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INFLUENCE OF DIFFERENT TRAINING SYSTEMS ON THE BEGINNING OF DOMESTIC PLUM PRODUCTION AND YIELD

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All growers prefer to obtain a first harvest as soon as possible. The aim of this study was to identify an effective tree training system for new Latvian plum cultivars, which provides the highest yield and fruit quality. The trial was established in 2012 at the Institute of Horticulture (formerly Latvia State Institute of Fruit-Growing) and included cultivars 'Ance', 'Adelyn', and 'Sonora'; and the controls 'Victoria' and 'Jubileum'. Planting distances were 4 × 2.5 m, and the rootstock was Prunus cerasifera*. Tree training was done using four systems: two systems with branch bending (Heka espalier and spindle); and two systems without bending (standard (round) and flat crown). Evaluation of average fruit weight and yield per trunk cross section area (TCSA) was done from 2015 to 2017. The Heka espalier and spindle systems had first yield in 2015, but systems without bending had first yield only in 2016. Average yield per TCSA was significantly higher for the Heka espalier system (0.49 kg·cm^{-2}) than for the spindle system (0.24 kg·cm^{-2}), standard crown system (0.17 kg·cm^{-2}), and flat crown system (0.30 kg·cm^{-2}). Cultivar 'Victoria' had the highest yield among all systems. Average fruit size showed the same results: the biggest fruits were obtained with the Heka espalier system, and the smallest for systems without bending in the standard crown.*

Key words: *fruit weight,* Prunus domestica *L., Heka espalier, spindle system, yield per trunk cross section area.*

INTRODUCTION

In commercial fruit growing it is important to have easily manageable trees, with good yield and high fruit quality. Usually, in a plum orchard four to six years pass until the first yield (depends on cultivar). Usually, trees grow very vigorously during this time, forming large and dense crowns. Cultivars that are grown for dessert fruits need picking by hand, but harvesting of vigorous trees is more difficult, needs more labour, and is less effective, compared to smaller trees. Pruning systems for plums differ between different countries and continents (Preston and Beakbane, 1974; Meland, 2005; Gonda, 2006; Mask *et al*., 2010) with fruit quality higher in well pruned and well insolated crowns. It has been recommended by some authors to reduce planting distances (3.5 × 1 m for Wangenheim prune and 4 × 1.5 m for *P. cerasifera* rootstocks), which can result in lower yield per tree, but higher per hectare (Mika *et al*., 1998; Gonda, 2006). Still, in Northern Europe this option does not work well, because there is lower daylight than in Southern Europe. At the Norwegian Institute of Bioeconomy Research, in Ullensvang a trial was established with different crown systems of domestic plums on semi dwarf rootstock St. Julien A (Meland, 2005). The yield per hectare in the first four cropping years was positively correlated with tree density, but after nine years cumulative yield per ha was higher in intensive pruning crown systems.

To obtain good quality fruits in orchards, it is very important to form an open tree crown, to cut shaded branches and rapidly growing branches, and taking into account differences between cultivars.

The practical importance of this research was to obtain first harvest as soon as possible together with fruit quality. Vegetative growth was lower when trees had earlier yield, as nutrients were diverted to form flower buds and fruits.

The aim of this study was to identify the most effective tree training system for new Latvian cultivars, which would provide the highest yield and best fruit quality.

MATERIAL AND METHODS

The trial was planted in 2012 at the Latvia Institute of Horticulture in Dobele, which is situated in the southern part of Latvia, latitude 56° 36.633` and longitude 23°17.888`.

The soils in the orchards are neutral or slightly basic (pH 6.7–7.4) sandy loam.

The climate in the region is favourable for fruit growing. The annual sum of active temperatures (over 5 °C) is 2423 °C; the annual daylight hour sum is 2452 hours. The active growth season is 135–140 days. The average annual snow and rainfall is 560 mm, which is less than in many other areas of Latvia. The maximum rainfall during the growth season is observed in July, while May and August have the least rainfall. The absolute minimal temperature is –36°C, which occurs only after each 5–10 years.

In the research period meteorological conditions were very different — year 2015 was dry, except July, when fruits started to crack after rainfalls. The year 2017 was very wet, with total annual precipitation 639 mm per year, and 139 mm in September, together with low temperature and solar radiation (Table 1). The calculated length of active growth period (days) was 163 in 2015, 155 days in 2016, and only 136 days in 2017.

In the last four years this region had sharp temperature fluctuations in the winter-spring period (Table 2), when temperature differences sometimes were more than 10 °C, which caused trunk and bud damages for some cultivars. In 2017, there were no significant fluctuations of temperatures more than 10 °C.

The cultivars used in the trial were ‘Ance’, ‘Adelyn’, and ‘Sonora’. In addition, ‘Victoria’ and ‘Jubileum’ were used as controls. The rootstock was myrobalan (*Prunus cerasifera)*.

Planting distances were 4 × 2.5 m (reduced in comparison with the most common planting distance for this rootstock — 5 × 3 m).

Trees were planted in spring, as one-year old plants, heading back the top of the tree after planting approximately at 0.8–1 m from the ground level.

The supporting system was established just after planting. The first rope was 0.8 m from the ground, second rope 1.8 m from the ground.

The crown systems used were:

1. with support system and with branch bending:

   - Heka espalier (with two axes);

   - spindle (one axis); and

2. without support system and without branch bending:

   - standard (round) crown;

   - flat crown.

Table 1

PRECIPITATION AND SOLAR RADIATION (2015–2017)

Month/ Year	Precipitation, mm			Solar radiation, W·m^{-2}		
	2015	2016	2017	2015	2016	2017
January	62.4	17.8	33.2	50	53	14
February	5.6	53.6	21.9	122	130	36
March	29.7	19.3	35.5	284	278	86
April	36.4	61.2	38.0	458	460	144
May	40.2	0.2	24.4	574	744	257
June	19.0	96.1	71.6	698	738	238
July	99.6	56.1	53.9	670	624	209
August	15.0	64	33.1	693	510	176
September	62.0	18.5	139.2	380	425	90
October	3.2	55.2	87.8	255	151	46
November	41.0	60.2	65.5	84	62.3	16
December	23.8	14.1	35.0	51	38	8
Sum per year	438	516	639	4319	4213	1318

Table 2

MINIMUM AND MAXIMUM TEMPERATURES AND TEMPERATURE FLUCTUATIONS PER DAY °C

Year	Date	Min t	Max t	Temperature fluctuations per day
2013	25.02	–10	2	12
	13.03	–17	–1	16
	14.03	–14	1	15
	17.03	–11	1	13
	23.03	–15	–1	14
	28.03	–11	3	14
	07.04	–8	6	14
	09.04	–7	5	12
	22.04	–3	14	16
2014	06.02	–10	0	10
	18.03	–6	7	13
	29.03	–3	10	13
	05.04	–6	11	17
2015	19.03	–4	13	17
2016	14.01	–10	–4	5
	15.01	–16	–3	14
	16.01	–17	–4	13
	18.01	–11	1	11
	13.03	–3	7	10
	23.03	–7	3	11
	15.04	–2	12	13

Trees in Heka espalier were trained in the first autumn, fixing the main axis to the supporting rope. Direction of the top was towards the South, to decrease sun-burn in early spring. For the second main axis formation a well growing lower branch was chosen and fixed to the supporting rope on the opposite side (to the north).

Trees in spindle system were trained in the first summer, fixing the leader axis to the lower support rope. In the

spring of second year the main 2–3 horizontal (skeletal) branches with flat angle were chosen and fixed to the first rope, at a near 90° angle. Branches with narrow angles were eliminated.

The main pruning and bending time was in spring, when buds started to burst. At this time, it is easy to see winter damages after thaws and temperature fluctuations.

The second pruning time was in summer on sunny days, to shorten new branches. In the period until autumn, many new fruit twigs had developed.

After the spring of the 6th year, we started to use mechanical pruning. Branches in the middle of the tree were pruned by hand.

Standard crown trees were trained without branch bending. Branches of the first level were spaced around the main stem. Every spring branches to the outside and competitor branches were cut.

Flat crown trees were trained without branch bending, but leaving branches only in the direction of rows.

Evaluation was conducted from 2013 to 2017. The following parameters were measured: trunk cross section area (TCSA) each autumn 20 cm above ground level; time of the first yield; average yield per tree and cumulative yield from 2015 to 2017 yield per TCSA, and average fruit weight.

RESULTS

Crowns with a support system developed fruit twigs abundantly already at an early tree age — on average in the 2nd or 3rd year. The first fruits in Heka espalier and spindle systems were observed in 2014, and the first significant yield in 2015. First fruits in crowns without a support system were observed in 2015, and first significant yield in 2016.

In 2014, cultivar 'Ance' had first fruits in the spindle system, cultivar 'Adelyn' had first fruits in Heka espalier, cultivar 'Sonora' had first fruits in the spindle system, and cultivar 'Victoria' had first fruits in all systems except in the flat crown. In 2015, trees in the support systems had yield above 2 kg per tree, while trees without a support system had yields < 0.5 kg (except 'Victoria'). Significant differences (p-value) were observed among cultivars (> 0.05) and among pruning systems (> 0.05).

The highest average yield per tree for three years for cultivar 'Ance' was on crowns with a support system, for cultivar 'Sonora' in the spindle system, while cultivar 'Adelyn' yield did not significantly differ among crown types. Both control cultivars had no significant differences among crown types (Fig. 1). Correlation analysis showed that the average yield per tree had significant correlation with trunk diameter (R = 0.661; p = 0) and number of flowers (R = 0.576; p = 0).

The cumulative yield (CY) per three years differed among cultivars and training systems (Fig. 2). Cultivar 'Ance' had the highest yield in support system crowns (18.3 kg in the spindle system, 14.6 kg in the Heka espalier system); cultivar 'Adelyn' had the highest yield in support system crowns (19.6 kg in the Heka espalier and 16.0 kg in the spindle system); cultivar 'Sonora' had the highest yield in the spindle system (16.6 kg). Control cultivar 'Victoria' had the highest yield in support system crowns (23.5 kg in the Heka espalier and in 21.4 kg the spindle system); cultivar 'Jubileum' had no significant differences among crown types.

From 2013 to 2017, measurements of trunk and calculations of trunk cross section area were made (Fig. 3).

In the planting year TCSA had no significant differences between variants, but in 2017 significant differences were observed not only between cultivars, but also crown types. Cultivar 'Adelyn' had significantly higher TCSA in the Heka espalier system 'Sonora' in the spindle system, 'Victoria' in the flat crown system, and 'Jubileum' in the spindle system. Cultivar 'Ance' showed no significant differences in TCSA among crown types.

Correlation analysis showed that TCSA had significant relationship with number of flowers (R = 0.338, p = 0), yield per tree (R = 0.663, p = 0) and average fruit weight (R = 0.520, p = 0). Cumulative yield and TCSA were significantly positively correlated for cultivars 'Adelyn' and

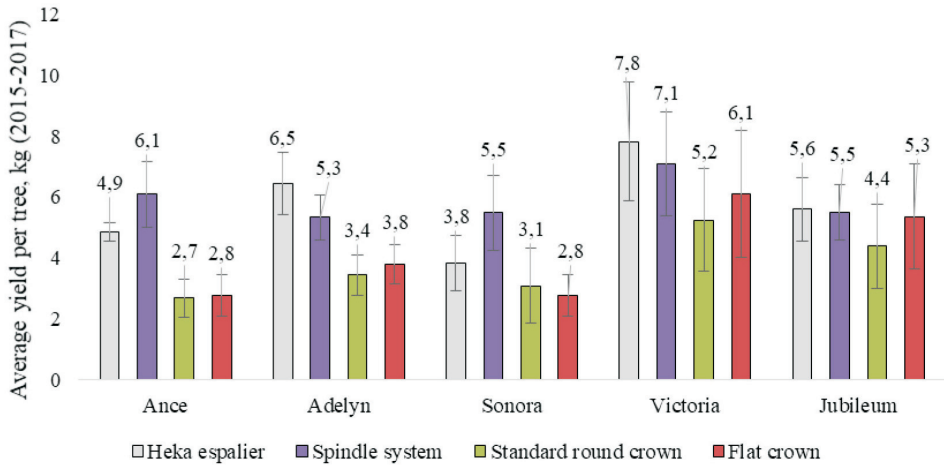

Fig. 1. Average yield per tree (2015–2017), kg.

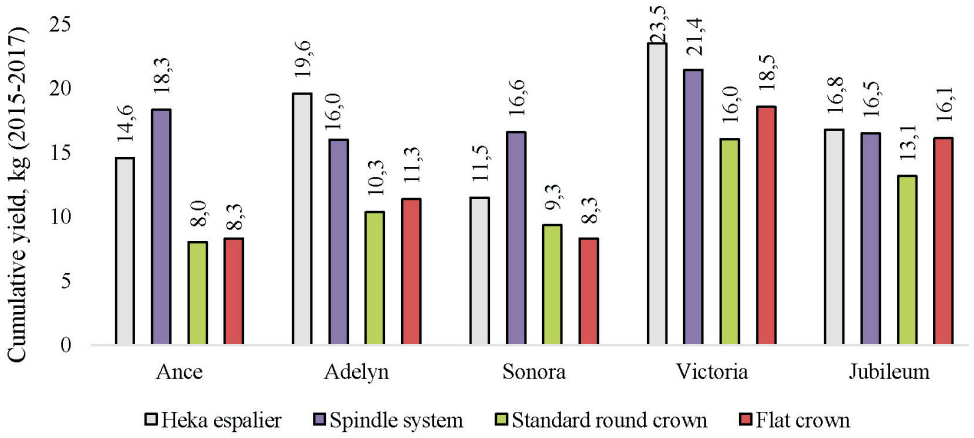

Fig. 2. Cumulative yield, kg per tree (2015–2017).

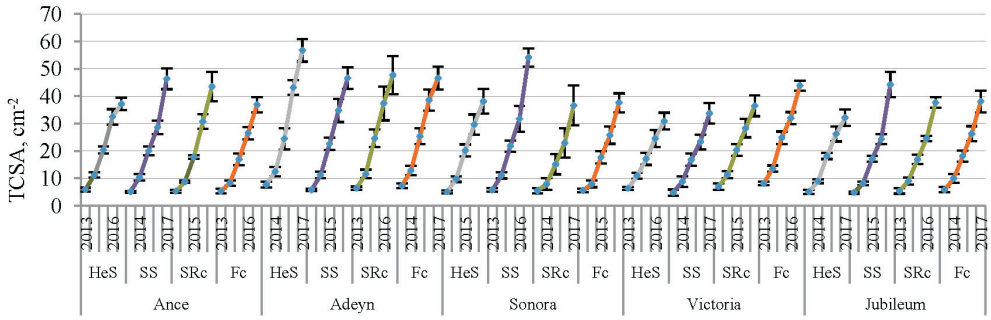

Fig. 3. Trunk cross section area (TCSA; cm^{-2}) 2013–2017. HeS, Heka espalier; SS, spindle system; SRC, standard round crown; Fc, flat crown.

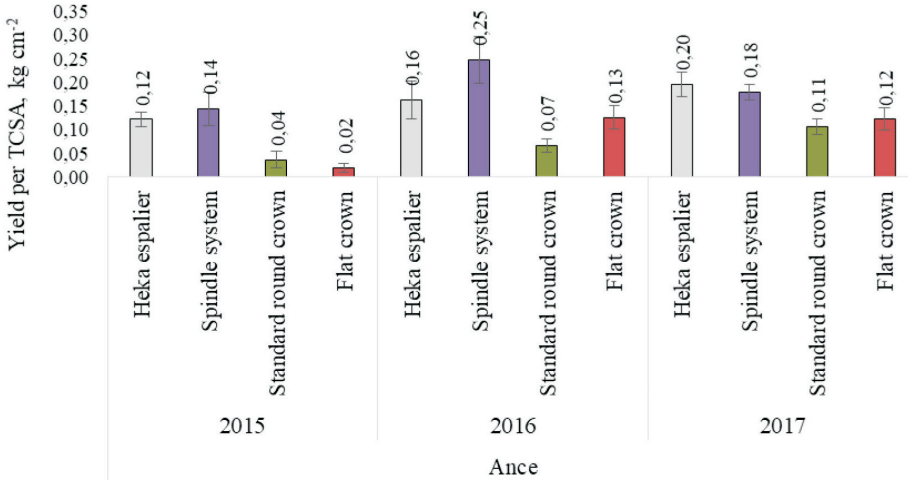

Fig. 4. Yield per trunk cross section area, kg cm^{-2}, cultivar 'Ance'.

'Sonora', while for cultivar 'Victoria' in in the Heka espalier system, the correlation was negative (and significant).

Yield per trunk cross section area is one of the main parameters that represents yield efficiency in an orchard.

Yield per TCSA was significantly correlated with yield per tree (R = 0.803; $p = 0$), number of flowers (R = 0.470; $p = 0$), and crown type (R = –0.243; $p = 0$), for each of the cultivars.

Cultivar 'Ance' is semi vigorous tree, about one metre higher than 'Victoria'. It forms a dense, spreading crown with well-developed new growth. The new shoots are semi-upright, with medium internode length. Branching is medium, and formation of secondary growth is medium. The flower buds are evenly distributed on 2- and 3-year old growth. It has the earliest start of production. 'Ance' already in 2015 gave significantly higher yield in support systems than in standard and flat crown systems (Fig. 4).

The increase of yield in support systems was rapid, whereby vegetative branches were densely covered with fruit twigs. In the spindle system, the yield reached 0.25 kg·cm^{-2} already in the 5th growth year. In all years the yield per TCSA was significantly higher in crowns with a support system ($p < 0.05$). Significant differences were not found among years ($p > 0.05$). As this cultivar forms a medium amount of laterals and flower buds after summer training, the yield increase was especially high in crowns with support systems.

Cultivar 'Adelyn' is a vigorous tree (~3.3 m) that forms a medium dense, upright crown with well-developed, long (~1.5 m) new growth. Young shoots are upright, with medium internode length. Branching is medium, and formation of secondary growth is low. Flower buds are evenly distrib-

uted on 2–3-year old wood and short spurs. Figure 5 shows the yield per TCSA of cultivar 'Adelyn'.

Cultivar 'Adelyn' showed differences in yield parameters between both crown types in support systems and between crowns without a support system in 2015 and 2017. In 2016, the differences were not significant. The cultivar tends to develop vigorous shoots with branched fruit twigs, if the branches are slightly spread more horizontally by bending. In support systems with bending of the axes, fruit twigs form along the whole length. In crowns formed without bending, the yield increase in the first years is slower, as the formation of fruit twigs is less intense. In the standard round crown the yield is lower, as regular pruning stimulates shoot growth, and the development of fruit twigs is slower.

Cultivar 'Sonora' is a vigorous tree (~3.3 m) that forms a dense, spreading crown with well-developed, long (~1.5 m) new growth. Young shoots are horizontal, with medium internode length. Branching is medium and formation of secondary growth is low. Flower buds are mostly located on 2-year old growth. Figure 6 shows the yield per TCSA of cultivar 'Sonora'.

Cultivar 'Sonora' had similar yield per TCSA without significant differences between training systems. The spreading character of its growth provided formation of similar yield both in training systems with support and without it. This means that in the first growth years, the support systems did not have great effect in the slowing down vegetative growth and formation of yield. This cultivar was showed the most stable results among all included in the trial, and different crown types did not produce significant differences of results. However, TCSA in the spindle system was significantly larger than in other training systems (Fig. 3), while yield per TCSA did not differ significantly.

Cultivar 'Jubileum' is a vigorous tree (~3.6 m), that forms a dense (for young trees) and medium dense (for oldest trees) and upright crown with well-developed, long (~1.5 to 2 m) new growth. Young shoots are upright, with medium internode length. Branching is medium and formation of secondary growth is low. Flower buds are evenly distributed on 2-year old wood and short spurs. Figure 7 shows the yield per TCSA of cultivar 'Jubileum'.

There were no significant differences for yield per TCSA in 2015 and 2017 between support systems for Cultivar 'Jubileum', but there were significant differences in 2016 between crown in the support system and without the support system.

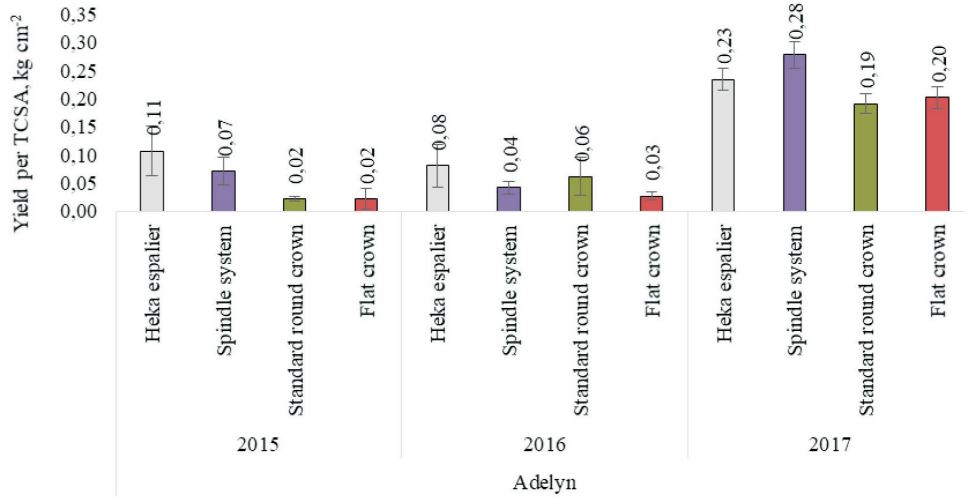

Fig. 5. Yield per trunk cross section area, kg·cm^{-2}, cultivar 'Adelyn'.

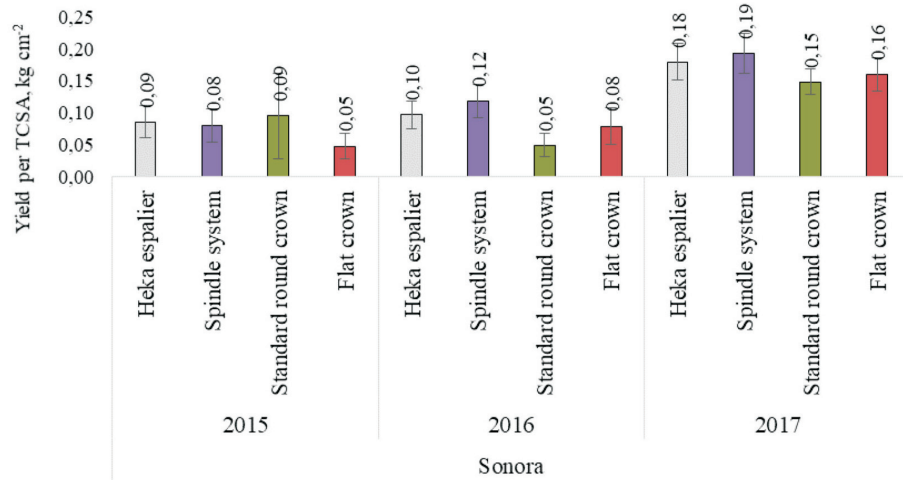

Fig. 6. Yield per trunk cross section area, kg·cm^{-2}, cultivar 'Sonora'.

For cultivar 'Victoria', the first sufficiently large yield was already in 2015. Significantly better results were in the Heka espalier system, in which the yield was approximately two times higher. In 2016 and 2017, differences among crown systems were not significant (*p*-value: among years 0.05; among pruning systems > 0.05). TCSA was significantly higher in the flat crown system, but this was not associated with a higher yield (Fig. 8).

The average fruit weight is one of characteristics which determines fruit quality. For cultivars 'Ance' and 'Adelyn', which have yellow fruit colour, if fruit size is smaller than typical for the cultivar, the development of blush also is lower, and the fruit taste is mediocre. Measurements of average fruit weight were done from 2015 to 2017 (Fig. 9).

Average fruit weight was higher with the Heka espalier system for cultivars 'Adelyn' and 'Jubileum'. Cultivar 'Jubileum' had one of significant highest average fruit weight on the same rootstock *P. cerasifera* (53.5 g). The spindle system gave higher fruit weight for cultivars 'Ance' and 'Sonora', and the flat crown system for cultivar 'Victoria'.

In the whole trial the *p*-value for differences among cultivars was > 0.05 (not significant); among pruning systems < 0.05 (significant).

Correlation analysis showed that the average fruit mass was significantly related to trunk diameter (R = 0.582; $p = 0$), TCSA (R = 0.520; $p = 0$), yield per tree (R = 0.381; $p = 0$), and number of flowers (R = 0.205; $p = 0$).

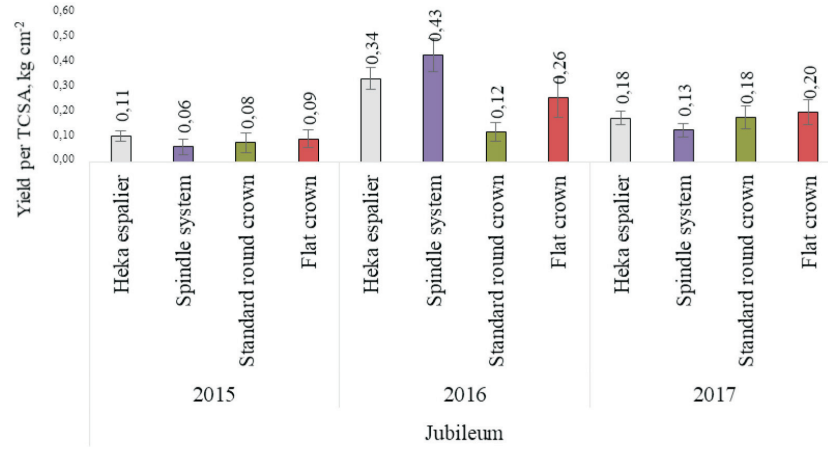

Fig. 7. Yield per trunk cross section area, kg·cm^{-2}, cultivar 'Jubileum'.

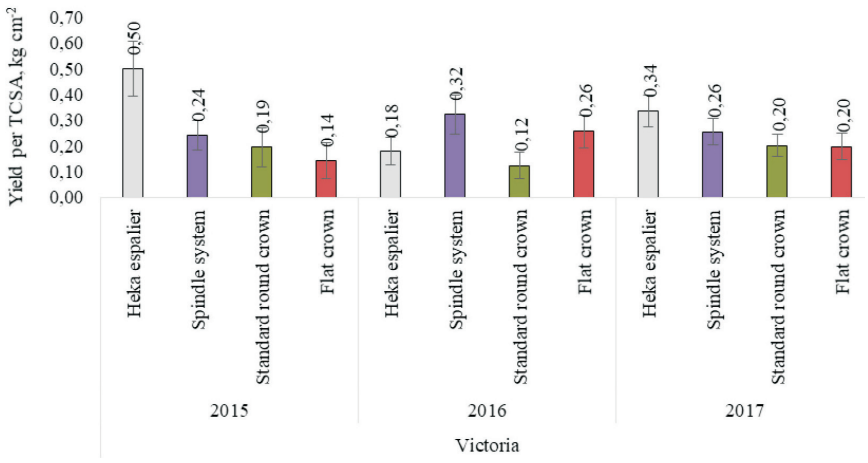

Fig. 8. Yield per trunk cross section area, kg·cm^{-2}, cultivar 'Victoria'.

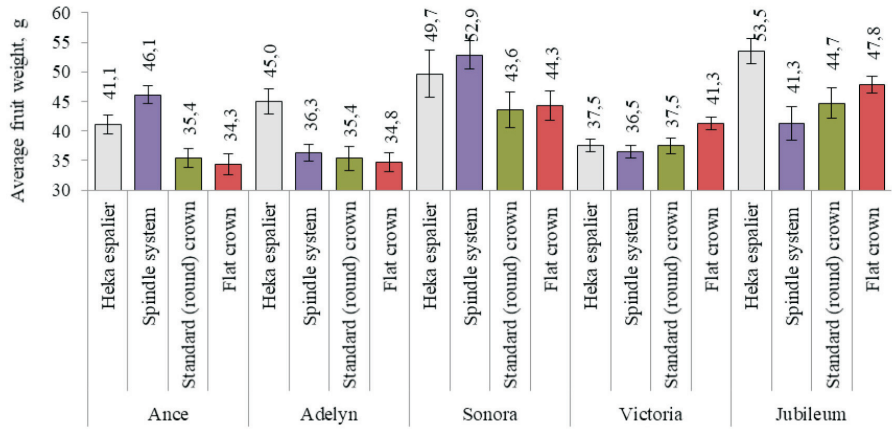

Fig. 9. Average fruit weight, g.

Comparison of the crowns trained with the studied support systems showed that, in the spindle system (one axis):

- more pruning is needed;
- and the stem is more exposed to sun.

In the Heka-espalier system (two axes):

- more bending is needed;
- less pruning is needed;
- and the trunk is better protected from the sun.

In the crowns trained without bending, but only with pruning:

- the tree habitus is more stronger, more upright;
- fruit twigs are formed later;
- labour consumption is much higher (a lot of pruning);
- and the first yield is produced one or two years later (depending on cultivars).

DISCUSSION

The rootstock used in our trial was *P. cerasifera*, which is the most popular rootstock in the northern part of Europe. Most researchers have used this rootstock in trials, as it is characterised by winter-hardiness, stable productivity, good compatibility with most cultivars, and is planted in commercial orchards (Dēķena *et al*., 2014; Grāvīte *et al*., 2016; Lanar *et al*., 2018).

In our trial the average yields per tree were earlier and higher in crowns with support systems. With traditional training and growing without supports, tree growth was slower. Higher yields on biaxial trees have been obtained also in Norway, where cumulative yield was higher with the Y-trellis system than for the hedgerow system for all included cultivars (Meland, 2005).

One of the characteristic parameters of tree growth is the trunk cross section area (TCSA). In the first years, trees grew similarly without significant differences, but in the fifth-year their growth diverged and significant differences were observed between cultivars and crown types. In Norway, TCSA was observed to be significantly higher for cultivars with a vertical axis, and lowest in the free spindle system (Meland, 2005), while in trials in Poland TCSA was the largest in the spindle system (Mika, 1998). In our trial, the effect of different training systems on TCSA depended on cultivar, except for 'Ance', which had similar TCSA for all systems.

Average fruit weight for cultivars 'Adelyn', 'Sonora' and 'Victoria' was the highest in systems that produced the largest TCSA (Heka espalier, spindle and flat crown, respectively). In contrast, 'Jubileum' had the highest TCSA with the spindle system, and the largest fruit weight with the Heka espalier system. 'Ance' showed no significant differences in TCSA among training systems, but had larger fruits with the spindle system. Similarly, in research at the Lithuanian Institute of Horticulture, using the same rootstock *P. cerasifera* (Lanauskas *et al*., 2018), cultivar 'Jubileum' was also among those with the largest fruits (56 g). Our results differ from those of other studies in which larger fruits were produced in the hedgerow system, and smallest in the spindle system (Mika *et al*., 1998). This indicates that each cultivar responds differently to a training systems.

CONCLUSIONS

1. The first yield in support systems was in 2015 (first fruits in 2014); in pruning systems the first yield was in 2016 (first fruits in 2015), a year later.

2. The highest average yield per tree, but without significant difference, was for cultivars 'Adelyn', 'Victoria' and 'Jubileum'. Cultivar 'Sonora' had significantly higher average yield per tree in the spindle system, and 'Ance' in crowns with support systems.

3. Cumulative yield for cultivars 'Ance', 'Sonora' and 'Victoria' was the highest in the spindle system, for 'Adelyn' in the Heka espalier system, while for 'Jubileum' it was similar in the Heka espalier, spindle system and flat crown systems.

4. Yield per TCSA was significantly higher in support systems for cultivars 'Ance', 'Adelyn', 'Jubileum' and 'Victoria', while 'Sonora' had no significant differences among crown types.

5. The average fruit weight significantly differed between crown types with and without support systems. Cultivars 'Ance' and 'Sonora' had significantly higher average fruit weight in both support systems, but 'Adelyn' and 'Jubileum' only in the Heka espalier system. For cultivar 'Victoria' significantly bigger fruits were obtained in the flat crown system.

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KOKU VEIDOŠANAS SISTĒMU IETEKME UZ MĀJAS PLŪMJU RAŽU

Visiem audzētājiem ir ļoti svarīgi iegūt ražu pēc iespējas ātrāk. Šī pētījuma mērķis bija atrast efektīvu koku veidošanas sistēmu jaunajām Latvijas plūmju šķirnēm, kas nodrošinātu augstāku ražu un augļu kvalitāti. Izmēģinājums tika veidots 2012. gadā Dārzkopības institūtā (agrāk Latvijas Valsts Augļkopības institūtā), un tajā bija iekļautas šķirnes ‘Ance’, ‘Adelyn’, ‘Sonora’; kā kontroles šķirnes izmantotas šķirnes ‘Viktorija’ un ‘Jubileum’. Stādīšanas attālumi 4 × 2,5 m, potcelms — *Prunus cerasifera*. Koku veidošana veikta četrās sistēmās — divas vainagu sistēmas ar zaru liekšanu — Heka špalera un vārpstveida vainags; un divas sistēmas bez zaru liekšanas — standarta (apaļais vainags) un plakanais vainags. Vidējā augļu masa un raža no stumbra šķērsgriezuma laukumu (SŠL) tika vērtēta no 2015. gada līdz 2017. gadam. Heka špaleras un vārpstveida vainagiem pirmā raža bija 2015. gadā, bet vainagos bez zaru liekšanas pirmo ražu ieguva tikai 2016. gadā. Trīs gadu laikā ievērojami lielāka raža uz SŠL bija Heka špaleras vainagiem — 0,49 kg·cm^{-2}. Vārpstveida vainagos raža iegūta 0,24 kg·cm^{-2}, standarta vainaga sistēmā — 0,17 kg·cm^{-2}, plakanos vainagos — 0,30 kg·cm^{-2}. Visaugstākā raža visās vainagu sistēmās bija šķirnei ‘Viktorija’. Augļu vidējā masa parādīja līdzīgus rezultātus: lielākie augļi tika iegūti Heka špaleras sistēmā, mazākie — bez zaru liekšanas standarta vainagos.