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Influence of the pruning system on the growth and productivity of slender spindle apple trees

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Abstract

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Slender spindle is currently the most widespread pruning system for apple trees in the Czech Republic. However, further modifications of this pruning system have been developed. In this study, two pruning systems were compared in the years 2012 to 2015: slender spindle and modified slender spindle (characterised by 'click' pruning). The pruning systems were validated on three varieties, using either winter pruning or winter pruning supplemented with late summer pruning in August. The studied parameters included the average length of annual shoots, increase of trunk cross-sectional area (ITCA), fruit yield per tree, specific yield, average fruit weight, number of fruits and their size in various parts of the tree crown, the number of interventions by pruning and the total weight of the removed biomass. There were no significant differences in most of the parameters mentioned above. Application of the 'click' pruning technique over several years significantly increased the number of cuttings but the total biomass removed was lower compared with traditional slender spindle.

Keywords: pome fruits; training; varieties; biomass; fruit weight

In many modern orchards, trees are grown in dense plantations. This is due to several reasons. Firstly, rootstocks limit the growth and the arrangement of growing systems so as to capture the maximum amount of sunshine; further, such arrangements result in increased fruit yield and quality and allow access by orchard workers. There are three main types of cultivation systems used in intensive orchards according to Marini (2009b): trellis, slender spindle and solax. A number of modifications to these systems have also been described as growers need to adjust the systems to their own cultivation conditions.

The shape and size of the tree crown are determined by the selected cultivation system. Currently, most apple and pear trees in Europe grafted onto dwarf rootstocks are cultivated as spindles or slender spindles (Buler, Mika 2009). The vertical axis is the basic form which is grown over by weaker semi-skeletal branches which grow shorter towards the top. The trees have a conic shape in the profile view. In young orchards, the spindled crowns give high yields and good fruit quality (Buler, Mika 2015). At the same time, we wish to draw attention the fact that after several years the trees may lack light at the base and inside the crown as a result of a number of shoots growing unrestrained in the upper part of the crown and shading its lower part. This corresponds with the observations of Hoying et al. (2006) who reported that during the 1990s many fruit growers started to avoid slender spindle pruning after planting and for several years subse-

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quently. The back-cutting of the central axis which was characteristic of slender spindle resulted in unrestrained growth, which considerably increased the need for summer pruning to provide a sufficient distribution of light needed to maintain good fruit quality.

The 'click' system describes a modification of the slender spindle shape using several simple rules so as to provide sufficient light and maintain a balance between growth and production in all parts of the crown. According to Harvey (2011), 95% of Dutch fruit farmers currently apply the 'click' pruning method as it is simple to learn and results in uniform trees.

The modified slender spindle differs from the classical method by the lower number of main branches, a free space ('window') above this level, and a targeted reduction of the selected annual shoots which lengthen the semi-skeletal fruit-bearing branches and the terminal branches (i.e., 'clicking'). The objective of this research was to compare two systems of winter pruning – one very widespread in practical fruit tree management of slender spindles, and its later modification, i.e., 'click' pruning with or without the inclusion of supplementary summer pruning.

MATERIAL AND METHODS

The experiment was performed over the years 2012–2015 in intensive orchards of the Agricultural Cooperative at Dolany. The farmland is situated at an elevation of 260 to 350 m with an annual average temperature of 7.4°C and with annual rainfall of 680 mm. The soil is mainly clay, medium-heavy loess type. The average pH in the selected orchards ranges between 6.6 and 7.3, phosphorus contents 106–188 mg/kg of soil, potassium contents 152–256 mg/kg, calcium 2,025–3,030 mg/kg and magnesium 106–136 mg/kg.

The year 2012 was characterised by a rather dry spring but there was a lot of rainfall during July (about 180% of normal in the region of Hradec Králové) which led to an increased incidence of apple scab. In 2014, the plantations were locally hit on May 4 and 5 by late spring frosts – the temperature dropped to –1.5°C in some places. That could have had a negative effect upon the harvest in that year.

Uniform trees of cvs 'Šampion' (planted in autumn 2009, tree spacing 3.5 x 1.0 m), 'Topaz' (planted in autumn 2009, spacing 3.5 × 1.2 m) and 'Gala' (planted in autumn 2010, spacing 3.5 × 1.0 m) were selected, all grafted on M9 T337 rootstock. All selected plots were watered using drip irrigation, and anti-hale protection was provided by a grey net. The plots were managed according to the measures commonly applied in intensive orchards. No blossom or fruit thinning was applied nor any treatment affecting growth.

The trees were given shape as slender spindles or modified slender spindles, with ultimate heights of 3.2 m. The experiment was established and evaluated in four blocks with five replicates of four trees each: slender spindle with winter pruning (SW), slender spindle with winter pruning supplemented with late summer pruning in August (SS), 'click' pruning with winter pruning (KW) and 'click' pruning with winter pruning supplemented by late summer pruning in August (KS). The experimental trees were of uniform crown and trunk size. Five randomly selected annual shoots in the lower (0.7–1.3 m), middle and top parts of the crown were measured annually (0–0.3 m below the base of the annual terminal shoot). Further, crosswise and lengthwise diameters of the trunk were measured at 0.3 m above ground – the place of measurement was marked on the trunk in colour. The pruning, depending on the selected variety, was either of the 'click' type, or according to the rules of slender spindle. The number of cuts using shears or a handsaw was counted, and the total mass of the removed wood was recorded (by weighing and calculating for dry matter). A late summer pruning followed for the treatment that included supplementary pruning. The first year of the experiment differed markedly from the subsequent years as the trees were still very young, the crowns thin and pruning was not necessary. About three weeks prior to harvest, the number of fruits was counted on individual trees together with their position in the crown (lower, middle or upper part). During the harvest, 10 apples were randomly chosen from each part of the crown and classified by their size as up to 65 mm, 65–70 mm, 70–75 mm, 75–80 mm and over 80 mm. Further, 25 randomly chosen fruits from each part of the crown were weighed. Crown dimensions were measured after the season's end, and included crown height h (from the first branching of the trunk up to the end of most of the separate annual shoots), the crown's lengthwise width w_1 (along the row) and the crosswise width w_2 (perpendicular to the row). The

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data were used to calculate the total mass of the removed wood, the annual increase of the trunk cross-sectional area, yield (absolute and specific), average weight of one fruit, and the percentage of the fruit size groups in separate parts of the crown. The results thus obtained were evaluated statistically at a significance level of $\alpha = 0.05$ using two-way analysis of variance. The Tukey test was used for a more accurate evaluation of the statistically important differences.

RESULTS AND DISCUSSION

Growth and fertility

The average length of annual shoots did not change substantially in 'Šampion' and 'Topaz' over the four years of the experiment, regardless of the pruning method. The average length of annual shoots ranged between 19 and 32.5 cm in different parts of the crown with modified slender spindle-winter pruning, with the exception of 'Šampion', where the length of terminal shoots ranged from 31 to 53 cm.

'Gala' showed a different average length of annual shoots. In 2012, the average length of annual shoots in different parts of the crown ranged between 14.2 and 18.7 cm, with the exception of the terminal shoot, i.e., a third less than with 'Šampion' and 'Topaz'. On the other hand, in 2013, the shoots were slightly longer than in the other two varieties, ranging between 27 and 36.5 cm. In 2014 and 2015, they ranged between 23.2 and 41.5. The annual terminal shoot length in 'Gala' ranged between 23.8 and 67 cm. Similar to 'Topaz', the shoots were statistically significantly longer than the average length of annual shoots in other parts of the crown. In 'Šampion', the shoots were significantly longer in the upper part of the crown with the exception of the terminal shoot, as shown in Fig. 1. There were no significant differences in the length of annual shoots observed in response to different pruning techniques.

Fig. 2 shows the average annual increases in trunk cross-sectional area for 'Šampion' and 'Gala' (1.9 and 2.1 cm^2). The increases in 'Topaz' were significantly bigger by about a third (3.3 cm^2). The differences between the pruning techniques were not statistically significant.

The influence of the pruning method was manifested in slight differences in overall tree productivity – the fruit yield per tree was significantly lower after four years of the experiment in 'Gala' subjected to modified slender spindle winter and summer pruning (KS) compared to the modified slender spindle with winter pruning (KW). Overall tree productivities observed in response to the remaining two pruning techniques did not differ significantly from each other. The same effects of pruning method on yield were observed in 'Šampion' and 'Topaz', with no statistically significant difference (Table 1).

The average annual yield of 'Šampion' regardless of the pruning system was 13.5 kg, and 7.5 kg with 'Gala'. With a spacing of 3.5 × 1.0 m and planting density of 2857 trees per ha, this would result in a yield of 38.6 and 21.4 t/ha, respectively. 'Topaz' had the highest average yield per tree at 16.1 kg, but with an extended distance between the trees in a row (at 1.2 m) and with a smaller number of trees per hectare (2,381 trees) the variety lagged behind 'Šampion' with a total yield of 38.1 tonnes.

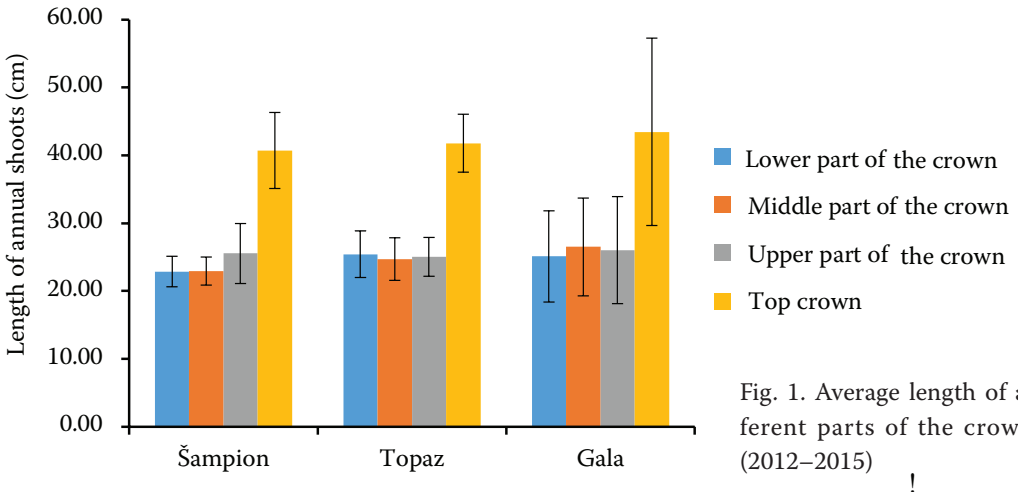

Fig. 1. Average length of annual shoots in different parts of the crown in three varieties (2012–2015)

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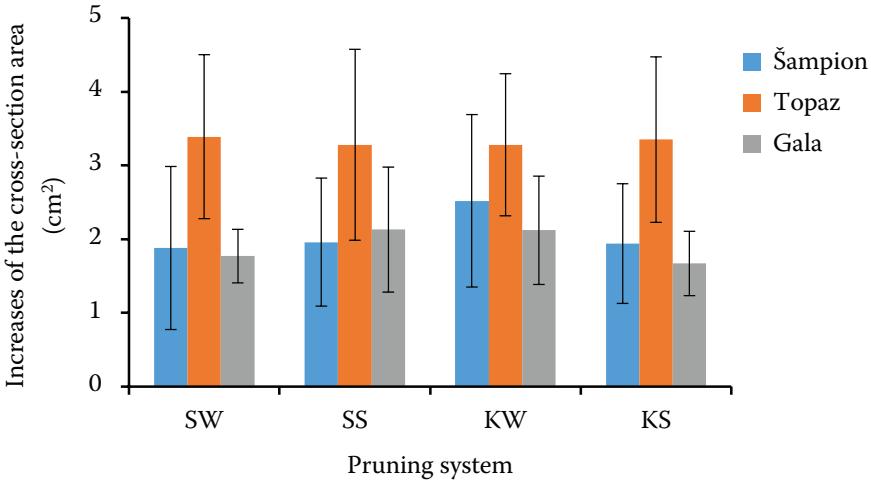

Fig. 2. Average annual increases in the cross-sectional area in three varieties (2012–2015)
SW – slender spindle, winter pruning, SS – slender spindle, winter + summer pruning; KW – modified slender spindle („clik"), winter pruning; KS – modified slender spindle („clik"), winter + summer pruning

The vegetation year also affected yields. The average yields for all varieties in the years 2012 and 2013 (8.7 and 8.8 kg/tree) were about half that of the years 2014 and 2015 (15.8 and 16 kg/tree).

As for the specific yield related to a unit of tree crown and to the unit of increase of the trunk cross-section area (ITCA), no significant influence of the pruning method was observed. As Table 1 shows, the lowest specific yield was found in 'Gala', while a specific yield almost twice as large was achieved with 'Topaz' and the most efficient variety was 'Šampion' with 7.1 kg/m^3 of the crown size. A similar trend, although with less pronounced differences, was revealed by the results of the yields related to the increase in the trunk cross-sectional area (ITCA). The lowest average yield, 4.13 kg/cm^2, was measured for 'Gala', higher values were achieved with 'Topaz' (5.25 kg/cm^2) and the highest specific yield was measured for 'Šampion' (7.63 kg/cm^2).

Assessment of the results over four years revealed no statistically significant differences between the pruning techniques, nor among average fruit weights, with the exception of 'Šampion', where significantly higher average fruit weights were found with the modified slender spindle pruning after the winter 'click' pruning (KW) compared with most other treatments. The smallest average weight was found with 'Šampion' (129 g). 'Topaz' and 'Gala' fruits weighed 145 and 142 g respectively; this difference was not statistically significant. Regarding the yearly results, the largest (heaviest) apples

Table 1. Yield characteristics of 'Gala', 'Šampion' and 'Topaz' (M9) (2012–2015)

Parameters	Variety	SW	SS	KW	KS
	Gala	7.28^{ab}	7.19^{ab}	8.30^{a}	7.09^{b}
Yield in kg/tree/year	Šampion	13.56^{a}	13.17^{a}	14.44^{a}	12.88^{a}
	Topaz	16.06^{a}	15.86^{a}	16.82^{a}	15.54^{a}
	Gala	3.30^{a}	3.11^{a}	3.49^{a}	3.46^{a}
Yield in kg/m^3 of crown volume	Šampion	7.18^{a}	7.10^{a}	7.16^{a}	7.01^{a}
	Topaz	6.41^{a}	6.83^{a}	6.78^{a}	6.47^{a}
	Gala	4.27^{a}	3.76^{a}	4.10^{a}	4.38^{a}
Yield in kg/cm^2 of trunk cross-section area	Šampion	8.69^{a}	7.81^{a}	6.60^{a}	7.40^{a}
	Topaz	5.15^{a}	5.39^{a}	5.44^{a}	5.02^{a}
	Gala	145.23^{a}	140.62^{a}	144.04^{a}	137.61^{a}
Average fruit weight (g)	Šampion	125.99^{a}	128.09^{ab}	136.30^{b}	125.62^{a}
	Topaz	145.82^{a}	146.17^{a}	142.77^{a}	144.14^{a}

mean values marked with the same letter do not differ significantly *from each other* (α = 0.05); SW – slender spindle, winter pruning; SS – slender spindle, winter + summer pruning; KW – modified slender spindle ('click'), winter pruning; KS – modified slender spindle ('click'), winter + summer pruning

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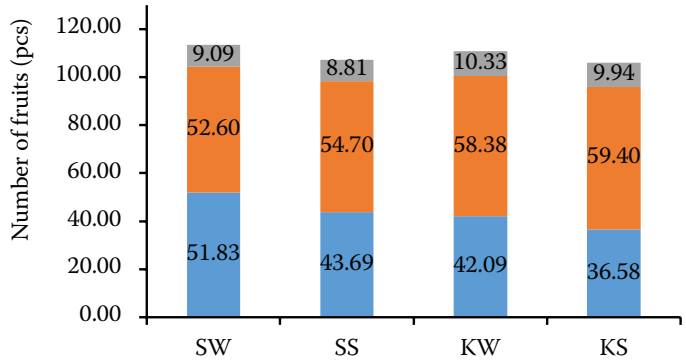

Fig. 3. Number of fruits of 'Šampion' in various parts of the crown (average 2012–2015). Planting in autumn 2009, spacing 3.5 × 1.0 m for abbreviation see Fig. 2

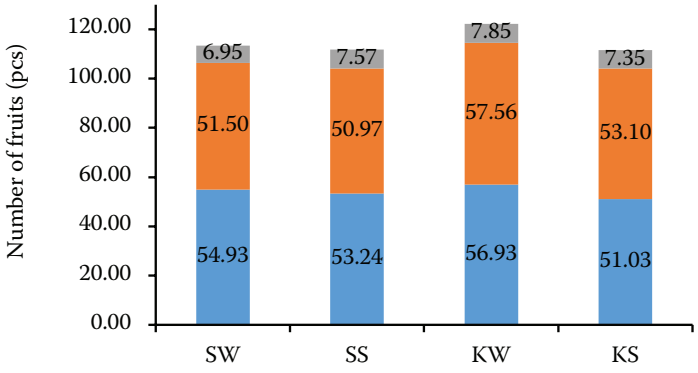

Fig. 4. Number of fruits of 'Topaz' in various parts of the crown (average 2012–2015). Planting in autumn 2009, spacing 3.5 × 1.2 m for abbreviation see Fig. 2

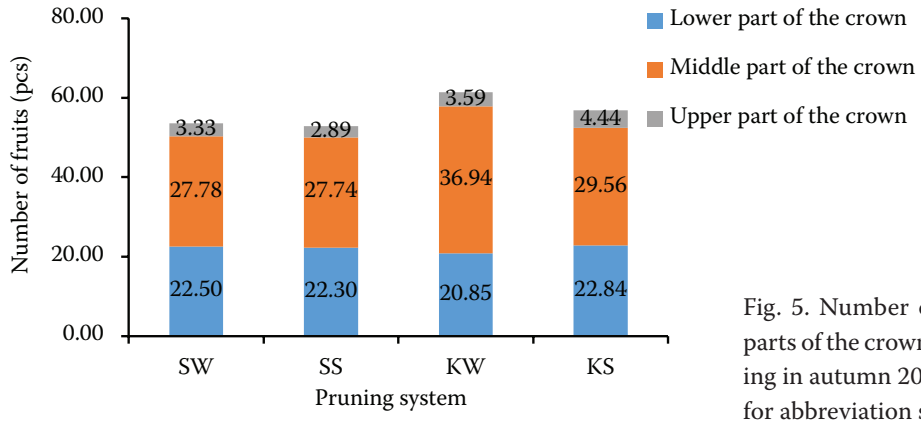

Fig. 5. Number of fruits of 'Gala' in various parts of the crown (average 2012–2015). Planting in autumn 2010, spacing 3.5 × 1.0 m for abbreviation see Fig. 2

were harvested in 2012 (average fruit weight 157 g). Average fruit weight did not differ greatly between 2013 and 2014 (139 and 140 g, respectively). Significantly smaller fruits were registered in 2015 (119 g). There was no statistically significant difference in the number of apples from the lower and middle part of the crown. There were much fewer fruits in the upper part of the crown with all four pruning techniques and in all three varieties (Figs 3–5). 'Gala' had significantly less fruits.

Annual measurement of the diameters of 10 randomly selected fruits from different parts of the crown and their classification into five categories by size showed that, after four years, the proportions of individual size groups were very similar in the lower and middle parts of the crown and did not differ to a large extent even in the top part (Fig. 6). The effect of the pruning technique upon fruit size varied depending on the variety. There were no statistically significant differences between the pruning techniques.

Pruning demands

The most demanding variety in terms of pruning was 'Topaz' (average 48 cuts per tree per year); 'Šampion' required 10 cuts per tree less, while the

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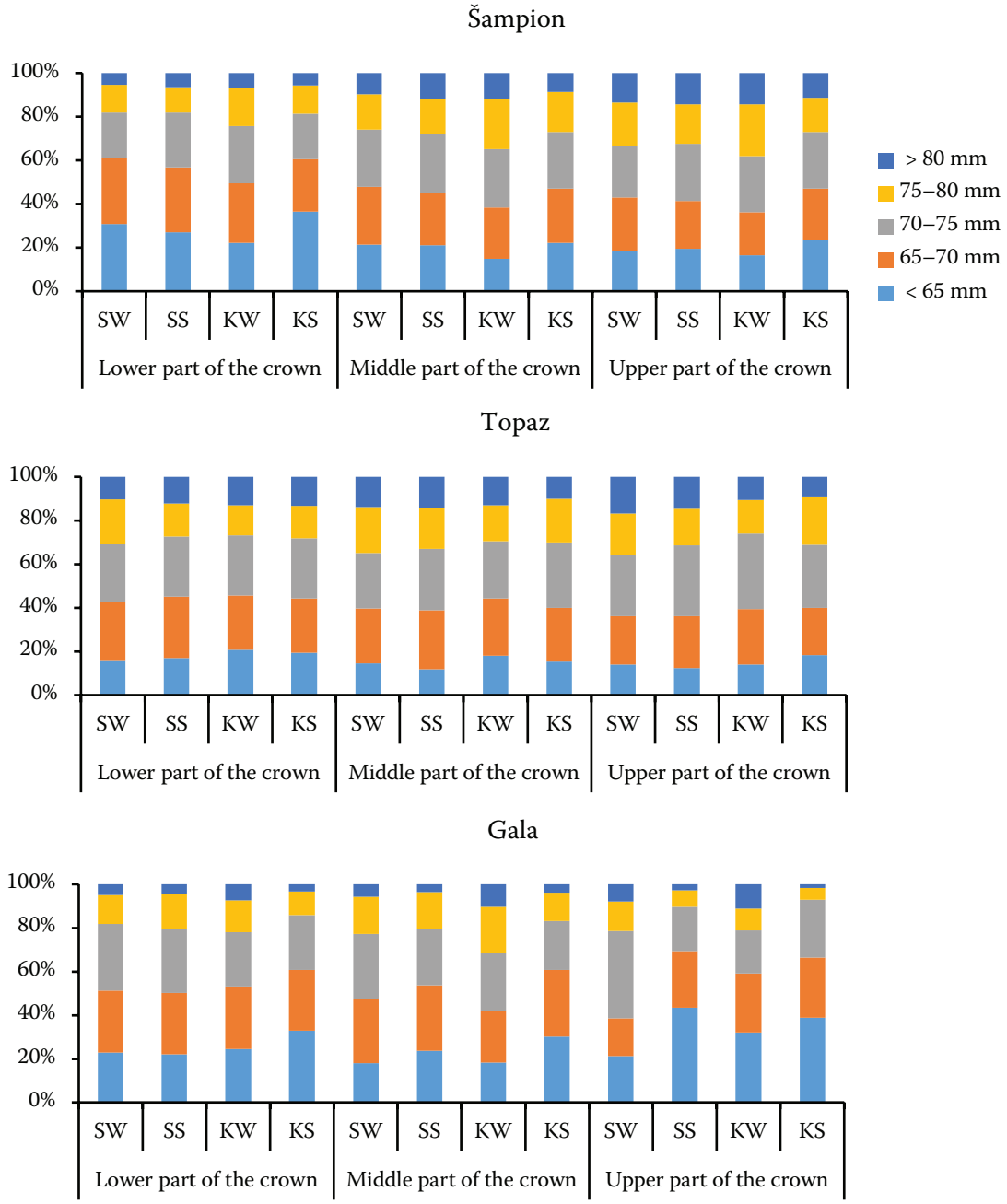

Fig. 6. Percentages of (a) 'Šampion'. (b) 'Topaz' and (c) 'Gala' fruits in individual size groups in various parts of the crown depending on the pruning method

SW – slender spindle, winter pruning; SS – slender spindle, winter + summer pruning; KW – modified slender spindle („clik"), winter pruning; KS – modified slender spindle („clik"), winter + summer pruning

least demanding was 'Gala' with 28 cuts. Similarly, the total volume of removed biomass calculated for dry matter in individual cultivars during the years was statistically different, depending on the variety and the pruning technique (Table 2). The treatment with complementary late summer pruning in August resulted in the removal of a higher total volume of biomass. The largest quantity of biomass removed in g of dry matter per tree was from 'Topaz' (434 g); about a third less was removed from 'Šampion' (292 g) and a half less was removed from 'Gala' (217 g) on average per year.

The results show that the pruning techniques (slender spindle and modified slender spindle with a 'click'

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Table 2. Average number of cuts and total mass of dry matter removed by pruning in 'Šampion', 'Topaz' and 'Gala' (2012–2015)

Variety	Parameters	Pruning system			
		SW	SS	KW	KS
Šampion	number of cuts per tree (pcs)	24.58[a]	37.85[b]	41.03[b]	47.78[c]
	biomass removed (g of dry matter per tree)	249.27[a]	336.97[b]	276.89[ab]	306.56[ab]
Topaz	number of cuts per tree (pcs)	30.46[a]	54.31[b]	44.71[c]	63.71[d]
	biomass removed (g of dry matter per tree)	390.34[a]	509.98[b]	335.8[a]	500.22[b]
Gala	number of cuts per tree (pcs)	19.29[a]	32.01[b]	29.85[b]	33.75[b]
	biomass removed (g of dry matter per tree)	178.41[a]	317.73[b]	181.74[a]	191.18[a]

mean values marked with the same letter do not differ significantly from each other (α = 0.05), for abbreviations see Table 1

type of pruning) differed mainly in their pruning demands and in the character of the follow-up response, and less so with respect to fruit production.

The 'click' pruning system proved to be more demanding in terms of the number of cuts using shears; in the end, however, the volume of biomass removed was less than in the case of traditional slender spindle pruning. That can be explained by the increased number of new shoots (the stubs left behind grow more frequently and with a larger number of shoots than with other pruning methods) which allows for a more frequent exchange of whole branches. In the 'Golden Delicious', 'Šampion' and 'Gala' varieties which tend to overproduce and to have smaller fruits, we do not leave branches older than 3 years of age in the middle and upper parts of the crown. Also, the deliberate shortening of annual shoots at the end of branches in the lower parts of the crown and the terminal branches ('clicking') frequently results in the growth of buds surrounding the cut. According to Blažek (2001), the removal of the shoot tops changes the hormonal composition in the remaining parts of crown, causing a rapid activation of the growth of side buds and the formation of new branches. The large number of annual shoots must be reduced to avoid excessive thickening of the crown. A further reduction of the growth of wood is a result of a lack of shortening of branches in the middle and top parts of the crown in the perennial wood which reduces the thickening of branches. Nevertheless, the differences between the increases in trunk cross-sectional area were not significant with respect to the pruning methods applied. As the experiments of many authors show (Blažek 2001; Wertheim 2005; Sus, Nečas 2011), a strong reduction in annual shoots considerably stimulates their further growth. In the 'click' pruning system, these phenomena are harnessed to support growth in the lower parts of crown and consequently to reduce the growth response of the terminal branches and the shoots in the upper parts of the tree. Nevertheless, measuring the length of the annual shoots in different parts of crown has not proven this effect.

As for the summer pruning, no important influence upon the growth of shoots has been found, which is in agreement with Marini's conclusions (Marini 2009a) that the summer cut does not suppress the lengthening of shoots in the following vegetation period. Summer pruning reduces the intensity of photosynthesis towards the end of vegetation, and, theoretically, it should reduce the deposition of carbonaceous substances which are used at the beginning of growth, inside the tree. The results of many experiments indicate, however, that the response to a certain type of pruning will be the same regardless of the time when it is carried out.

Marini (2009a) and other authors (Scotti 1984; Saure 1990; Stover et al. 2003) claim that summer pruning reduces the shade inside the tree and usually improves the red colouring of the fruit; further, it sometimes has a positive effect upon the development of the blossom buds. The average weight of a single fruit was not significantly affected by the pruning system. A similar conclusion was made by Sus et al. (1997) in experiments with various timings and combinations of pruning techniques of slender spindles at the time of full fruitfulness. No significant differences were found, and, taken together, the pruning system did not influence fruit size. A certain reduction in fruit size in the studied cultivars was observed for those techniques with supplementary summer pruning and where pruning was postponed

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until the time of flowering. In this experiment, summer pruning had no effect on the size of the fruits. No statistically significant differences in the overall yield per tree were observed between the slender spindle pruning and 'click' pruning methods. The supplementary summer pruning in both systems mainly had a negative effect upon the yield although this was not statistically significant. This was observed even earlier when the winter pruning was annually supplemented with late summer pruning in early August (Sus, Prskavec 1991). In a comparison of the slender spindle system and the solax method (Blažek, Pištěková 2009), cv. 'Šampion' was the most productive, just as in the experiments described here.

As for the specific yield as determined by crown volume or the cross-sectional area of the tree trunk, their values change both with respect to variety and pruning method; however, the differences were not statistically significant.

The size and location of the fruits in the crown were not affected by the pruning technique. The results obtained show that in young trees even the 'window' did not result in any substantial reduction in the number of apples on the tree nor in any yield reduction. On the other hand, the number of apples in the lower part of the crown did not increase substantially (as a result of improved exposure to sunshine), which was one of the desirable outcomes of the use of the 'click' pruning technique. The year and the variety had a considerable effect upon the parameters observed. The 'Topaz' variety was clearly the most demanding and 'Gala' the least demanding. 'Šampion' proved to be the most productive, but with the smallest average fruit weight. Lespinasse and Lauri (1996) argued that each variety has its own character of branching and fertility and that it is economically advantageous to use such natural qualities.

CONCLUSION

Following the assessment of the results of a four-year experiment comparing two systems of slender spindle pruning, we can conclude that there are no significant differences between the use of the 'click' system and traditional slender spindle pruning. This was tested with three varieties with different characteristics of growth and fertility. The only demonstrable difference was that the use of the 'click' pruning method requires an increased number of cuts while at the same time reducing the volume of wood biomass removed after the pruning.

Nevertheless, the experiment was performed on young trees in their first years of fertility, a period in which a certain degree of growth is natural for some trees. It remains unclear whether the pruning systems will be efficient when the trees grow older and their growth is slower, whether the more frequent exchange of the wood will not have a negative effect upon the total fruit yield or whether, on the contrary, the effect of the 'window' and regulated growth will not have a positive effect in promoting the controlled growth of tree height and fruit size.

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