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Long-term evaluation of rootstock effects on cropping and tree parameters of selected sweet cherry cultivars

Jitka Blažková, Adéla Skřivanová, Pavol Suran, Lubor Zelený, František Paprštein*

Research and Breeding Institute of Pomology Holovousy, Holovousy, Czech Republic

**Corresponding author: jitkachodovice@seznam.cz*

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Abstract: The cropping of six sweet cherry cultivars that originated in the Research and Breeding Institute of Pomology at Holovousy, and a standard one, 'Burlat', were evaluated on three rootstocks in the period of 2007–2017. Trees planted in a spacing of 1.5 m × 5.0 m were trained as tall spindle axes utilising their natural tendency to develop a central leader. On the standard rootstock, P-TU-2, 'Tim' was the most productive with a mean total harvest of 47.6 kg per tree. 'Sandra' yielded the most on the PHLC rootstock with 56.2 kg per tree and 'Helga' yielded the most on Gisela 5 with a mean total harvest of 55.9 kg per tree. The mean impact of the rootstock on the tree vigour, measured upon the trunk cross section area, ranged from 148.4 cm^2 on the standard rootstock P-TU-2 to 114.1 cm^2 on the PHLC and 125.2 cm^2 on Gisela 5 . On the standard rootstock P-TU-2, the most vigorous one according to this criterion was 'Jacinta' (178.0 cm^2) whereas 'Justyna' (109.7 cm^2) was the least vigorous. On the PHLC, the most vigorous was 'Sandra' (147.2 cm^2) and the least was 'Amid' (94.0 cm^2). The other tree characteristics were mainly dependant on the cultivar and minimally, or not at all, influenced by the rootstock vigour.

Keywords: growth habit; length of spurs; tree canopy density; tree size; fruit yield; *Prunus avium*

This paper is a continuation of our previous publications concerned with cropping and the evaluation of tree characteristics of four sweet cherry cultivars that were developed in the Research and Breeding Institute of Pomology at Holovousy (Blažková at al. (in-press)).

The cultivar 'Amid' was bred in Holovousy as a cross between the 'Kordia' and 'Vic' cvs. It ripens in the 6th sweet cherry week. Trees grow in medium-vigorous way and their canopies are medium-dense. The branches are set at wide angles and are abundantly covered by fruiting wood. The fruits are large, have a globose-conical to a heart-like shape. The fruit weight usually varies around 10 g and the average fruit width is around 26 mm (Blažková, Hlušičková 2007a).

The early ripening cultivar 'Burlat' originated in France, where it was found as a chance seedling in 1915. In the Czech Republic, it has been grown since 1981 (Kutina et. al. 1991). Its fruits ripen in the second sweet cherry week. The trees are vigorous and their canopy is slightly upright.

The cultivar 'Helga' was bred in Holovousy as a cross between 'Early Rivers' and the French cultivar 'Moreau'. The fruits belong to a gean type of sweet cherry. The fruits ripen in the 2nd or 3rd sweet cherry week. The trees grow in a medium-vigorous way. The canopy is rather thin. The fruits are medium large, their weight usually varies between 7.5–8.5 g. The trees are precocious and productive (Blažková, Hlušičková 2007b).

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The sweet cherry 'Jacinta' was selected in Holovousy within the seedlings obtained from the 'Vega' cultivar after open pollination. The fruits belong to a gean type of sweet cherry. The fruits ripen in the 3rd sweet cherry week. The trees grow in a medium-vigorous way. The canopy is round medium-dense. The branches are set at wide angles and are well covered by fruiting twigs. The fruits are large, heart-like in shape. Their weight mostly varies around 11 g and the average fruit width is around 29.5 mm (Blažková, Hlušičková 2007c).

The cultivar 'Justyna' was bred in Holovousy as a cross between 'Kordia' and the American cultivar 'Starking Hardy Giant'. The fruits belong to a bigarreau type of sweet cherry. The fruits ripen in the 5th or 6th sweet cherry week. The trees grow in a medium-vigorous or in a vigorous way. The canopy is rather dense. The fruits are large, their weight usually varies between 9–10 g and the average fruit width is around 26 mm (Blažková, Hlušičková 2007d).

The sweet cherry 'Sandra' was selected from the progeny 'Kordia' × 'Seedling No. 13'. The fruits belong to a bigarreau type of sweet cherry and ripen in the 4th to 5th sweet cherry week. The trees grow in a medium-vigorous way. The canopy spread has a medium-density. The branches are set at wide angles and are well covered by fruiting wood. The fruits are very large, their shape is heart-like. Their weight mostly varies around 11 g and the average fruit width is around 27 mm (Blažková, Hlušičková 2007e).

The sweet cultivar 'Tim' was selected from the progeny 'Krupnoplodnaja' × 'Van'. The fruits belong to a bigarreau type of sweet cherry. The fruits ripen in the 6th sweet cherry week. The tree vigour is of a medium type. The canopy is round-upright, medium-dense. The branches are set at wide crotch angles and they are well spurred. The fruits are large, globose elongated. Their weight varies about 11 g and the average fruit width is around 29 mm. The fruit skin is dark red (Blažková, Hlušičková 2007f).

The majority of the above-mentioned and herein evaluated items are genetically related according to their origin and constitution of S alleles (Sharma et al. 2014, 2016; Lisek et al. 2015).

In this study, as a standard seedling rootstock, P-TU-2 was used that was selected and registered in the Czech Republic in 1971 (Blažková et al. 2010).

The dwarfing rootstock for the sweet cherry PHLC that was bred in Holovousy was previously evaluated under the designation 'HL-6' and it is used in high-density crop plantings. It reduces the tree size up to by 80% compared to the standard F 12/1 and induces very early fruiting and high yields. It is suitable for slender spindle systems (Paprštein et al. 2008).

The dwarf sweet cherry rootstock Gisela 5 originated during the sixties of the last century in the University in Giessen, Germany. It was selected in the progeny obtained by crossing *Prunus avium* with *Prunus canescens.* Gisela 5 is known to reduce the vigour by up to 50 percent or more compared to Mazzard seedlings (Springer 2008). It produces trees that are open with spreading wide branch angles, but the branching may be sparse (Long, Kaiser 2010). According to the range of other studies, Gisela 5 significantly reduces the vegetative growth and improves the cropping of sweet cherries (Vercamen et al. 2006).

In the study of new training systems for high-density planting of sweet cherry, where 10 cultivars were evaluated on the Gisela 5 rootstock, the five-year-old trees trained in the spindle system had a trunk cross-sectional area of only 26.2 cm^2 on average (Musacchi et al. 2015). The values of the cultivars ranged between 10.9 cm^2 in 'Sylvia' up to 37.6 cm^2 in 'Glance Star'.

The sensorial characterisation of four sweet cherry cultivars grown in Spain were linked to the ripening stage. Some volatile acids and aromatic alcohols were characteristic of the 'Sweetheart'. The high pH values and some aldehydes were related to the "Picota" type cultivars. The 'Ambrunes'. was mainly distinguished by its greater sweetness and by some aliphatic alcohols, whereas the 'Pico Colorado'. was characterised by its greater firmness (Serradilla et al. 2017).

New high-density training systems for the sweet cherry have been introduced in an attempt to produce high-quality fruit and achieve earlier orchard productivity (Whiting et al. 2005; Whiting, Smith 2007; Lang et al. 2014).

The yields and tree vigour of four sweet cherry cultivars grafted on the Colt rootstock and planted in a spacing of 4 m × 2 m, were evaluated in the period of 2009–2013 in Serbia. The final mean trunk cross sectional area ranged between 59.1 cm^2 in the cultivar 'Celeste' up to 84.5 cm^2 in the cultivar 'May Early'. The yield efficiency ranged between 0.02 kg/cm^2 in the cultivar 'Sunburst' up to 0.08 kg/cm^2 in the cultivar 'May Early' (Miloševič et al. 2015).

The tree architecture significantly influences a range of characteristics in an orchard. Beside the start of the cropping and the yields, it also affects the harvest efficiency. The highest mean harvest rates of 0.94 kg/min and 0.78 kg/min were recorded in the cultivars 'Cowiche' and 'Tieton7', respectively, on the Gisela 5 root-

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stock in orchards trained in an upright fruiting offshoots system (Ampatzidis, Whiting 2013).

The cherry tree is characterised by two main features: (1) it has upright scaffold branches with lateral flowering on the preformed portion of both the short and long shoots; and (2) it is characterised by a strong dimorphism between the short and long shoots, with a marked acrotony, i.e., the longer laterals are in the top position, just below the annual growth termination (Lauri, Claverie 2008).

The effect of the harvest ripening stage on the aroma of sweet cherries was studied by Serradilla et al. (2012, 2017). The most relevant sensorial attributes were linked to the ripening stage, the parameters associated with the organic acid accumulation and some volatile acids and aromatic alcohols that were a characteristic of the 'Sweetheart' cultivar. Generally, the ascertained aroma compounds could be distinguished in each cultivar.

The volatile organic compounds were evaluated with the aim to investigate the morpho-chemical and aromatic characteristics of the sweet cherry cultivars in Italy. The tentative identification of some key volatile organic compounds for the cherry fruit was performed and preliminary conclusions on the characterisation of the ancient and widespread Italian cultivars were given (Taiti et al. 2017).

Recently, a high-yield potential has been achieved up to the 5th year after planting in high-density training system of the sweet cherry cultivar 'Rainier' on the Gisela 3 rootstock where 2 222 trees per hectare was planted in a spacing of 1.5 m × 3.0 m (Law, Lang 2016).

The aim of the work was the long-term evaluation of the rootstock effects on the cropping and tree parameters of the selected sweet cherry cultivars.

MATERIAL AND METHODS

The dwarfing rootstocks PHLC and Gisela 5 that are commonly grown in the Czech Republic have been compared in the experimental orchard with the standard rootstock P-TU-2 by using seven sweet cherry cultivars. Beside the standard 'Burlat', there were novelty cherries recently bred in Holovousy, the Czech Republic: 'Amid', 'Helga', 'Jacinta', 'Justyna', 'Sandra' and 'Tim'. The experimental orchard was established at Holovousy in 2006. One-year-old nursery trees obtained after summer budding were planted in a spacing of 5 m × 1.5 m. From each cultivar – a rootstock combination of three trees were grown and evaluated. The climatic conditions at Holovousy are characterised by the average annual temperature of 8.1 °C and the average annual rainfall of 650 mm. The soil is a medium loamy sand with a rather deep cultivated layer on gravely substrate. The orchard is located at the elevation of 350 m and it is situated on a very gentle south-facing slope.

The orchard management was based on using mown grass kept in driveways and herbicide strips (1.5 m) based upon the application of contact herbicides along the rows of trees. The trees were trained as tall spindle axes utilising their natural tendency to develop a central leader. Wooden stakes were used to support the trees at the beginning to help in the process of training the tree canopy in the first years. Later on, summer pruning was applied to keep the tree canopy in a given space, if necessary. No irrigation was applied in the orchard. Spraying treatments against pests and diseases were conducted according to the recommendations for commercial orchards.

The trees started their fruiting stage mostly in the third or fourth year after planting, depending on the rootstock used. All the fruits were harvested after arriving into the harvest stage of each cultivar and the total fruit harvest per tree was weighed. The first access to evaluating the tree vigour, based upon measuring the trunk's cross-sectional area, was performed at the end of the 2015-growing season.

In the last year (2017), during August, several tree characteristics of each tree were measured or evaluated using a 1–9 rating scale. The bottom of the trunkF's cross-sectional area, in cm^2, and the canopy volume, in m^3, were directly measured. The following were rated:

- *tree growth habit* (1 – top upright; 9 – overhanging);
- *canopy density* (1 – very dense; 9 – very thin);
- *fruiting spurs on two or three old parts of the wood* (1 – no; 9 – very numerous);
- *length of fruiting spurs:* (1 – very short below 1 cm, 9 – very long);
- *bare wood tendency of branches* (1 – very strong; 9 – no).

The data on the weighed or measured characteristics were statistically evaluated by an analysis of variance (ANOVA).

RESULTS

Impact of Late Spring Frosts

Very severe late spring frosts, during the flowering of the sweet cherries, reduced or eliminated cropping of sweet cherries in an extreme way in the ex-

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Table 1. The mean harvest per tree in kg during years of the evaluation in the trial

Rootstock	Cultivar	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
P-TU-2	Amid	0.4	0	1.17	0	0.4	0.9	6.7	10.6	13.8	0	34.0
	Helga	0	0	0	0	0.9	0.3	6.8	20.1	16.3	0	44.4
	Jacinta	0.2	0.6	0	0	1.8	0.4	4.0	11.3	11.0	0	29.2
	Justyna	0	0	0.4	0.5	1.0	0.5	10.5	11.9	10.6	0	35.3
	Tim	0	0	0	0	1.6	1.8	10.3	20.5	13.4	0	47.6
	Mean	0.12	0.12	0.3	0.09	1.1	0.77	7.6	14.9	13.0	0.00	38.1
PHLC	Amid	2.3	3.0	2.0	0.7	7.7	0.8	4.5	16.3	6.8	2.8	46.8
	Burlat	2.5	0	0.3	0.6	7.3	2.4	6.7	18.4	12.0	1.0	51.1
	Helga	1.4	0	0	1.9	3.9	1.6	10.7	14.9	11.6	2.5	48.5
	Jacinta	3.1	4.0	2.3	0.4	5.3	0.6	7.8	11.2	7.8	0	42.6
	Justyna	3.7	0	0	0.3	6.1	1.2	11.9	18.1	14.9	0	56.2
	Sandra	0	0.3	1.0	1.4	8.3	0.5	6.8	14.0	9.9	0.6	42.9
	Tim	2	4.4	0.9	0.6	3.6	1.7	6.7	19.5	7.4	1.9	48.8
	Mean	2.14	1.67	0.9	0.84	6.0	1.26	7.9	16.1	10.1	1.26	48.1
Gisela 5	Burlat	1.5	3.6	2.7	0.7	4.2	2.3	6.3	13.9	13.3	0.7	49.1
	Helga	0	1.5	3.5	0.6	5.5	0.2	10.2	18.8	14.9	0.6	55.9
	Sandra	1.3	0.6	3.0	1.0	2.6	0.6	8.4	16.1	10.3	0.4	44.2
	Mean	0.93	1.89	3.1	0.77	4.1	1.06	8.3	16.3	12.8	0.55	49.8
Total mean		1.20	1.20	1.2	0.58	4.0	1.05	7.9	15.7	11.7	0.68	45.1
Significant difference at $P < 0.05$		0.42	0.54	0.44	0.16	0.87	0.23	0.70	1.07	0.90	0.28	0.69

perimental orchard in the years 2011 and 2017. To a smaller degree, this also took place in the year 2013 (Table 1). Regarding the impact on the rootstock, the strongest damage was on the P-TU-2, where no fruit set occurred at all in 2017, whereas only the cultivar 'Justyna' brought 0.5 kg per tree in 2011. The frost damage on the remaining two rootstocks was similar in both years and the amount of harvested fruits fluctuated around 1 kg per tree.

Regarding the cultivars, 'Helga' was the most tolerant to the spring frosts, where 1.9 kg and 2.5 kg of fruit per tree was harvested in 2011 and 2017, respectively. It was followed by 'Amid' which had a total harvest from both years of 0.9 kg less than 'Helga'. Contrary to this damage 'Justyna' and 'Jacinta' had a total harvest equal to 0.3 and 0.4 kg per tree from both years, respectively.

Productivity on P-TU-2

The trees of 'Amid' and 'Jacinta' started fruiting in 2008 which was in the third year after planting. In the case of 'Justyna', it was one year later. The 'Halka' and 'Tim' trees started fruiting as late as in the fifth year after planting, but because of the frost damage to the flowers that year, the first crop occurred in 2012. 'Tim' was the most productive on this rootstock, which had a total harvest of 47.6 kg per tree. It was followed by 'Halka', 'Justyna' and 'Amid' having 44.4 kg, 35.3 kg and 34.0 kg per tree, respectively. On the contrary, the least productive was 'Jacinta' which only had 29.2 kg per tree in total. The cultivar 'Tim' also had the highest annual yield per tree of 20.5 kg in 2015.

Productivity on PHLC. All the cultivars on this rootstock except 'Sandra', which started one year later, started fruiting in 2008 which was in the third year after planting. 'Justyna' yielded the most on the rootstock having a total harvest of 56.2 kg per tree. 'Burlat' and 'Tim' followed in the decreasing order of the total harvest per tree having a harvest of 51.1 and 48.5 kg per tree, respectively.

Also, on this rootstock, 'Tim' had the highest annual yield per tree of 19.5 kg in 2015. 'Amid', 'Helga' and 'Sandra' had the next sequence of productivity with 48.8, 48.5 and 42.9 kg per tree, respectively. The least relatively productive one was 'Jacinta' which had a total yield equal to 42.6 kg per tree.

Productivity on Gisela 5. On this rootstock, all the cultivars except 'Helga' with a one-year delay started fruiting in 2008 which was in the third year after planting. Despite of it, 'Helga' had the highest total

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Table 2. The yield efficiency upon the mean yields in the years 2014–2016

Rootstock	Cultivar	Yield per tree (kg)	Trunk cross section area in 2015 (cm^2)	Yield efficiency (kg/cm^2)	Yield (t/ha)
P-TU-2	Amid	10.4	106.1	0.098	13.8
	Helga	14.4	127.4	0.113	19.2
	Jacinta	8.8	131.7	0.067	11.7
	Justyna	11.0	81.2	0.135	14.7
	Tim	14.7	102.8	0.143	19.7
	Mean	11.9	109.8	0.108	15.8
PHLC	Amid	9.2	69.6	0.132	12.3
	Burlat	12.4	82.4	0.150	16.5
	Helga	12.4	99.4	0.125	16.5
	Jacinta	8.9	104.6	0.085	11.9
	Justyna	15.0	55.7	0.269	20.0
	Sandra	10.2	108.9	0.094	13.6
	Tim	11.2	70.4	0.159	14.9
	Mean	11.3	84.4	0.134	15.1
Gisela 5	Burlat	11.2	71.9	0.155	14.9
	Helga	14.7	69.5	0.211	19.5
	Sandra	11.6	87.7	0.132	15.5
	Mean	12.5	76.4	0.163	16.6
Total mean		11.8	91.1	0.129	15.7
Significant difference at $P < 0.05$		0.9	1.53	0.015	0.89

harvest on the rootstock equal to 55.9 kg per tree which was absolute top producer in this study. It was followed by 'Burlat' and 'Sandra' in this parameter which brought 49.1 and 44.2 kg per tree, respectively. Thanks to 'Helga', the Gisela 5 rootstock also had the highest total rootstock mean average of 49.8 kg per tree which was 1.7 kg higher than in the PHLC one.

Cropping efficiency and yields per hectare

P-TU-2. 'Tim' (0.143 kg/cm^2), had the highest cropping efficiency on this rootstock, which was very closely followed by 'Justyna' (0.135 kg/cm^2). On the contrary, the least productive was 'Jacinta' (0.067 kg/cm^2) which was 53.1% less than 'Tim' (Table 2) in this parameter. The remaining 'Amid' and 'Helga' were placed in the middle of both extremes. These cultivars ranged in the same order in the mean yield per hectare, where 'Tim' had 19.7 t/ha and 'Jacinta' 11.7 t /ha.

PHLC. The mean level of the parameter on this rootstock was 0.134 kg/cm^2, which was 19.6% higher than the one for P-TU-2. Regarding the cultivars, 'Justyna' (0.269 kg/cm^2) had the highest cropping efficiency on this rootstock which had an exceptional mean yield per tree in this period (14.97 kg) and its trunk cross-sectional area was the smallest. The second highest in the cropping efficiency on this rootstock was achieved by 'Tim' (0.159 kg/cm^2). On the contrary, 'Jacinta' (0.085 kg/cm^2) had the lowest mean yield per tree in this period. Nearly all the other cultivars were quite close to the rootstock mean. The cultivar 'Justyna' also had the highest mean yield per hectare (19.96 t/ ha), whereas 'Jacinta' (11.9 t/ ha) had the lowest one.

Gisela 5. This rootstock invoked the mean the highest cropping efficiency of 0.163 kg/cm^2 which was 21.6% higher than on the PHLC one. 'Helga' (0.211 kg/cm^2) was the most productive on this rootstock, whereas cropping of 'Sandra' and 'Burlat' was on the lowest level (0.132 kg/cm^2) and the medium level (0.155 kg/cm^2), respectively. Regarding the yield per hectare, the most productive was 'Halka' with 19.5 t, followed by 'Sandra' with 15.5 t and 'Burlat' with a very slightly lower yield of 14.9 t.

Tree characteristics

P-TU-2. he tree vigour of the cultivars measured upon the trunk cross-sectional area ranged between 109.7 cm^2 in 'Justyna' and 178.0 cm^2 in 'Jacinta' (Table 3). The other three cultivars ('Tim', 'Amid' and 'Helga') ranged with an increasing performance value inside both extremes. The order of the cultivars according to the size of the volume was identical. Con-

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Table 3. The tree characteristics measured or rated on the trial

Rootstock	Cultivar	Trunk cross section area (cm^2)	Canopy volume (m^3)	Tree growth habit	Canopy density	Fruiting spur frequency	Length of spurs (mm)	Bare wood tendency
P-TU-2	Amid	143.4	5.87	5	6	6	53	8
	Helga	172.2	6.96	3	6	7	34	7
	Jacinta	178.0	8.63	6	5	3	51	3
	Justyna	109.7	4.98	8	8	5	49	3
	Tim	138.9	5.94	5	5	7	38	7
	Mean	148.4	6.5	5.4	6.0	5.8	45.0	5.6
PHLC	Amid	94.0	3.19	6	7	4	48	7
	Burlat	111.4	3.6	5	6	6	35	7
	Helga	134.3	3.21	4	5	6	26	6
	Jacinta	141.3	4.75	6	5	3	43	3
	Justyna	75.3	2.52	8	8	4	36	4
	Sandra	147.2	3.79	7	5	7	27	7
	Tim	95.1	2.77	6	6	7	31	6
	Mean	114.1	3.4	6.0	6.0	5.3	35.0	5.7
Gisela 5	Burlat	117.90	3.33	5	7	6	25	7
	Helga	113.9	2.53	5	5	6	23	7
	Sandra	143.70	3.51	7	5	7	27	6
	Mean	125.2	3.1	5.7	5.7	6.3	25.0	6.7
Total mean		128.0	4.4	5.8	5.9	5.6	36.0	5.9
Significant difference at $P < 0.05$		3.74	0.46	0.26	0.28	0.39	2.40	0.34

cerning the growth habit 'Helga' was classified as the most relatively upright, whereas 'Justyna' was evaluated as slightly spreading in an opposite extreme with an overhanging canopy shape. 'Justyna' was also distinguished by having the thinnest canopy, whereas all the other cultivars were rather classified on a medium level with regards to the canopy density, especially in the case of 'Jacinta' and 'Tim'. 'Helga' and 'Tim' were characterised as having the highest relative fruiting spur frequency on two or three old wood parts while 'Jacinta' had the lowest relative frequency. The mean length of the fruiting spurs ranged from 38 mm in 'Tim' up to 53 mm in 'Amid'. The relatively higher bare wood tendency was observed in 'Jacinta' and 'Justyna', but the lowest was observed in 'Amid'.

PHLC. The smallest tree size, measured upon the trunk's cross-sectional area, was remarkably 'Justyna' (75.3 cm^2) followed by 'Amid' (94.0 cm^2) and 'Tim' (95.1 cm^2). On the contrary, the most vigorous according to this criterion was 'Sandra' (147.2 cm^2) which was followed by 'Jacinta' (141.3 cm^2). The cultivar 'Justyna' was the least vigorous according to the canopy volume as well, but 'Tim' was the next one in the order of the increasing sequence. In the opposite direction, 'Jacinta' had the greatest canopy volume of 4.75 m^3 which was nearly 1 m^3 more than 'Sandra' which followed. In the mean trees The PHLC rootstock had a 24.14 % smaller trunk cross-sectional area in the mean tree size and P-TU-2 had a 47.37 % smaller canopy volume.

Concerning growth habit, 'Justyna' was again unique by its overhanging canopy shape. In this characteristic, the cultivar 'Sandra' was the closest to this. All the other cultivars had a growth habit on the medium or nearly medium level. From the point of view of the canopy density, 'Justyna' followed by 'Amid' had the thinnest canopies. The canopy densities on the remaining cultivars were on the medium or nearly medium level. 'Sandra' and 'Tim' were characterised by having the relatively highest fruiting spur frequency on two or three old wood parts, while 'Jacinta' had the relatively lowest one. The mean length of the fruiting spurs ranged from 26 mm in 'Helga' up to 48 mm in 'Amid'. The mean length of the fruiting spurs on this rootstock was equal to 35 mm, whereas it was 45 mm on P-TU-2, i.e., 10 mm less. 'Jacinta' was distinguished by having a relatively higher bare wood tendency, however, this feature was rather negligible in 'Amid', 'Burlat' and 'Sandra'.

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Gisela 5. The tree vigour according to the trunk's cross-sectional area ranged between 'Helga' (113.93 cm^2) and 'Sandra' (143.7 cm^2). The mean value of this characteristic was 9.7% higher than the PHLC, however, it was caused by the use of more vigorous cultivars. With only the exception of 'Burlat', which was slightly insignificantly more vigorous on Gisela 5 , the other two cultivars had a smaller tree vigour on this rootstock. In the case of 'Helga' and in 'Sandra', it was 15.2 % and 2.4 % smaller, respectively. The canopy volume raged from 'Helga' (2.53 m^3) through 'Burlat' (3.33 m^3) up to 'Sandra' (3.51 m^3). These values were 21.2%, 8.26% and 7.9% smaller than on the PHLC, respectively.

The tree growth habit of 'Sandra' was more spread out than in both the other cultivars. The tree canopy of 'Burlat' was significantly thinner in comparison to both the other cultivars. The cultivar 'Sandra' was slightly better within the fruiting spur frequency in the group. All the tree cultivars were distinguished by the shortest fruiting spur length in the mean (25 mm) and the smallest bare wood branching tendency (6.7).

DISCUSSION

The mean values of the tree vigour in this study, according to the trunk's cross-sectional area, were distinctly smaller than in our previous paper (Blažková et al. (in press)) in the case of the P-TU-2 and PHLC rootstocks, but it was mainly due to the cultivar 'Justyna' whose tree vigour was very low. The other difference to our previous study was in the mean vigour of the same cultivars evaluated on the PHLC and Gisela 5 which were practically the same in this study.

The most vigorous cultivar in this study was 'Jacinta', whose canopy volumes were extremely large. This cultivar's greater tree vigour was already discussed in the first part of its description (Blažková, Hlušičková 2007d).

The tree vigour parameters within the evaluated cultivars in this study are generally in agreement with the data in literature (Akçay et al. 2008; Gjamovski, Ljubojević et al. 2016).

The tree growth and yield of some sweet cherry cultivars grafted on the Gisela 5 rootstock have been studied in Turkey (Akçay et al. 2008). There cultivar 'Venus' had the largest trunk diameter (7.85 cm) and 'Sweetheart' had the smallest (3.72 cm). All the studied cultivars had a different canopy development and architectural habits; 'Lapins' and 'Kordia' had upright growth with very few lateral shoots, whereas 'Veysel' had many lateral shoots and 'Sweetheart' had the smallest crown development. The best cumulative yields over the first three years were obtained from 'Techlovan' (4.50 kg/tree). Furthermore, in Macedonia, the yields of 10 cultivars on the Gisela 5 rootstock planted in a spacing 2.0 × 3.8 m and with a trained central leader system were evaluated (Gjamovski et al. 2016). There, the cultivar 'Octavia' brought the highest total harvest per tree (41.3 kg) up to the 5^{th} year after planting, but 'Kordia' (31.1 kg) was the next one, whereas 'Sunburst' (12.4 kg) was the least productive. Regarding the tree vigour parameters, 'Kordia' had the highest trunk cross-sectional area (97.0 cm^2), whereas 'Sylvia' (58.9 cm^2) had the smallest. In the case of the canopy volume, 'Stark Hardy Giant' (5.4 m^3) was the most vigorous, but 'Kordia' (4.7 m^3) was the next one, while 'Summit' (2.9 m^3) ranged on the opposite extreme. The cropping density, fruiting spur frequency and bare wood tendency (Lauri, Claverie 2008) belong to the range of tree characteristics that are mainly connected with the cultivar, but not with rootstock vigour.

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