RESULTS OF EXPERIMENTS WITH DENSELY-PLANTED SOUR CHERRY TREES FOR HARVESTING WITH A CONTINUOUSLY MOVING COMBINE HARVESTER

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A B S T R A C T

Sour cherry trees cultivars Debreceni Botermo, Nefris, English Morello and local Sokówka Serocka were densely planted at 4 x 1.4 x 1.5 and 4 x 2 m, and the leader trained for mechanical harvesting with a self-propelled straddle harvester working in continuous motion. From the 3rd year onward the trees were renewal-pruned. Branches older than 3 years were cut back and replaced by young wood. All the cultivars were suitable for mechanical harvesting, although the trees of 'English Morello' were the most difficult to train because of weak growth and trailing shape. Growth measurements over six years indicated that the optimal planting density for 'English Morello' trees was 4 x 1.5 m, and for the other cultivars 4 x 2 m. The harvester designed at the Institute of Horticulture, Skierniewice, was operated by 4 people and appeared to be able to harvest fruit with 95% effectiveness, delivering about 2000 kg of fruit per hour. Fruit quality was good for industrial processing, but not as good as that of hand-picked cherries suitable for freezing.

Key words: Morello cherries, mechanical harvesting, self – propelled straddle harvester

INTRODUCTION

The growing of sour cherry in Poland plays an important economic role. The fruit is grown on about 35 thousand hectares, and the annual harvest ranges from 180 to 200 thousand tonnes, except in the years when spring frosts damage the flowers or fruitlets. About 65% of harvested fruit is exported to Western Europe after initial treatment (Nosecka, 2005). The

price of sour cherry fruit is decided upon by large foreign corporations in the fruit industry, and with a large supply of this fruit in Europe prices in Poland have recently been low and production less profitable (Nosecka, 2005). Profitability of sour cherry production in Poland can be increased by intensifying production and lowering costs. First of all, the cost of harvesting should be reduced as it amounts to 55% of all production costs (Brzozowski, 2005). Sour cherries can be shaken off with mechanical shaking devices onto collecting screens spread under the trees, but the picking of fruits from the screens and cleaning them is quite troublesome and labour-intensive (Callesen, 1997). The fastest and most efficient way to collect sour cherries is with a continuously moving combine harvester, as in harvesting currants (Wawrzyńczak et al., 1998; 2001; 2006). A prototype of such a harvester was built at the Institute of Pomology and Floriculture in Skierniewice, and the technology of its construction was transferred to the agricultural machinery industry. A few units were thus produced, but their performance in orchards indicates the need for improvements in the design. In the coming years, economic conditions will force fruit growers to employ mechanical means of harvesting sour cherries.

Sour cherry grown at low density has a natural tendency to form dwarf trees, without a leader, with a few raised boughs. They form a flattened spherical crown with trailing branches ('English Morello') or a conical one with rigid branches ('Debreceni Botermo') (Rejman, 1994). Trees in this form are not suitable for harvesting with a continuously moving combine (Mika et al., 1982). Combine harvesting requires a dense row of trees in which each tree has a well-defined vertical leader to a height of 2.5-3.0 m with horizontal or angular branches that are thin and pliable (Mika et al., 2000). The trunk must have a minimum height of 70 cm. The described form is obtained by cutting off all lateral shoots after planting and forcing the growth of the leader by cutting out all new strong shoots that compete with it as soon as they appear (May-June). It takes 3 years to form the crowns. Once the formation of the crowns has been completed, renewal pruning begins, which is the post-harvest cutting out of 3-year-old and older branches. After pruning, the leader is left mainly with one- and two-year-old shoots; three-year-old shoots are also permissible if they are thin and short (Mika et al., 2000). Growing sour cherry trees at high density and the way they are formed and pruned changes their biology of growth and fruiting. Renewal pruning moves the fruit-bearing zone from the perimeter of the crown to its centre. It stimulates the growth of many young shoots, which is particularly beneficial to the sparsely-branching cultivar English Morello.

The aim of this study was to determine the optimum tree spacing for planting four sour cherry cultivars most commonly grown in Poland, to

adjust pruning to the peculiarities of their growth, to improve the existing combine harvester and to define the operating parameters of the combine in relation to the cultivars.

MATERIAL AND METHODS

In order to determine the optimum planting density of a few sour cherry cultivars for combine harvesting and the way to form and prune them, they were planted on 1 ha plot in the Experimental Orchard in Dąbrowice in 2004. The cultivars were laid out in rows and included: 'Debreceni Botermo' ('Debreczyn'), 'Nefris', 'English Morello' and 'Sokówka Serocka' (No. 29). All these cultivars had been grafted on *Prunus mahaleb*. In order to determine the optimum tree spacing for collecting fruit with a combine harvester, three distances for in-row planting were used: 1.0 m, 1.5 m, and 2.0 m, while maintaining the same distance of 4 m between the rows. New ways of pruning and shaping the crowns were used. In April 2005, the tree crowns were cut back by removing all lateral shoots to a height of 70 cm, leaving 1 or 2 buds at the base of the shoots above that level. All leaders taller than 150 cm were not cut back. Towards the end of May, for a period of 3 years, 2 or 3 of the top shoots competing with the leader and the excess of fruitlets were removed so that the leader could grow to a height of 2.5-3.0 m. From the third year onwards, renewal pruning was implemented, which consisted in cutting out every year 3 or 4 of the oldest, large branches, while leaving a stump at the leader, and moderate thinning of the crown. Each cultivar was planted in two rows growing side by side, with one row intended for harvesting by hand and the other with a combine harvester. In order to ensure cross pollination, beehives were placed on both sides of the experimental block. The rows were divided into plots with different tree spacing. There were five trees in each plot for combine harvesting and three trees to be harvested by hand. There were 4 replicates of each plot.

Every year measurements of the diameter of the tree trunks were taken, and when the trees were fully grown (2008-2009), the extent of the shoots branching out and the distribution of flower buds on one-, two-, and three-year-old shoots were recorded. Solar insolation of the crowns was also measured at three levels with a portable solarimeter and on this basis the density of the tree rows was determined. The measurements also included fruit yield per plot, mean fruit weight and the refractive index. The parameters determined on the combine-harvested plots were: the force needed to detach fruit from stem, the quantities of fruit collected, remaining on the tree, fallen to the ground, and damaged, and also harvesting efficiency in kg/h, and the number of damaged shoots (broken or with bark rubbed off). The results were analysed statistically with an analysis of variance, and the significance of the differences was assessed with Duncan's test.

RESULTS AND DISCUSSION

The results of the measurements of trunk diameter and crown height and span showed large differences in the intensity of the cultivars' growth, and even greater differences in the structure of their crowns (Tab. 1). The strongest growing trees were those of the 'Sokówka Serocka' and 'Debreceni Botermo', significantly less vigorous were the trees 'Nefris', and the least vigorous those of 'English Morello'. There was no significant effect of planting density on tree growth vigour until the sixth year after planting. The density of the crowns was determined by measuring the sunlight reaching the base of the crown (at a height of 1.0 m). The measurements showed an exceptionally low density of the crowns of the 'English Morello' in relation to all the other cultivars (Tab. 2). This feature indicates the need for dense planting and modest pruning of 'English Morello' trees (Mika, 2006). The different distances at which the trees were planted in a row had little impact on the levels of insolation, because the trees planted at low density used the free space in the row to fill it with branches. In three cultivars, insolation levels at the base of their crowns were very low, twice or 3 times as low as those in dwarf apple trees planted at a similar density (Mika et al., 2001). Despite the poor exposure of the base of the crowns to sunshine there was no marked reduction in the quality of the fruit in this zone, as is the case in apple. This leads to the conclusion that sour cherries respond less dramatically to extensive shading (exposure to less than 20% of the insolation level above the crowns), so they can be planted densely. Considering the growth of the 'English Morello' and the other cultivars, planting density of 4 x 1.5 m can be recommended for 'English Morello' and 4 x 2 m for the vigorously growing 'Debreceni Botermo', 'Nefris' and 'Sokówka Serocka'. The poor growth of 'English Morello' trees and their tendency to bear fruit early made the leader become indistinguishable. It was necessary to cut back he leader over 3 consecutive years in order to stimulate its growth. The 'Nefris' and 'Sokówka Serocka' branched out abundantly, 'Debreceni Botermo' moderately, and 'English Morello' sparsely (Tab. 3). 'English Morello' set only flower buds along the shoots, which terminated with one leaf bud. After fruiting, the shoots were left as bare wood. Only very long shoots (60-100 cm) set numerous leaf and flower buds. With renewal pruning, all the cultivars set flower buds abundantly on one-year-old growth (74-99%). The 'Debreceni Botermo' set significantly more buds on two- and three-year-old shoots than the other cultivars. Planting density had no influence on the above characteristics of tree growth. The allogamous 'Debreceni Botermo' and 'Nefris' began to flower 7-10 earlier than 'English Morello', which enabled cross-pollination between them. The late-flowering 'English Morello' is self-pollinating.

Table 1. Trunk cross-sectional area (TCSA), tree height and crown span in the sixth year after planting (2010)

Cultivar	TCSA [cm²]	Tree height [m]	Crown span [m]
Debreceni Botermo	38.36 bc*	3.15 c	2.03 ab
Nefris	33.21 b	2.77 bc	2.08 ab
English Morello	24.58 a	2.36 a	1.94 a
Sokówka Serocka	41.53 c	3.08 bc	2.25 b

*Means were evaluated within the columns. Duncan's multiple range t-test at p = 0.05

Table 2. Canopy density in tree rows as a percent of light intensity measured at 1.0 m above the ground

Cultivar	Distance between trees in a row [m]		
	1.0	1.5	2.0
Debreceni Botermo	6.3	5.2	4.9
Nefris	3.5	7.8	9.2
English Morello	26.5	20.9	16.7
Sokówka Serocka	3.1	2.3	4.9

Table 3. Mean number of bifurcations on a 3-year-old sour cherry bough and the percentage of flower buds on 1-, 2-, and 3-year-old shoots (2008-2010)

Cultivar	Debreceni Botermo	Nefris	English Morello	Sokówka Serocka
Number of bifurcations	21.7 b*	48.1 c	12.5 a	48.1 c
% flower buds on shoots				
1-year-old	74.4 a*	98.4 c	99.5 c	88.6 b
2-year-old	13.0 c	0.1 a	0.2 a	0.3 a
3-year-old	12.6 c	1.5 a	0.3 a	6.3 b

*Explanation: see Table 1

The beginning of fruit ripening in the cultivar 'Debreceni Botermo' came, depending on the year, between the tenth and twentieth of June. Soon after, the cultivar Nefris began to ripen, and about 7 days later the 'Sokówka Serocka' and 'English Morello'. Harvesting of 'English Morello' sour cherries was possible until 10 July. Up until the sixth year after planting (2010), fruit yields were quite low, mainly because of injuries caused by spring frosts. For that reason, no fruit crop was harvested in 2006-2007, and in 2009 it was much reduced. The most abundant and consistent fruit crop was produced by the 'Debreceni Botermo', and the worst by 'Sokówka Serocka'. The obtained results did

not confirm the opinion that the 'Debreceni Botermo' produced small fruit crops in Polish climatic conditions (Szpadzik et al., 2009). The 'English Morello', known for its high productivity (Szpadzik et al., 2009), did not produce the expected high yields because tree growth was too slow on the low fertility soil of Class IV B. The 'Sokówka Serocka', despite the strong growth and excellent condition of the trees, produced fruit very sparingly. This confirms the often repeated opinion that national, locally-bred cultivars bear fruit abundantly only in those habitats where they come from. There were no significant differences in fruiting between the trees intended for manual collection of fruit and those for combine harvesting. The different density of planting in a row had little effect on the yield per tree (Tab. 4). Fruit quality depended on the cultivar and the method of harvesting (Tab. 5). Sour cherries 'Sokówka Serocka' had the highest values of the refractive index, and those of the 'Nefris' the highest weight. The differences in these parameters between the other cultivars were not very significant. Tree planting density had little effect on fruit quality traits. Sour cherries 'Debreceni Botermo' and 'Sokówka Serocka' had significantly higher values of the refractive index for the planting distance of 2 m than 1 m. There was an inverse relationship for mean fruit weight.

Table 4. Effect of cultivars and tree spacing on total fruit yield [kg/tree] for 2008-2010

Cultivar	Distance between trees in a row [m]			Productivity index [kg cm^{-2} TCSA]
	1.0 m	1.5 m	2.0 m	
Debreceni Botermo	13.2 c*	14.1 c	16.3 c	1.13 b
Nefris	9.8 b	12.2 b	12.2 b	1.03 b
English Morello	9.6 b	9.3 b	10.0 b	1.17 b
Sokówka Serocka	4.6 a	7.5 a	6.4 a	0.44 a

*Explanation: see Table 1

Table 5. Effect of cultivars and tree spacing on fruit quality traits

Cultivar	Refractive index [%]			Mean fruit weight [g]		
	1 m	1.5 m	2 m	1 m	1.5 m	2 m
Debreceni Botermo	13.7 a*	13.6 a	14.3 b	3.9 a	4.4 ab	4.2 a
Nefris	14.7 ab	14.4 a	14.8 b	5.1 c	4.9 bc	5.3 b
English Morello	14.0 ab	13.8 a	13.6 a	4.4 b	4.5 ab	4.2 a
Sokówka Serocka	17.1 c	17.9 c	18.2 c	4.3 b	4.1 a	4.1 a

*Explanation: see Table 1

The three cultivars: Debreceni Botermo, Nefris, Sokówka Serocka were all easily adapted for harvesting with a continuously moving combine. The 'English Morello' proved to be the most difficult to shape for this method of harvesting because of the leader becoming indistinguishable and the difficulties with forming a trunk that was at least 70 cm tall. These difficulties could well be avoided by growing sour cherry trees on a soil one class higher in terms of fertility.

In the years 2009-2010, sour cherries of all four cultivars were harvested with a combine harvester. The self-propelled combine operating in continuous motion collected fruit at the following parameters: operating speed – 0.8 km· h^{-1} frequency of shaking – 14 Hz, stroke of shaking fingers – 90 mm. Prior to harvesting, 100 fruits of each cultivar were used to measure the detachment force between fruit and stem with an electronic dynamometer with an accuracy of 0.01 N. Fruits were harvested when the average fruit detachment force dropped below 3 N. The results of those measurements are summarized in Table 6.

Table 6. Fruit detachment force measured before mechanical harvesting

Cultivar	Pedicel-fruit detachment force [N]		
	minimum	mean	maximum
Debreceni Botermo	0.14	2.18	6.4
English Morello	0.15	2.12	4.09
Sokówka Serocka	0.39	2.68	4.89
Nefris	0.31	2.61	6.29

Table 7. Results of sour cherry harvests with a continuously moving self-propelled combine harvester

Cultivar	Fruit remaining on tree [kg/%]	Fruit fallen to the ground [kg/%]	Fruit collected [kg/%]	Yield [kg/%]	Harvest duration [h]	Harvest efficiency [kg/h]
Debreceni Botermo 2009-2010	73.47	76.81	1225.47	1375.76	0.53	2312
	5.34%	5.58%	89.08%	100.00%		
English Morello 2009-2010	28.48	155.61	923.90	1107.99	0.51	1812
	2.57%	14.04%	83.39%	100.00%		
Sokówka Serocka 2010	10.49	26.79	342.47	379.75	0.25	1370
	2.76%	7.05%	90.18%	100.00%		
Nefris 2010	8.21	30.56	793	831.77	0.30	2643
	0.99%	3.67%	95.34%	100.00%		

During the harvest, records were kept of the quantities of the fruits harvested, fallen to the ground and remaining on the trees, and also the duration of the harvest. The values of the harvest parameters recorded during the harvesting of sour cherries with a combine harvester are summarized in Table 7.

CONCLUSIONS

1. There are considerable differences in growth intensity, shoot propagation, crown structure, and the characteristics of flower bud setting in the four most commonly grown sour cherry 'Debreceni Botermo', 'Nefris', 'English Morello' and 'Sokówka Serocka'.
2. The 'English Morello' stands out with its poor growth, low ability to propagate shoots, and a peculiar way of setting flower buds that causes the shoots to become bare wood and the crown to adopt a trailing habit.
3. 'English Morello' requires special shaping treatments in order to define the leader and make the trunk suitable for combine harvesting.
4. 'English Morello' requires fertile soil. It should not be planted on poor soil.
5. The 'Debreceni Botermo' sets significantly more buds on two- and three-year-old shoots than all the other cultivars.
6. The differences in the growth and fruiting characteristics of the cultivars should be taken into account when determining planting density and tree shaping and pruning requirements.
7. The results of the experiment, located on a soil of average quality, suggest that the optimal spacing for planting sour cherry trees intended for combine harvesting is: 4 x 1.5 m for a weak-growing cultivar and 4 x 2 m for a vigorous one.
8. The improved version (2009-2010) of the combine harvester, operated by 4 people, makes it possible to collect sour cherries with an efficiency of 2.0 tonnes per hour at 95% effectiveness in collecting the fruit. Four people picking sour cherries by hand can reach an efficiency of about 50 kg per hour.

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WYNIKI BADAŃ NAD UPRAWĄ WIŚNI W ZWARTEJ ROZSTAWIE I ZBIOREM OWOCÓW KOMBAJNEM W RUCHU CIĄGŁYM

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S T R E S Z C Z E N I E

W Sadzie Doświadczalnym w Dąbrowicach przez 6 lat uprawiano cztery odmiany wiśni ‘Debreceni Botermo’, ‘Nefris’, ‘Łutówka’ i ‘Sokówka Serocka’ przystosowane do zbioru owoców kombajnem w ruchu ciągłym. Drzewa posadzono w rozstawie 4 m między rzędami i w zmiennej rozstawie w rzędzie: 1 m; 1,5 m; 2 m. Uformowano korony przewodnikowe i zastosowano cięcie odnawiające od czwartego roku drzew. Po czterech latach od założenia sadu zbierano owoce kombajnem samobieżnym pracującym w ruchu ciągłym. Zbiór kombajnowy porównywano ze zbiorem ręcznym.

Stwierdzono duże różnice między odmianami w intensywności wzrostu drzew, strukturze koron, charakterze zawiązywania się pąków kwiatowych na pędach. Różnice te należy uwzględnić przy formowaniu i cięciu drzew. Na podstawie uzyskanych wyników sugeruje się rozstawę drzew 4 x 1,5 m dla odmian rosnących słabo i 4 x 2 m dla odmian rosnących silnie. Kombajn obsługiwany przez 4 osoby zbierał 2 tony owoców na godzinę przy sprawności 95% owoców zebranych. Cztery osoby zbierały w tym czasie około 50 kg owoców. Jakość owoców zbieranych kombajnem była nieco gorsza niż zbieranych ręcznie. Owoce te chętnie kupowano do tłoczenia.

Słowa kluczowe: wiśnia, zbiór mechaniczny, kombajn samojezdny