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COMPARISON OF THE YIELDING OF PLUM, SOUR CHERRY, AND SWEET CHERRY TREES TRAINED TO A TRELLIS FOR MECHANICAL HARVESTING OF FRUIT WITH THOSE TRAINED TO A LEADER

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ABSTRACT

In 2014, plum, sour cherry and sweet cherry trees were planted in an experimental plot of the Institute of Horticulture – National Research Institute at a distance of 4.5 m between rows and, depending on the cultivar, every 1.5, 2.0 and 2.5 m in a row. The trees were trained in the shape of the letter 'Y', with the shoots raised at an angle of 20° or 30° to the horizontal, intended for mechanical harvesting of dessert fruit with a harvester attached to a tractor. The two tree canopy formation systems at both shoot inclination angles were compared with the standard spindle crown with a vertical leader, from which the fruit was picked by hand. After 3 years of training the trees, mechanical harvesting of dessert fruit began with a harvester designed at the Institute of Horticulture in Skierniewice. The trees formed in the shape of the letter 'Y' produced comparable yields, and also higher and lower yields, depending on the cultivar, in comparison with the trees trained to a spindle crown.

Key words: stone fruit, canopy form, way of harvesting, tree efficiency

INTRODUCTION

Due to the high cost of manual harvesting of stone fruits, possibilities have arisen to harvest them mechanically. In recent years, great progress has been made in the mechanical harvesting of soft fruits intended for processing. Nowadays, several species of fruit shrubs and trees, such as olive, sour cherry, plum and other species, are harvested mechanically [Brown et al. 1983, Wawrzyńczak et al. 1998, Jiménez et al. 2011, Ferguson et al. 2012, Mika et al. 2012, Rabcewicz et al. 2017]. Experimental work has been underway to improve the technology of stone fruit harvesting [Ampatzidis et al. 2012, Larbi and Karkee 2014, He et al. 2015]. In the beginning, the mechanical harvesting of the stone fruits was carried out with the use of shaking devices that gripped the tree trunk. However, this method has several disadvantages, in particular the bruising of the harvested fruit and the low harvesting effectiveness [Castro-García et al. 2012]. On the contrary, the mechanical harvesting of soft dessert fruits has not yet been satisfactorily solved. Attempts at the mechanical harvesting of dessert stone fruits have revealed that tree architecture is in this case, very important. The trees should have only one layer of branches that in shape the letter 'Y'.

The mechanical harvesting of plums for industrial purposes has already been resolved. Diener et al. [1982] reported that a harvester had been constructed in West Virginia that was capable of harvesting fru-

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it from both large trees and smaller ones that were grown at high densities. The fruit harvesting combine mentioned by the authors had a very high harvesting efficiency of 6–7 t · h^{-1}. However, the fruit was not suitable for the dessert market due to the bruising caused by the combine harvesting. In 2008, at the Institute of Horticulture – National Research Institute in Skierniewice, attempts were initiated to machine-harvest dessert fruit from trees shaped in the form of a horizontal crown, with only one layer of branches spread in the shape of the letter 'T'. In that experiment, a task was undertaken to mechanically harvest plums for dessert use from trees planted at high density [Mika et al. 2016]. The thickness of the canopy of the trees formed in this way was about 1.5 m along the vertical section. The dessert plums of these trees could be harvested with a small harvester hitched to a tractor. During the combine harvest, the fruits were lifted off the tree crowns and fell onto a mobile conveyor from a short distance, a maximum of 1.5 m, so that they did not bruise as much as during harvesting with a large harvester for processing. In that experiment, in the years 2008–2015, two systems of training the canopy of 'Elena' plum trees were compared: trees in the form of a horizontal T-shaped crown and tall trees in a standard conical form [Mika et al. 2016].

Most of the sour cherry fruit is used for industrial purposes, as the demand for dessert sour cherries is low. On small plantations, sour cherries intended for processing are harvested by hand. On large plantations, sour cherries have long been harvested mechanically with shaking the trees by the trunk. The cherries fall from the trees onto the tarpaulins spread on the ground under them. The quality of mechanically harvested sour cherries is inferior to that of hand-picked sour cherries; however, they are allowed to be processed later in juices and jams. Sour cherry fruit intended for frozen food should be picked by hand [Mika et al. 2011]. Research on the mechanical harvesting of sour cherries for processing was conducted by Peterson and Wolford [2001]. The experiments by Mika et al. [2011] investigated the use of a self-propelled harvester for the mechanical harvesting of sour cherries intended for processing from densely planted trees with spindle-shaped leader crowns pruned with the renewal method. The results obtained were satisfactory. The effectiveness of mechanical harvesting of sour cherries can be improved by spraying the trees with Ethrel 7–14 days before harvesting to facilitate detachment of the fruit from the stalk [Peterson 2005 after Bukovac et al. 1971]. Manual harvesting of stone fruits, such as plums and sour cherries, is arduous and very labour-intensive. For this reason, the horizontal T-shaped canopy seems to be a justified solution for the mechanical harvesting of dessert plums and sour cherries.

As the standard of living increases, so does the demand for fresh sweet cherries in Europe and the United States. The fruit should be large, attractive, tasty, and available for a long time (up to 10 weeks in Europe). The production of sweet cherry fruit has been steadily increasing in Europe, the United States, Canada, and Chile. In all these regions, the shortage of manpower for manual harvesting can be an obstacle to the cultivation of sweet cherry.

The main objective of the experiment was to create a new orchard architecture and determine the suitability of trees trained to a horizontal 'Y' crown for the mechanical harvesting of plums, sour cherries and sweet cherries as dessert fruit, in comparison with standard trees with a spindle crown, the fruit of which were picked by hand.

MATERIAL AND METHODS

In spring of 2014, at the Institute of Horticulture, the National Research Institute in Skierniewice, Poland, fruit trees, including plum, sour cherry and sweet cherry trees, were planted in an experimental 0.75 ha plot (longitude 51°57'N, latitude 20°08'E, altitude 120 m).

The following cultivars were planted: two plum cultivars 'Record' and 'Empress' grafted on Wangenheim Prune semi-dwarfing rootstock and one plum cultivar 'Węgierka Zwykła' ('Common Prune') grafted on the Myrobalan plum; two sweet cherry cultivars: 'Lapins' grafted on the Colt rootstock and 'Kordia' grafted on the F12/1 rootstock; and four sour cherry cultivars: 'English Morello', 'Nefris', 'Kelleris 16' and 'Debreceni Botermo' grafted on the Mahaleb cherry. The trees of all the cultivars were planted with the same spacing between the rows, which was 4.5 m. The spacing in the rows varied according to the expected growth of trees of a given cultivar. Low-vigour sour cherry trees were planted 1.5 m apart in a row, moderate-vigour plum and sweet cherry trees every 2.0 m, and the vigorously growing plum and sweet cherry trees every 2.5 m. To create optimal conditions for the continuous operation of the fruit harvester, each cultivar was planted in a separate 160-m-long row. The rows of the plum cultivars grafted on the semi-dwarfing rootstock contained 80 trees, the rows of the plum trees grafted on the vigorous rootstock – 72, and of the sour cherry trees – 94. There were 69 sweet cherry trees of the 'Lapins' cultivar and 32 of the cultivar 'Kordia' growing in a row.

Three methods of tree crown formation were used in the experiment:

1. Formation of tree crowns in the shape of the letter 'Y' with shoots raised at an angle of 20° to the horizontal (Fig. 1).
2. Formation of tree crowns in the shape of the letter 'Y' with shoots raised at an angle of 30° to the horizontal (Fig. 2).
3. Control – formation of trees in the shape of a spindle crown with a leader tied to a stake (Fig. 3).

Fig. 1. Plum trees with the branches stretched at the angle 20° to the horizontal (photo by Z. Buler)

Fig. 2. Sour cherry trees with the branches stretched at the angle 30° to the horizontal (photo by Z. Buler)

Fig. 3. Control. Plum trees trained in the leader spindle form (photo by Z. Buler)

In June 2014, a load-bearing structure was installed in the entire plot. In the control plot, where the standard spindle-shaped leader crowns were to be formed, strong metal stakes were driven into the ground and all trees were tied vertically to them. In order to form a trellised canopy, 2 m long concrete posts were installed in the rows of trees (sunk into the ground to a depth of 80 cm), and on top of them, at a height of about 1.2 m, steel brackets were mounted horizontally, which were used to stretch four wires along the rows. To obtain a relatively uniform growth of trees, two planes of crown training were introduced, with the branches tilted upward at 20° and 30°.

In June, the shoots of the trees trained to a trellised Y-shaped crown began to be tied to the wires stretched along the row. The tying of the shoots in the trellised crowns continued until August, successively as the shoots grew and developed. In spring, in the control plum trees, i.e., the trees trained to a spindle crown, the leader was cut back slightly at a height of 1.7 m, and undesirable lateral branches were cut off. In the control sour cherry trees, due to their tendency to fruiting too early, all lateral shoots were cut short to 1–2 buds, leaving only 5–10 cm long stubs. After such pruning, the leader quickly gains dominance and forms the main axis on the tree crown. From the left-over stubs, new shoots developed, weaker than the leader, which were suitable for tying to the wire trellis. The leaders of the sour cherry trees were cut 90 to 100 cm above the ground. The sweet cherry trees were not branched at planting. Their leaders were cut 90 to 100 cm above the ground so that lateral shoots would grow from buds below that height. The control

'Kordia' trees had 2 to 4 lateral shoots in the crown, which were not shortened. The leaders in this sweet cherry cultivar were cut back at a height of 90–100 cm above the ground.

Tree training treatments for all the control trees in the experiment were carried out from May to August. In May, those trees had clips put on the young shoots that grew vertically to make them grow horizontally. Despite these measures, strong vertical shoots started to grow at the top of the leader. Therefore, in late May/early June, all the top shoots growing out at an acute angle to the leader were removed in the control trees. Attempts were made to prevent all new growth except for the shoot that was an extension of the leader. The crown of the trees in the control combination should adopt a slender shape, which is necessary for dense tree planting. As a result of this treatment, many small, short, horizontal fruiting shoots grew out on the leader during the first year. In June began the bending of the lateral shoots to a horizontal position so that the crowns could adopt the correct shape. The shoots were bent back with strings tied to pins driven into the ground. Bent shoots grow less vigorously, produce more flower buds, and therefore bear more fruit. Shoots were bent back several times over the summer.

The rows of trees were divided into three 50 m long blocks. The blocks were separated from each other by a 10 m wide access road used to drive the combine into rows of trees. For each tree species, there was a control block for manually harvesting the fruit from the trees with spindle-shaped crowns. The harvest of fruit from the Y-shaped trees that grow in the other two blocks was done with a combine harvester.

The appropriate time to harvest the fruit from the trees was determined by measuring the force of detachment from the peduncle using a digital dynamometer Lutron FG 5000A (49,03 N × 0,01 N). The average fruit detachment force one day before harvest, depending on the cultivar within the species and the year, ranged from 3.4 to 7.2 N for sweet cherries. Sour cherries were characterised by lower values of fruit detachment force during the study. These ranged from 1.5 to 5.4 N. The force of binding the fruit to the peduncle during the trials for plums ranged from 5.1 to 12.6 N.

The fruit was harvested using a dessert fruit harvester developed at the National Institute of Horticultural Research. Technical data of the harvester are as follows: length 10.3 m in working position, width 2.8 m, height 3.4 m, number of shakers – 1, shaking frequency 0–20 Hz, crew 2–3 people. The fruit shaking time during harvesting was determined by the operating speed of the harvester, which ranged from 0.35 to 0.5 km·h–1 depending on the fruit yield per tree for the given cultivar. The higher the fruit yield per tree, the lower the operating speed of the harvester. The frequency of operation of the fruit shaker during combine harvesting depended on the previously measured fruit-peduncle bond strength. The higher the force of binding the fruit to the peduncle, the higher the frequency of the shaker operation. The frequencies used, depending on the cultivar within the species and the year, ranged from 7 to 12 Hz for sweet cherries, from 8 to 11 Hz for sour cherries and from 7 to 11 Hz for plums.

The experiment assessed the yielding of trees of all the cultivars and compared the fruit yields obtained in the three different methods of crown formation. The results were statistically evaluated and presented in the form of tables and graphs (Statistica data analysis software system version 13. TIBCO Software Inc. 2017). The results were statistically processed by analysis of variance for each cultivar separately using Duncan's t-test at $P < 0.05$

RESULTS AND DISCUSSION

The plum, sour cherry, and sweet cherry trees in all the tree-training systems came into bearing fruit in the third year after planting (2016). Depending on the species and cultivar, the fruit yields were from 1 to 5 kg · tree^{-1} (Figs 4–12). The highest yields were recorded for the trees of the plum cultivar 'Record' grown in the shape of the letter 'Y' with the shoots raised at an angle of 20° to the horizontal. They were almost as high as 8 kg · tree^{-1} (Fig. 5). Fruit yields fluctuated in all the years of the experiment due to changeable weather conditions during the growing season. The experiment showed that the trees formed in the shape of the letter 'Y' with shoots raised at an angle of 20° or 30° to the horizontal gave comparable, and in some cases even higher, but also lower, yields than the trees trained to a spindle-shaped leader crown (Figs 4–12). The obtained results of tree

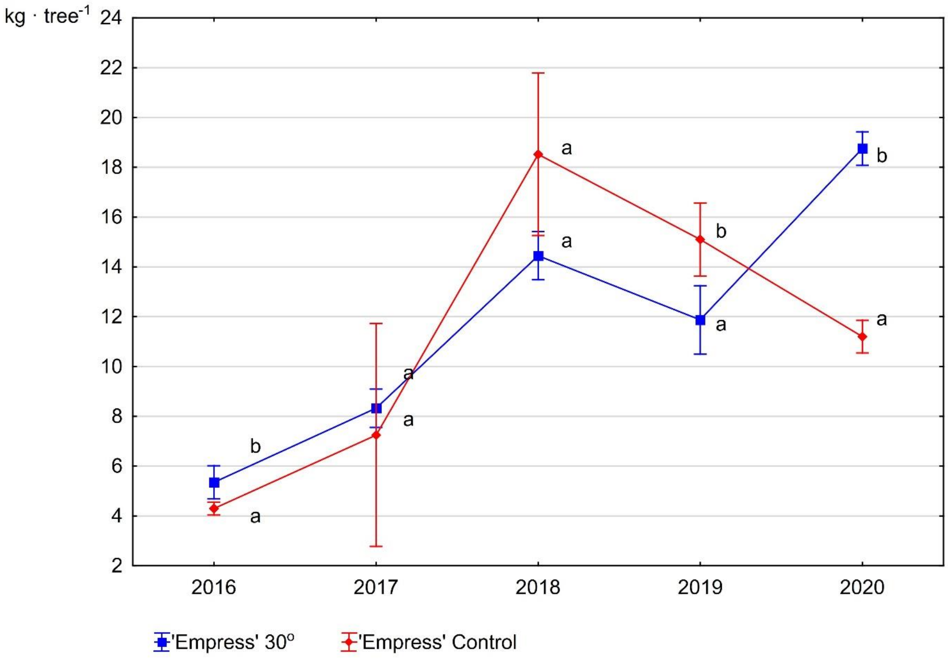

Fig. 4. Yielding of 'Empress' plum trees in kg · tree^{-1} in two tree-training systems in the years 2016–2020

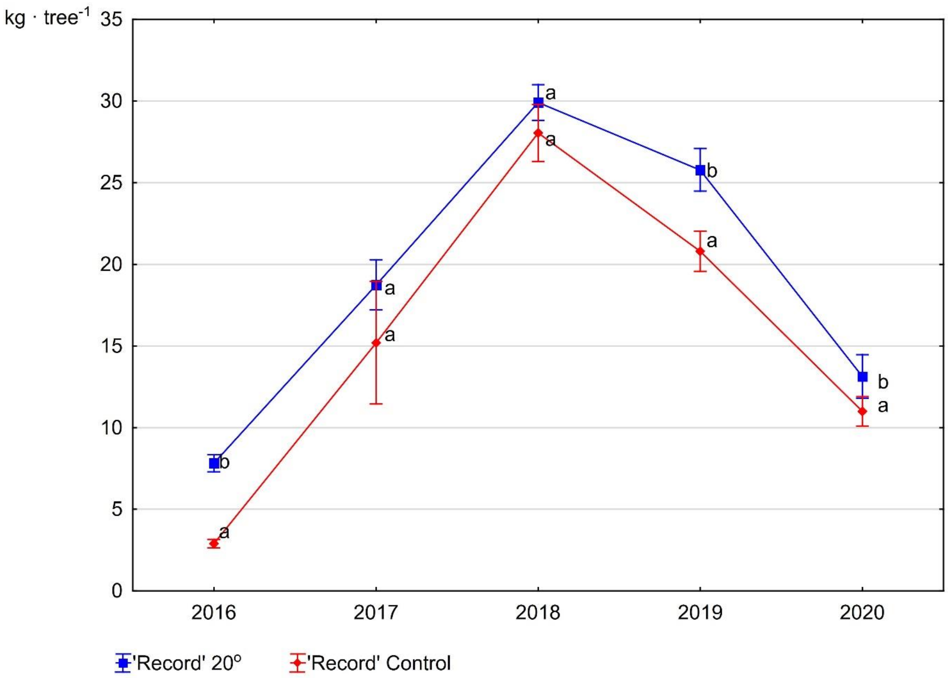

Fig. 5. Yielding of 'Record' plum trees in kg · tree^{-1} in two tree-training systems in the years 2016–2020

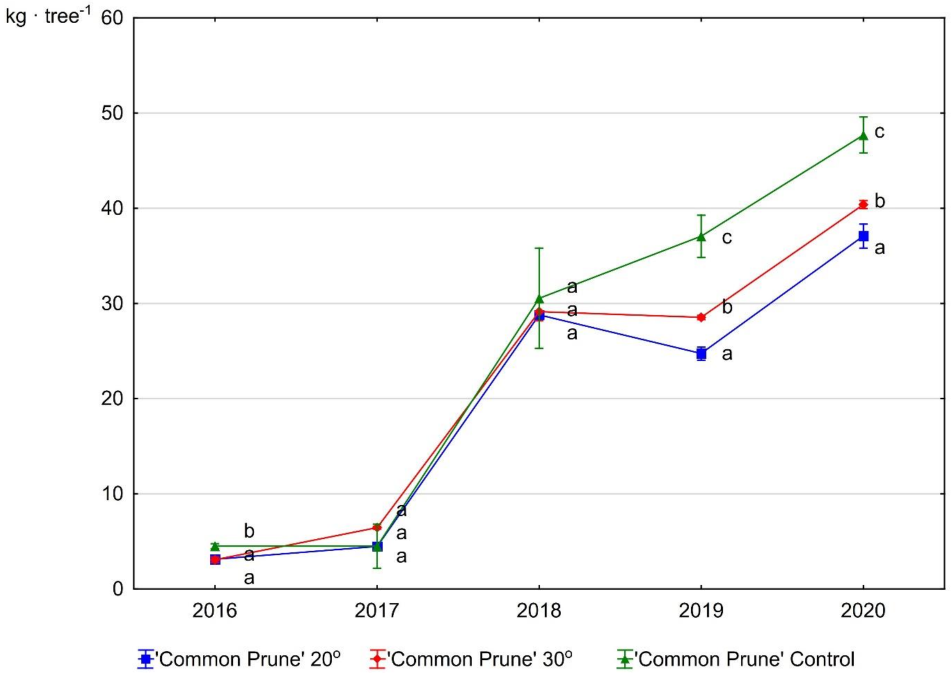

Fig. 6. Yielding of 'Common Prune' plum trees in kg · tree^{-1} in three tree-training systems in the years 2016–2020

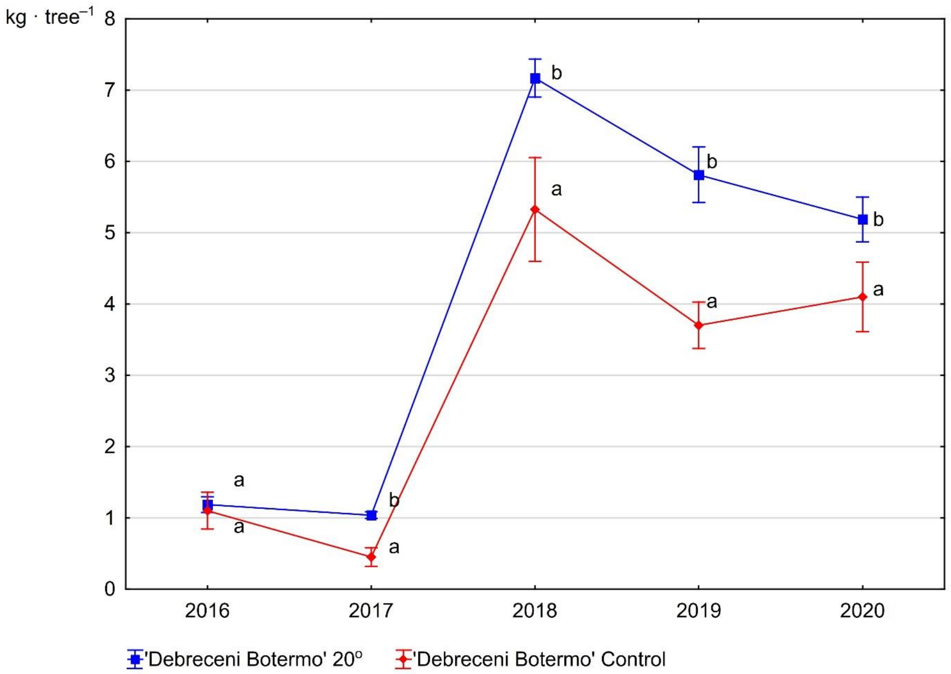

Fig. 7. Yielding of 'Debreceni Botermo' sour cherry trees in kg · tree^{-1} in two tree-training systems in the years 2016–2020

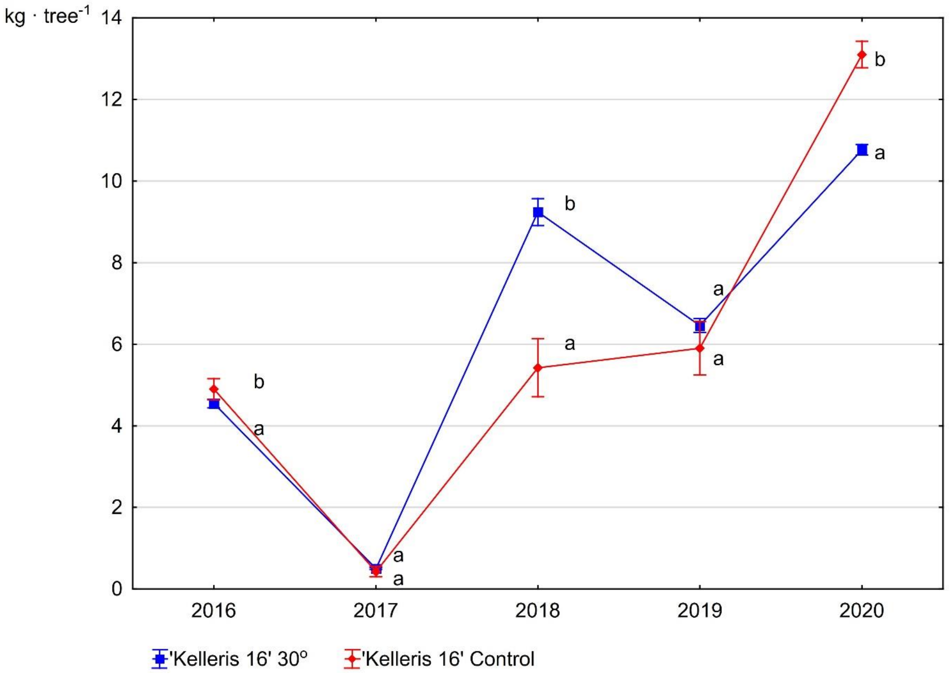

Fig. 8. Yielding of 'Kelleris 16' sour cherry trees in kg · tree^{-1} in two tree-training systems in the years 2016–2020

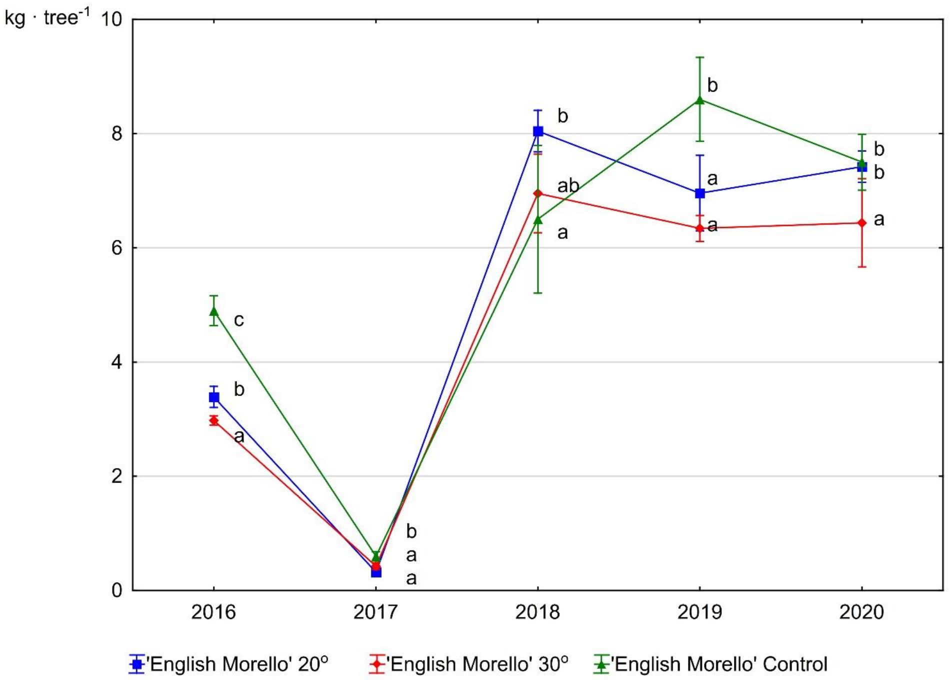

Fig. 9. Yielding of 'English Morello' sour cherry trees in kg · tree^{-1} in three tree-training systems in the years 2016–2020

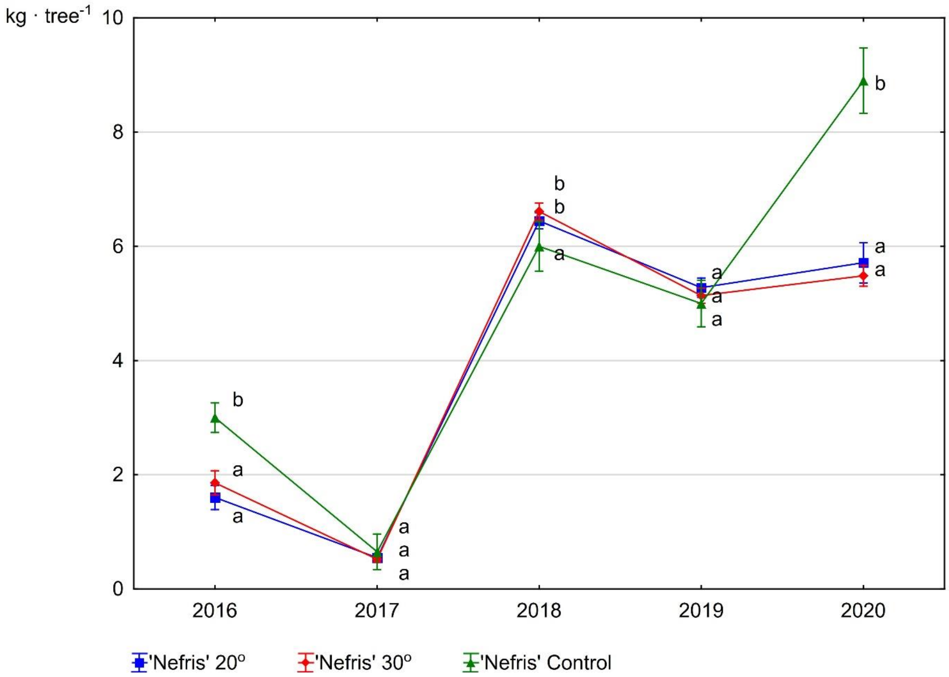

Fig. 10. Yielding of 'Nefris' sour cherry trees in kg · tree^{-1} in three tree-training systems in the years 2016–2020

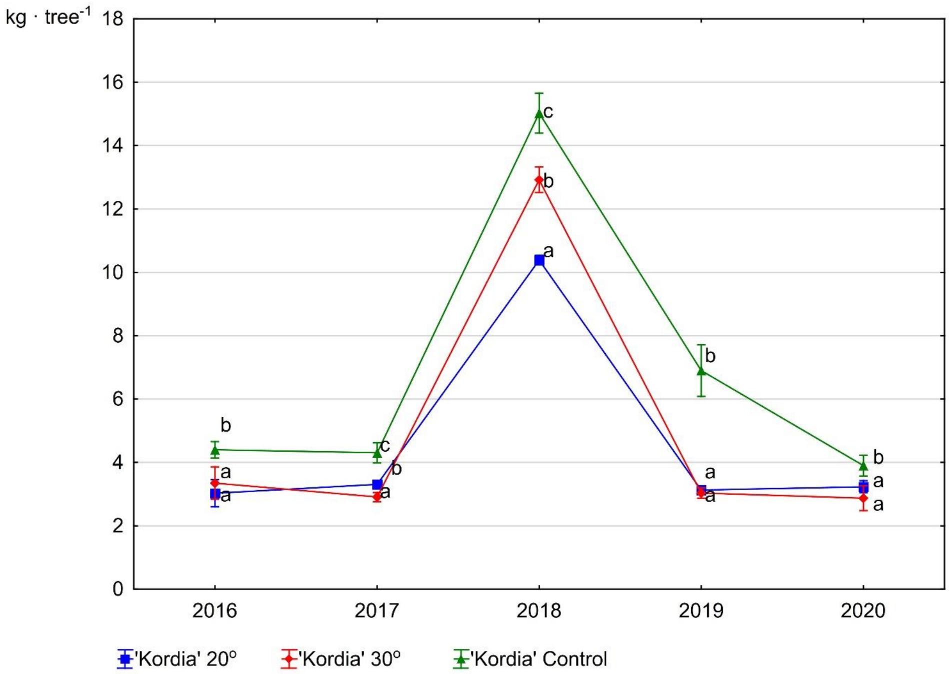

Fig. 11. Yielding of 'Kordia' sweet cherry trees in kg · tree^{-1} in three tree-training systems in the years 2016–2020

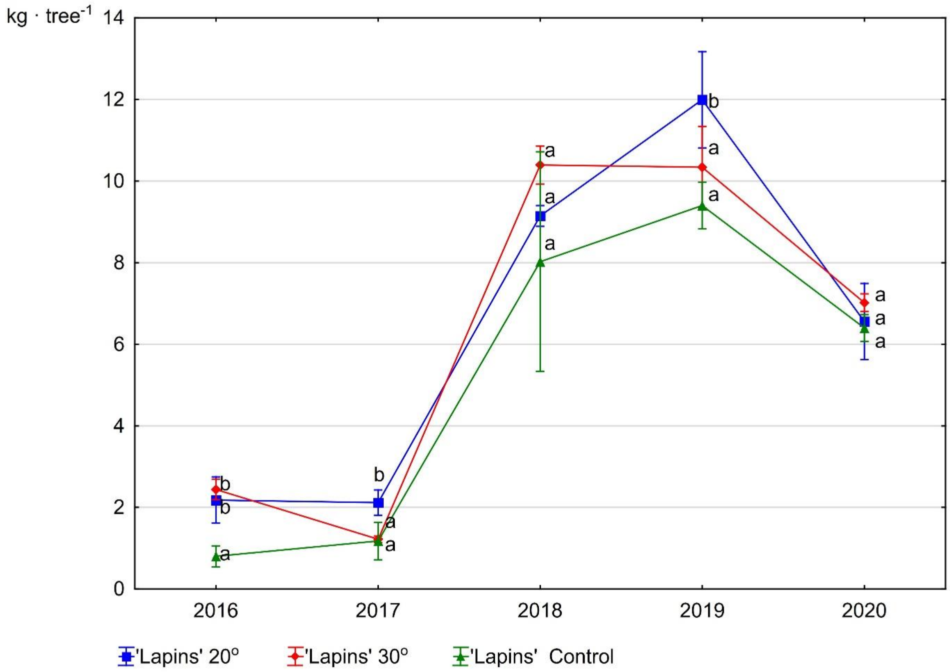

Fig. 12. Yielding of 'Lapins' sweet cherry trees in kg · tree^{-1} in three tree-training systems in the years 2016–2020

yield confirm the previous research of many authors [Ampatzidis et al. 2012, Day et al. 2013, Larbi and Karkee 2014, He et al. 2015, Mika et al. 2016]. In the fourth year after planting the trees (2017), fruit yields were low due to a cool spring and frosts in April. This had a clear negative impact on the yield of all four sour cherry cultivars (Figs 7–10). In 2018, the weather conditions in the spring were very favourable. The trees of all the plum, sour cherry, and sweet cherry cultivars bloomed profusely and bore fruit abundantly. Fruit yield depended on the tree species and cultivar. For plum trees it ranged from 14.5 to 30.6 kg · tree^{-1} (Figs 4–6), for sour cherry trees from 5.3 to 9.2 kg · tree^{-1} (Figs 7–10), and for sweet cherry trees from 8.0 to 15.0 kg · tree^{-1} (Figs 11–12). In vigorously growing apple and pear trees, shoot bending advances and increases the fruiting of trees. This outcome was not found in this experiment. The fruit yields obtained from the trees whose shoots were bent back at an angle of 20° or 30° were similar, and in some cases higher, but also lower, than the yields produced by the control trees, i.e. those growing straight with a vertical leader and a spindle crown. In 2018, as a result of the very abundant production of trees of all cultivars, the harvest with the combine achieved 20–30 times higher productivity per hour than manual harvesting for plums, and 60–70 times higher productivity for sour cherries and sweet cherries. In 2019 and 2020, spring temperatures were exceptionally moderate, with many sunny days with little rainfall. The trees of all species bloomed profusely, preparing a heavy fruit set. Unfortunately, in April, during the flowering of trees, spring frosts occurred, which destroyed some of the flowers on trees of different cultivars. This situation contributed to poor fruit development and lower tree yields. This was especially evident in both sweet cherry cultivars (Figs 11–12), as well as in the sour cherry cultivars 'Debreceni Botermo' (Fig. 7) and 'Nefris' (Fig. 10), and in the plum cultivars 'Empress' (Fig. 4) and 'Record' (Fig. 5). In 2020, high fruit yields were obtained only for sour cherries from the trees of the cultivar 'Kelleris 16'. They ranged from 10.8 to 13.1 kg · tree^{-1} (16.0–19.4 t · ha^{-1}) – Fig. 8. Record yields were obtained for plums from the trees of the cultivar 'Common Prune'. The yields ranged from 37.1 to 47.7 kg · tree^{-1} (32.9–42.4 t · ha^{-1}) – Fig. 6. Yields of plums at the level of 20 t · ha^{-1} and sour cherries at 15 t · ha^{-1} are profitable in Poland, giving returns on the

Table 1. Total fruit yields in kg · tree^{-1} for three tree training systems for the years 2016–2020

Cultivar	Tree-training system		
	control	'Y'-system 20°	'Y'-system 30°
	plum trees		
'Record'	78.0 ±6.02 a*	95.4 ±1.93 b	–
'Empress'	56.4 ±2.44 a	–	58.8 ±0.92 a
'Common Prune'	124.3 ±4.57 c	98.2 ±1.43 a	107.6 ±0.98 b
	sour cherry trees		
'Debreceni Botermo'	14.7 ±0.68 a	20.4 ±0.57 b	–
'Nefris'	23.6 ±1.31 b	19.6 ±0.83 a	19.6 ±0.45 a
'Kelleris 16'	29.8 ±1.27 a	–	31.5 ±0.41 b
'English Morello'	28.1 ±1.17 b	26.1 ±0.75 b	23.1 ±1.70 a
	sweet cherry trees		
'Kordia'	34.5 ±1.23 c	23.1 ±0.56 a	28.4 ±0.43 b
'Lapins'	25.8 ±2.90 a	32.0 ±1.58 b	31.4 ±1.77 b

* Means in each line separately for the cultivar indicated by the same letter do not differ significantly according to the Duncan test at $p = 0.05$

expenditure incurred. Tree training systems with a horizontal Y-shaped crown with shoots raised at an angle of 20° to the horizontal or with shoots raised at 30° to the horizontal significantly increased the production of 'Empress' and 'Record' plum trees (in some years) – Figs 4–5, 'Debreceni Botermo' sour cherry trees (Fig. 7), and 'Lapins' sweet cherry trees (Fig. 12). Trees with a horizontal crown at either of the two angles of shoot inclination gave significantly lower yields compared to the control in the case of the plum cultivar 'Common Prune' (Fig. 6), the sour cherry cultivars 'Kelleris 16' (Fig. 8), 'English Morello' (Fig. 9) and 'Nefris' (Fig. 10) in some years, and the sweet cherry cultivar 'Kordia' (Fig. 11). The total yields for the years 2016–2020 show that the 'Record' plum trees, the 'Debreceni Botermo' and 'Kelleris 16' sour cherry trees, and the 'Lapins' sweet cherry trees trained in the trellis systems with a horizontal crown ('Y'-20° and 'Y'-30°) produced higher fruit yields than the control trees (Tab. 1). This is a very positive result for these cultivars, which was not expected at the time of setting up the experiment.

The result obtained in our trial are more or less similar to that presented by Mika et al. [2012]. Stone fruit destined to mechanical harvesting should be densely planted to form continuous wall within the row. Trees should be trained to a spindle-shaped leader system or to 'Y' system with limited number of main branches. When trees come into bearing they should be pruned by the renewal method to assure new fruiting wood. In such training system of plum trees it is possible to obtain harvesting efficiency 2–3 t·h^{-1}, with an effectiveness of 90–95%. In the trial presented by Mika et al. [2012], the quality of plums harvested for processing, especially of the small-fruited varieties from the 'Węgierki' ('Common Prune') group, was so good that, after sorting, 80% was suitable for the local dessert fruit market. However, this harvester is not suitable for harvesting large-fruited dessert plums, nor dessert sour cherries, nor sweet cherries from the standard spindle-shaped leader crown because some of the crop shows bruising marks. The fruits shaken off trees with this harvesting technology fall onto a moving conveyor from too high a height of 0.5 to 2.5 m.

The results of our trial supports intensive research undertaken by many research centers to solve the problem of mechanical harvesting of sweet cherries [Peterson and Wolford 2001, Peterson 2005, Seavert and Whiting 2011, Ampatzidis et al. 2012, Ampatzidis and Whiting 2013, Larbi and Karkee 2014, He et al. 2015]. The studies by Ampatzidis et al. [2012], Larbi and Karkee [2014], He et al. [2015] indicate that mechanical harvesting of sweet cherry fruit is possible when trees are shaped like the letter 'Y' with a limited number of branches in their crown.

The architecture of the tree canopy in an orchard has a large impact on the efficiency of both manual and mechanical harvesting. The crowns of sour cherry trees adapted for mechanical harvesting of dessert fruit should have 2–3 skeletal limbs inclined towards the inter-row and trained to the Y-shape. The main limbs should be short and stiff, inclined at an angle of 45–60° to the horizontal [Peterson 2005]. One of the best shapes of tree canopy from which fruit will be harvested mechanically is the Y-trellis system. In their experiment, Peterson and Wolford [2001] found that the highest efficiency during mechanical harvesting of sweet cherries was obtained when the trees were trained in the Y-trellis system, with 6–8 skeletal limbs in the crown inclined at an angle of 45–60°. Day et al. [2013] compared the Y-form with standard tall trees that had a vertical leader and found that standard trees were only slightly more productive than short Y-shaped trees.

CONCLUSIONS

1. Plum, sour cherry and sweet cherry trees trained to a horizontal Y-shaped crown with shoots raised at an angle of 20° or 30° to the horizontal are useful for harvesting dessert fruit with a harvester hitched to a tractor.

2. Plum, sour cherry and sweet cherry trees of the cultivars 'Empress', 'Record', 'Debreceni Botermo' and 'Lapins' trained in a horizontal Y-shaped crown with shoots raised at an angle of 20° or 30° to the horizontal produced fruit yields similar to or higher than the yields of the trees with a spindle crown.

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