema	25.3	b	3.31	a	6.68	b	4.77	b	2.2	a
SL64	26.3	b	3.38	a	6.20	b	3.05	ab	2.4	a
Bogdány	25.6	b	3.41	a	5.97	b	4.11	ab	2.5	a
					'Axel'®					
Gisela 5	15.8	a	2.51	a	2.00	a	1.66	a	2.1	a
Bogdány	20.6	b	2.56	a	2.46	ab	2.23	ab	2.5	ab
Cema	22.0	b	3.41	a	4.10	b	2.85	b	3.2	b

Means are separated by Duncan's Multiple Range test at P<0.05

Table 4. Density of burse shoots on different rootstocks in 2003 (4th leaf)

Rootstock	Total nr/tree		Density nr/cm² TCSA		Density nr/one m of branch	
			'Vera'®			
Gisela 5	232	ab	8.7	a	13.9	ab
Edabriz	56	a	3.0	a	11.1	ab
Prob	202	ab	5.6	a	18.5	b
PiKu1	149	ab	5.9	a	12.2	ab
Brokgrow	88	a	3.1	a	9.9	ab
Cema	325	b	6.2	a	13.0	ab
SL64	164	ab	3.8	a	9.3	a
Bogdány	225	ab	4.5	a	11.4	ab
			'Axel'®			
Gisela 5	308	a	15.7	b	21.3	a
Cema	352	a	10.4	a	22.2	a
Bogdány	307	a	11.3	ab	18.5	a

Means are separated by Duncan's Multiple Range test at P<0.05

PiKu 1, Bogdány, Tabel® Edabriz and Brokgrow. Differences between Axel trees on different rootstocks are not significant.

The effect on precocity is a very important factor in rootstock evaluation, which is determining in rootstock selection for intensive orchards (*Sansavini & Lugli,* 1996; *Kappel* et al., 2005; *Lang,* 2005). Considering the first crop of 'Vera'® trees in 2004 *(Table 5)* the most precocious rootstock is Gisela® 5, but PiKu 1 and CEMA produced similarly large

Table 5. Yield of sweet cherry trees on different rootstocks 2004–2007, (kg tree-1)

Yield of trees (kg tree-1)					
Rootstocks	2004	2005	2006	2007	Cumulated 2004–07
'Vera'®					
Gisela 5	13.9 e	13.9 bc	15.2 ab	25.7 a	66.2 ab
Edabriz	4.0 a	6.6 a	12.8 a	27.8 ab	51.1 a
Prob	7.8 abc	7.6 ab	12.3 a	25.8 a	53.3 a
Piku 1	12.2 de	16.6 c	20.8 bc	39.5 bc	89.1 c
Brokgrow	6.0 ab	8.2 ab	14.2 a	36.9 abc	67.1 ab
Cema	11.9 cde	17.4 c	17.3 abc	42.5 c	89.0 c
SL 64	9.9 b-e	18.1 c	22.7 c	41.4 c	91.6 c
Bogdány	9.0 bcd	15.7 c	22.0 c	38.6 bc	83.6 bc
'Axel'®					
Gisela 5	13.2 b	7.9 a	9.8 a	11.2 a	40.4 b
Edabriz	2.9 a	4.8 a	11.4 a	8.7 a	26.0 ab
Prob	5.1 a	3.1 a	5.8 a	7.5 a	21.5 a
Cema	16.2 b	13.1 b	25.2 b	29.2 b	81.7 c
Bogdány	13.2 b	13.1 b	28.4 b	30.7 b	85.2 c

Means are separated by Duncan's Multiple Range test at $P<0.05$

yield without any statistically proved difference. 'Axel'® trees produced largest crop in the first year on CEMA, Bogdány and Gisela® 5 rootstocks. These precocious yields can be explained partly by larger canopy volume (bearing surface) *(Table 3)* and by the similar density of burse shoots counted in 2003 *(Table 4)* on the trees standing on these rootstocks. On the other hand, in tree architecture and training applied in the test orchard there are no strong limbs, only fruiting branches on the central leader, which creates favorable conditions for burse shoot (spurs) formation. These conditions also may contribute to increased precocity on vigorous mahaleb rootstocks. The relative large burse shoot density on Tabel® Edabriz and Prob rootstock did not result in precocious cropping, one of possible causes besides the smaller canopy volume can be a lower fruit set, but this factor should be more investigated. Our data on large precocious yields on vigorous rootstocks suggest that acceptable precocity can be achieved even on vigorous rootstocks, when the tree architecture and training support the precocious formation of fruiting branches. Considering the yields of first two years (2004, 2005) also trees on rootstocks Gisela® 5, Piku 1, Cema, SL 64 and Bogdány proved to be more precocious than trees on Prob, Tabel® Edabriz and Brokgrow *(Fig. 1. and 2.).*

There are significant differences between measured cumulative yields on trees standing on different rootstocks. Cumulative yield of 'Axel'® was the highest on Bogdány and on CEMA, contrary to Gisela® 5, which produced only 50%

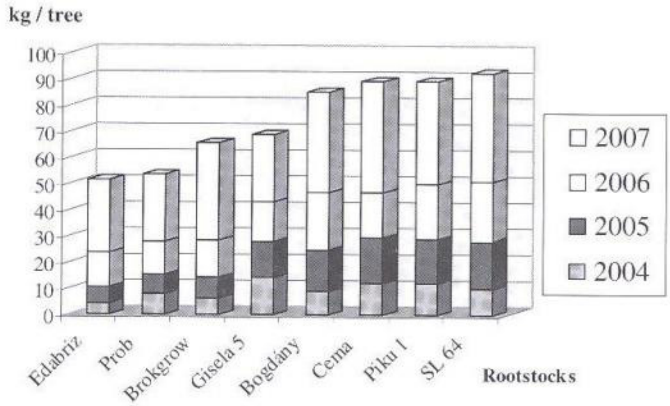

Fig. 1.: Yields of 'Vera'® trees on different rootstocks (2004–2007)

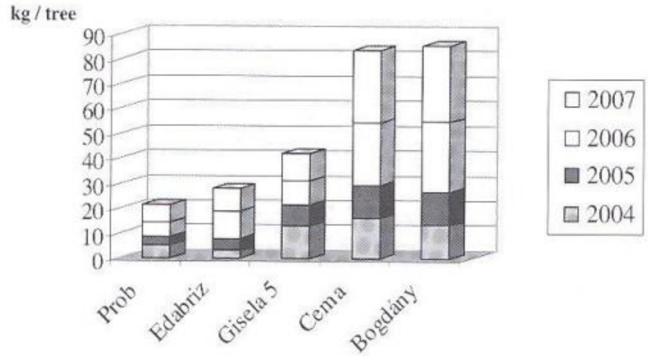

Fig. 2.: Yields of 'Axel'® trees on different rootstocks (2004–2007)

of the previous ones. The productivity results of the two other dwarfing rootstocks were not even 50% of Gisela® 5. Cumulative yield of 'Vera'® was the highest on SL 64, and no significant difference was found, compared to trees on rootstocks Cema, Bogdány and Pi-Ku 1. Cumulative yield production of trees was smaller on Gisela® 5, Prob, MaxMa 97 and Tabel® Edabriz rootstocks.

Calculation of yield efficiency *(Table 6)* by trunk cross-sectional area (kgcm$^{2-1}$ of TCSA) of sweet cherry trees confirm data known from the literature (*Charlot,* 2005; *Franken-Bembenek,* 2005; *Stehr,* 2005; *Hilsendegen,* 2005; *Bujdosó & Hrotkó,* 2005; *Usenik* et al., 2008) except for Eadbriz and Prob, which were less efficient. The highest efficiency is calculated on Gisela® 5 at both cultivars, a

Table 6. Cumulative yield efficiency (2004-2007) of 'Vera'® and 'Axel'® cherry trees

	CYE kg/m³ canopy volume				CYE kg/cm² TCSA			
Rootstocks	'Vera'®		'Axel'®		'Vera'®		'Axel'®	
Gisela 5	9.03	d	8.41	c	1.27	c	1.23	b
Edabriz	5.17	ab	2.90	a	0.78	b	0.54	a
Prob	4.50	a	5.73	b	0.65	ab	0.65	a
Piku 1	7.14	c			1.09	c		
Brokgrow	4.84	c			0.56	a		
Cema	6.68	bc	8.94	c	0.66	ab	0.74	a
SL 64	7.31	c			0.64	ab		
Bogdány	6.05	abc	7.59	c	0.51	a	0.63	a

Means are separated by Duncan's Multiple Range test at $P<0.05$

similar efficiency showed 'Vera'® trees on PiKu 1 root. The efficiency calculated by canopy volume (kgm^{3-1}) performed differently. Canopy of 'Vera'® trees were still most efficient on Gisela® 5, but canopy of 'Axel'® sweet cherry was most efficient on CEMA, Gisela® 5 and Bogdány without any significant differences.

The tree efficiency kg/cm^2 of TCSA) and orchard efficiency (t ha^{-1}) under high density conditions should be separately considered (Hrotkó 2007, 2008). Our calculation of orchard efficiency on area unit basis showed differences compared to tree efficiency *(Table 7)*. At cultivar 'Vera'® the calculation with the actual density (4×2 m, 1250 trees ha^{-1}) resulted highest orchard efficiency ($tha^{-1}year^{-1}$) on SL 64, CEMA, PiKu 1 and Bogdány, while 'Axel'® at the same orchard density produced highest orchard efficiency also on CEMA and Bogdány. For rootstocks Gisela® 5, Prob and Tabel® Edabriz, which could allow higher orchard density, a calculation was made for 4×1.5 m (1666 trees ha^{-1}), assuming that the productivity of trees do not change. In this calculation the orchard efficiency of 'Vera'® on Gisela® 5 rootstock reached that level, achieved on mahaleb rootstocks with 1250 trees ha^{-1}. In this calculated density Pi-Ku 1 rootstock proved to be the most effective ones *(Table 7)*, but such calculation for 'Axel'® still resulted in low orchard efficiency for dwarfing rootstocks.

Table 7. Calculation of average orchard efficiency for one year (yield tha^{-1})

Rootstocks	'Vera'® (1250 tree/ha; 4×2m)	'Vera'® (1666 tree/ha; 4×1.5m)	'Axel'® (1250 tree/ha; 4×2m)	'Axel'® (1666 tree/ha; 4×1.5m)
Gisela 5	20.6	27.5	12.6	16.8
Edabriz	16	21.3	8.1	10.8
Prob	16.6	22.2	6.7	8.9
Pi-Ku 1	27.9	–		
Brokgrow	21	–		
Cema	27.8	–	25.5	–
SL 64	28.6	–		
Bogdány	26.1	–	26.6	–

Means are separated by Duncan's Multiple Range test at P<0.05

Also rootstocks affect fruit weight, however, in several case the rootstock effect is overlapped with crop load and leaf area ratio (*Edin* et al., 1996; *Simon* et al., 1999; *Jiménez* et al., 2004; *Bujdosó & Hrotkó,* 2005; *Quarteri* et al., 2008). According to our data, dwarfing and moderate vigorous rootstocks decrease fruit weight. We measured the largest fruits on the vigorous rootstocks Cema, SL 64, and Bogdány, especially on Bogdány, where we measured 9,5–10,4 g depending on cultivar. On dwarfing rootstocks, Tabel® Edabriz, Gisela® 5 and Prob fruits were considerable smaller *(Table 8)*. The rootstock effect on average fruit weight is more conspicuous on self fertile 'Axel'® trees, the fruit weight is reduced by 37–42% compared to that of trees on rootstock Bogdany, while on cross pollinated 'Vera'® the differences are around 27%. As the 'Axel'® trees on Bogdány, SL 64 and CEMA showed high yield efficiency, the crop load cannot be the only reason for fruit weight reduction. Since the decrease in shoot growth started already in 2003 on dwarfing rootstocks *(Table 4)*, which leads to a smaller leaf area. As *Flore* et al., (1996) and *Cittadini* et al., (2006) reported, a reduced leaf surface/fruit load ratio causes smaller fruit size. What is more, the increasing the yield efficiency of self fertile scion cultivars (like 'Axel'®), also may contribute to the fruit weight reduction.

Table 8. Effect of rootstocks on average fruit weight in 2005–2007

Rootstocks	Fruit weight (g) 'Vera'®		Fruit weight (g) 'Axel'®	
Gisela 5	8.72	a	7.11	b
Edabriz	8.98	ab	7.68	b
Prob	8.65	a	5.53	a
Piku 1	9.71	abc		
Brokgrow	9.38	abc		
Cema	9.88	abc	9.36	c
SL 64	10.18	bc		
Bogdány	10.40	c	9.72	c

Means are separated by Duncan's Multiple Range test at P<0.05

According to our results the trees on vigorous rootstocks produced higher orchard efficiency both with 'Vera'® and 'Axel'®, so we can highly recommend SL 64, Bogdány, Cema and Pi-Ku 1 for high density orchard (Hungarian spindle, *Hrotkó,* 2007) under our or similar site conditions. When calculating orchard efficiency at spacing 4 × 2 meters (1250 tree/ha), we received highest yield values on Bogdány, CEMA, SL 64, and PiKu 1 rootstocks, with large fruit weight. The calculation with more dense spacing (4 × 1.5 m, 1666 trees/ha) for Gisela® 5, Tabel® Edabriz and Prob would result a similar large orchard efficiency, but these rootstocks involve the risk of smaller fruit size. These results confirm Zahn's opinion (*Zahn* 1990, 1996) that high density sweet cherry orchards can be planted on vigorous rootstock too, but precocious cropping is essential.

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