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Pruning terms and techniques affect vigour and flower formation of Ukrainian sweet cherry cultivars

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Abstract: Excessive tree vigour and late entrance into full production, inherent to sweet cherry trees, are major challenges in the intensive cultivation of this crop. Possible ways to reduce the vigour and stimulate flower induction include shifting the term of pruning and reducing its severity. However, the reaction of the trees may differ depending on specific cultivar, soil and climatic conditions. Therefore, the aim of the study was to determine the effect of various techniques and terms of pruning on young sweet cherry trees in order to adapt the intensive cultivation technology to the arid conditions of southern Ukraine. The results showed a strong cultivar-specific reaction to various pruning treatments. Pruning young sweet cherry trees in late summer contributed to a reduction of trunk and canopy indices by 11-22% on one of the cultivars and an increase in the number of flowers per tree by 1.4-1.7 times on both cultivars, compared to dormant pruning. Low severity pruning reduced 1-year-old shoot length by 9-25% and increased the number of flowers by 1.5-2.5 times compared to more aggressive pruning. The effect of pruning treatments on tree vigour was more pronounced during the first and second year of their application.

1. Introduction

Sweet cherry (*Prunus avium* L.) is one of the most important stone fruit crops in the world, its annual gross production has increased by 1.4 times over the last 20 years and reached 2.6 million t in 2020 (FAO, 2020). Ukraine is one of the main sweet cherry producing countries, with annual production volume ranging between 60-85 thousand t, with 60% of industrial production concentrated in the south-eastern region (State Statistic Service of Ukraine, 2020). There is a well-developed extensive traditional cultivation technology of the crop in the region that utilizes Mahaleb seedlings as rootstock, a central leader training system, and plant density of 200-350 trees ha^{-1} (Rulyev, 2003).

The main drawback of such cultivation technology is late entry of the trees into production and, as a result, late return of initial capital investment. Additionally, modern export markets for Ukrainian sweet cherry show increased requirements for the size and overall quality of the fruits. It is well known that the highest quality cherries are formed on young wood (Dolya, 2011; Claverie and Lauri, 2005). Trees with large canopies, characteristic for traditional cultivation technology, are not always able to ensure timely fruiting wood renewal, and thus, good fruit quality.

These factors contribute to the fact that sweet cherry cultivation technology in Ukrainian orchards is being intensified. Orchards with trees grafted on dwarfing rootstocks are not always commercially successful due to the low adaptivity of those rootstalks to the arid continental climate of southern Ukraine. Therefore, new orchards utilising interstems and rootstocks of medium and high vigour with a density of 667-1200 trees ha^{-1} to promote precocity may be a better alternative (Kishchak *et al.*, 2020; Bondarenko, 2018).

It should be noted that currently there are no well-developed pruning technologies for such orchards in Ukraine, and direct use of foreign techniques is ineffective and requires adaptation to the specific climate and soil conditions in the cultivation region. The main challenge when cultivating high density orchards is controlling the vigour and the size of tree canopies. Aggressive annual pruning in order to keep tree canopies within the limits of the planting scheme can cause strong vigour reaction, reduce flower bud initiation, and delay fruiting (Lang, 2005).

Different agronomic techniques can be used in order to reduce the vigour of sweet cherry trees. Application of growth regulators contributes to reduction in shoot length and increases the number of generative buds on a tree (Jacyna *et al.*, 2012; Elfving *et al.*, 2003). Root pruning can also be effective in reducing vigour (Pal and Mitre, 2016; Webster *et al.*, 1997). Another promising and easily applied method is shifting the term of tree pruning. In Ukraine, pruning in the second half of the growing season is being actively used in apple orchards (Melnyk and Mulienok, 2020; Chaploutskyy and Melnyk, 2015), and in the world - for sweet cherry as well (Blažková and Drahošová, 2012). In addition to potential decrease in vigour due to removing a part of assimilation area prematurely, pruning trees in August-September, compared to traditional pruning during dormancy, has an advantage that wounds from the cuts heal faster and trees are more resistant to pathogens, especially those of bacterial aetiology (Spotts *et al.*, 2010; Colhoun *et al.*, 2015). While scientific data on the degree of spread of bacterial diseases in Ukrainian orchards is insufficient (Patyka *et al.*, 2016), farmers report visual manifestations of bacterial diseases in most sweet cherry plantations (pers. comm.), underlining the importance of using agronomic measures, including pruning, to contain the infection. It is also indicated that summer pruning can reduce winter frost damage to generative organs for certain sweet cherry cultivars (Vaszily *et al.*, 2011).

Another challenge in intensive sweet cherry cultivation is the need of regular fruiting wood renewal in order to maintain yields and fruit quality. Inherently, sweet cherry has low regeneration and shoot-formation ability, further complicating this process for the farmer. Therefore, it is often recommended to avoid thinning cuts on 1-year-old wood and to instead use stub cutting to preserve a bigger number of growth points on the tree. Also, in order to stimulate spur formation, heading cuts can be avoided. That, however, reduces the number of new shoots in the subsequent season and worsens their position on a tree (Long *et al.*, 2015; Mika, 2006). In general, optimal techniques of pruning for intensive sweet cherry orchards in Ukraine are not yet fully determined.

The objective of this study was to determine the reaction of the young sweet cherry trees of different cultivars to various techniques and terms of pruning in order to adapt the intensive cultivation technology to the arid conditions of southern Ukraine.

2. Materials and Methods

Site description

The study was conducted in a commercial sweet cherry orchard located near the city of Melitopol, south-eastern Ukraine (46°80’N, 35°34’E, 38 m a.s.l.). The climate is moderately continental, the mean daily air temperature in January is -3.1°C and in July is +22.8°C; the average annual amount of precipitation is 475 mm. The soil of the experimental site is southern chernozem (black soil), with loam soil texture.

Experimental design

The orchard was planted in late October 2014 using 4.5×2 m planting scheme (1111 trees ha^{-1}) with 1-year-old maiden trees without lateral branches. Trees were grafted on Colt rootstock and trained as spindle canopies with a single central leader. Bud scoring and branch bending were applied to the trees during the first 2 years after planting, where necessary. Different pruning treatments were applied in the orchard starting from the 3rd leaf, and the results of the study in 2017, 2018 and 2019 present the reaction of the trees after 1, 2 and 3 pruning cycles, respectively. The orchard is drip irrigated. Plant protection and fertilisation were carried out in accordance with the recommendations for sweet cherry cultivation in the region.

'Krupnoplidna' and 'Melitopolska Chorna' cultivars were chosen for the study as they are the main cultivars in commercial orchards in southern Ukraine and have distinct growth habits, not similar to each other. Both cultivars are late ripening and were bred in Melitopol Fruit Growing Research Station named after M.F. Sydorenko, Melitopol, Ukraine (Quero-García *et al.*, 2017).

Two pruning terms were studied: during dormancy and in late summer. Dormant pruning is traditional for sweet cherry cultivation in Ukraine, and in the conditions of our experiment was performed in the second half of February in dry weather. Late summer pruning was performed between the 25th and 31st of August. While it is sometimes advised to prune trees earlier, even immediately after harvest (Ayala and Lang, 2017), our previous experience suggested that pruning as late as the 15th of August can cause regrowth, so the term was shifted to eliminate this risk.

Three different pruning severities with various techniques were studied:

- High severity (control). Traditional style of pruning for sweet cherry in Ukraine. Heading cuts are applied to most 1-year-old shoots (either by removing one third of the shoot length or pruning it back to 60 cm if removing one third of the shoot length still leaves more than 60 cm of length); thinning cuts are applied to undesirable 1-year-old shoots that grow straight up or down, overly thicken the canopy, intertwine with other shoots, or hinder tractor movement between the rows. On average, 45-50% of a tree's 1-year-old wood is removed by pruning.
- Medium severity. Heading cuts are applied only to strong 1-year-old shoots longer than 60 cm; stub cuts are applied to undesirable 1-year-old shoots, with stub length of 15-20 cm; thinning cuts are not used. On average, 35-40% of a tree's 1-year-old wood is removed by pruning.
- Low severity. Heading or thinning cuts are not used; stub cuts are applied to undesirable 1-year-old shoots, with stub length of 15-20 cm. On average, 25-30% of a tree's 1-year-old wood is removed by pruning.

In all variants of the experiment, the extension shoot of the central leader was headed to 80 cm every year. For the sake of the experiment, cuts on 2-year-old and older wood were avoided unless absolutely necessary. Pruning in all variants was done manually.

The following variants of the length of the stubs on annual shoots were studied: short stubs with 1-2 buds and long stubs with a length of 20 cm. Those lengths were chosen as the ones that are easy to apply to pruning in industrial orchards (20 cm is roughly the length of the pruning shears).

Every combination of cultivar, pruning term, pruning severity, and stub length was replicated 3 times with 3 trees in each replication. The experiment was arranged using randomized block design.

Measurements

Tree canopy parameters, trunk cross-sectional area (TCSA), and number and length of 1-year-old shoots were measured before pruning each year on the 15th of August.

Canopy volume was calculated as the volume of a cone using the following formula:

$$\text{Canopy volume} = 1/3\,(H-0.6)\,\pi\,\frac{(w_1 + w_2)^2}{4}$$

where H = height of the tree, m; 0.6 = distance between the ground and first lateral branch, m; W_1 = maximum width of the tree in the row, m; W_2 = maximum width of the tree across the row, m.

TCSA was measured 30 cm above the grafting point. All 1-year-old shoots longer than 10 cm were measured. Shoots shorter than 10 cm were considered spurs and not included into calculations of the number of 1-year-old shoots per tree and mean shoot length.

Number of flowers per tree was counted during full bloom (15th-25th of April during the years of the research). In the 3rd leaf (2017), both cultivars had only up to 20-30 flowers per tree, so the flowering data for this year was excluded. Spring frosts during flowering (minimal air temperature in the orchard reached -4.3 C in April 2018 and -7.8 °C in April 2019) damaged up to 95% of pistils, which led to a poor fruit set and a very low number of fruits per tree. Thus, the data on yield and fruit quality was also excluded.

Data analysis

Statistical analysis of the results was conducted using the software Minitab 19 (Minitab Inc., State College, PA). Since the studied cultivars reacted differently to the treatments, a two-way analysis of variance was performed separately for each cultivar, with Tukey's range test with an accuracy of 0.05 carried out post hoc to determine the significant differences between the means. In addition, the cultivars were compared using a one-way analysis of variance with the same post hoc test. The exception was the reaction of trees to stub cutting, which was more uniform among the cultivars, and a single combined analysis of variance was performed. In order to determine the relationship between the indices, Pearson's correlation was used.

3. Results

Trunk cross-sectional area and canopy volume

The results of the experiment indicate different reactions by sweet cherry cultivars to pruning treatments. 'Krupnoplidna' trees inherently have a more spreading growth habit, wider crotch angles with a tendency to form round canopies, and better shoot formation ability at a young age. 'Melitopolska chorna' trees are more upright, with narrow crotch angles, and produce fewer shoots.

As a result, low pruning severity with no heading cuts allowed 'Krupnoplidna' trees to increase their canopy volume faster, exceeding the variant with high pruning severity by 35% in 2017 and 12-16% in 2018 and 2019 (Table 1). For 'Melitopolska Chorna' trees, pruning severity had no effect on canopy volume.

Pruning severity had a different effect on tree trunks depending on cultivar. 'Krupnoplidna' trees had higher TCSA and annual increase in TCSA when pruning severity was low, while for 'Melitopolska Chorna' those indices were the highest with aggressive high-severity pruning.

Table 1 - Influence of pruning term and severity on trunk cross-sectional area and canopy volume of sweet cherry trees

Variant	TCSA in 2019 (cm^2)	Annual increase in TCSA (cm^2)	Canopy volume (m^3)		
			2017	2018	2019
		'Krupnoplidna'			
Pruning severity					
High (c)	80.8 b	23.2 b	4.8 b	7.5 b	10.4 b
Medium	90.3 ab	26.2 ab	6.0 a	7.4 b	11.5 ab
Low	95.2 a	28.3 a	6.5 a	8.4 a	12.1 a
Pruning term					
Dormancy	93.3 a	26.6 a	5.9 a	8.7 a	11.6 a
Late summer	84.2 b	25.2 a	5.6 a	6.8 b	11.0 b
		'Melitopolska Chorna'			
Pruning severity					
High (c)	92.0 a	27.9 a	3.3 a	5.2 a	9.8 a
Medium	80.6 b	23.9 b	3.3 a	5.2 a	9.7 a
Low	76.8 b	22.2 b	3.4 a	5.4 a	9.8 a
Pruning term					
Dormancy	83.3 a	24.6 a	3.2 a	5.2 a	9.7 a
Late summer	83.0 a	24.8 a	3.4 a	5.4 a	9.7 a
Cultivar comparison					
Krupnoplidna	88.7 a	25.9 a	5.8 a	7.8 a	11.3 a
Melitopolska Chorna	83.2 a	24.7 a	3.3 b	5.3 b	9.7 b

TCSA = Trunk cross-sectional area.
Different letters within the same group indicate significant difference between the means according to Tukey's test ($p<0.05$).

Pruning 'Krupnoplidna' trees in late summer decreased tree vigour, with an 11% decrease in TCSA and lower canopy volume, most notably by 22% in 2018, compared to pruning during dormancy. These indices were not significantly different when comparing the effect of different pruning terms on 'Melitopolska Chorna' trees.

Due to growth habit differences, 'Melitopolska Chorna' trees had more compact canopies compared to 'Krupnoplidna', especially at a younger age: the difference of canopy volumes between the cultivars was 1.8 times in 2017, 1.5 times in 2018 and 1.2 times in 2019. Cultivars had no significant influence on TSCA of trees in the trial.

1-year-old shoot parameters

It was determined that low and medium pruning severity led to an 11-23% increase in the number of 1-year-old shoots per 'Krupnoplidna' tree in the first two years of the research (Table 2). After 3 cycles of pruning, however, this indicator levelled off among all variants. Pruning severity had no effect on the number of shoots on 'Melitopolska Chorna' trees.

Low pruning severity without heading or thinning cuts decreased the mean length of 1-year-old shoots by 9-25% on both studied cultivars, compared to traditional pruning techniques. For 'Krupnoplidna' trees, this effect appeared most strongly in the year following the first application of such pruning, while for 'Melitopolska Chorna' the shoot length decrease was more apparent starting from the second pruning cycle.

Pruning term had little effect on the number of shoots per tree, regardless of cultivar. The only statistically significant difference was observed for 'Melitopolska Chorna' in 2019, indicating that trees pruned during dormancy retained more vigour. Late summer pruning reduced the mean shoot length of 'Krupnoplidna' trees by 10-12% during the first two years of the research.

In general, the cultivar comparison highlights that 'Krupnoplidna' trees formed more new shoots per tree, especially in the first years after planting, whereas 'Melitopolska Chorna' trees formed more vigorous longer shoots.

Flower formation

Both the severity and term of pruning had a significant effect on flower formation in the orchard. In the case of 'Krupnoplidna', both low and medium prun-

Table 2 - Influence of pruning term and severity on shoot parameters of sweet cherry trees

Variant	Number of 1-year-old shoots per tree			Mean length of a 1-year-old shoot (cm)		
	2017	2018	2019	2017	2018	2019
			'Krupnoplidna'			
Pruning severity						
High (c)	62 b	131 b	239 a	77.7 a	51.1 a	51.4 a
Medium	73 a	146 ab	218 a	69.9 a	45.2 ab	44.3 b
Low	71 a	162 a	218 a	60.9 b	42.4 b	45.0 b
Pruning term						
Dormancy	66 a	136 b	232 a	73.2 a	49.1 a	46.6 a
Late summer	71 a	157 a	218 a	65.8 b	43.4 b	47.3 a
			'Melitopolska Chorna'			
Pruning severity						
High (c)	39 a	80 a	206 a	77.5 a	64.8 a	62.2 a
Medium	38 a	78 a	185 a	75.4 a	61.3 a	59.0 a
Low	36 a	78 a	180 a	70.2 b	48.9 b	49.4 b
Pruning term						
Dormancy	37 a	79 a	212 a	73.7 a	57.8 a	58.6 a
Late summer	38 a	79 a	169 b	75.0 a	58.8 a	55.2 a
Cultivar comparison						
Krupnoplidna	68 a	146 a	225 a	69.5 b	46.2 b	46.9 b
Melitopolska Chorna	38 b	79 b	190 b	74.3 a	58.3 a	56.9 a

Different letters within the same group indicate significant difference between the means according to Tukey's test ($p < 0.05$).

ing severity increased the number of flowers per tree on average by 1.5-1.7 times compared to high pruning severity (Fig. 1). For 'Melitopolska Chorna', only low pruning severity with no heading and thinning cuts affected the number of flowers per tree. The increase, however, was more significant - by 2.5 times on average.

Pruning the orchard in late summer promoted flower formation for both cultivars. Summer-pruned trees on average formed 1.4 and 1.7 times more flowers for 'Krupnoplidna' and 'Melitopolska Chorna' cultivars respectively, compared to dormant pruning. It should be noted that regardless of pruning treatments, based on the number of flowers per tree, 'Krupnoplidna' trees entered production during the 4th leaf (2018) while 'Melitopolska Chorna' trees still could not be considered bearing even in the 5th leaf (2019).

Stub length

Stub length of 1-year-old shoots significantly influenced the proportion of stubs that produced new shoots in the subsequent season. This index was 1.2 times higher on long stubs compared to short stubs (Table 3). Long stubs also formed 1.6 times more shoots per stub, which can be explained by a much higher number of buds on them compared to shorter stubs with only 1-2 buds. Stub length did not affect mean length of the new shoots on stubs, while pruning term did not significantly influence any of the studied parameters.

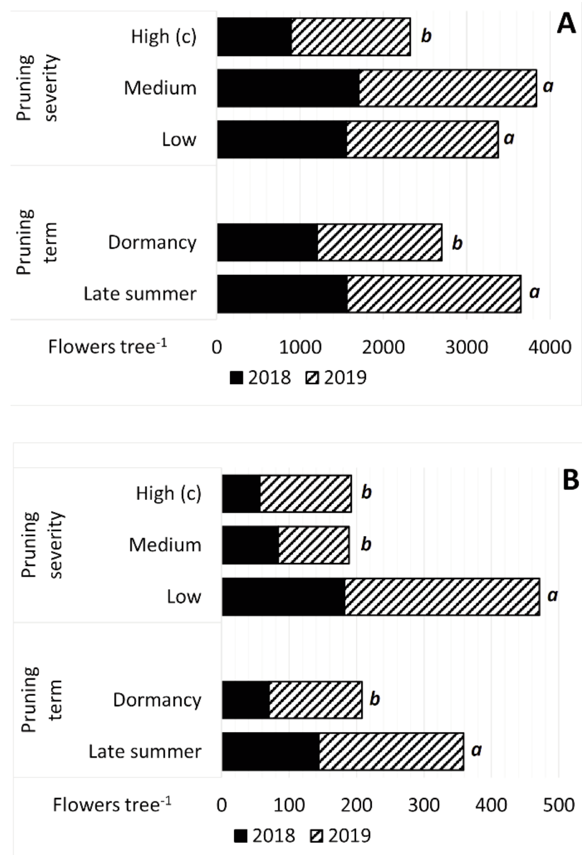

Fig. 1 - Influence of pruning term and severity on the number of flowers formed on sweet cherry trees of 'Krupnoplidna' (A) and 'Melitopolska Chorna' (B) cultivars. Note the difference of scale between the graphs. Different letters within the same group indicate significant difference between the means according to Tukey's test (p<0.05).

Table 3 - Reaction of sweet cherry trees to stub cutting

Variant	Proportion of stubs that produced shoots next year (%)	Number of 1-year old shoots per stub	Mean length of a 1-year-old shoot on a stub (cm)
Stub length			
Short (1-2 buds)	82 b	1.4 b	62.7 a
Long (20 cm)	96 a	2.2 b	67.7 a
Pruning term			
Dormancy	89 a	1.8 a	63.4 a
Late summer	90 a	1.8 a	67.0 a
Tree age			
3rd leaf (2017)	93 a	1.8 a	75.7 a
4th leaf (2018)	90 ab	1.8 a	58.1 b
5th leaf (2019)	85 b	1.8 a	61.8 b
Cultivar			
Krupnoplidna	85 b	1.9 a	62.3 b
Melitopolska Chorna	94 a	1.7 a	68.1 a

Different letters within the same group indicate significant difference between the means according to Tukey's test (p<0.05).

The proportion of stubs that produced new shoots decreased over the duration of the trial. As trees got older and more points of growth were formed throughout the tree canopy, new stubs were slightly less likely to form new growth. The number of shoots per stub, however, was not influenced by the tree age. Mean shoot length on the stubs followed the same tendencies as this index for the whole tree, being the highest in 2017 and decreasing by 18-23% in each subsequent year.

Stub cuts on 'Melitopolska Chorna' trees had a higher chance to produce new growth the next year, and those shoots were longer, compared to 'Krupnoplidna' trees.

4. Discussion and Conclusions

One of the main takeaways of our study is a strong cultivar-specific reaction to various pruning treatments. Most of the vigour indices were affected by pruning more significantly when it was applied to the trees of the cultivar 'Krupnoplidna', which is characterized by spreading round canopies and a higher ability to produce new shoots compared to the more compact upright canopies and fewer shoots formed per tree of 'Melitopolska Chorna' cultivar. This proves the importance of a cultivar-based approach to the choice of optimal training systems, plant density and pruning measures in intensive sweet cherry orchards (Long *et al.*, 2021).

The effect of different pruning severities on trunk growth was inconsistent among the studied cultivars. Other research on this topic shows similar results: exposure of trees to low severity pruning or no pruning at all can lead, depending on the cultivar studied, to TCSA decrease, increase, or no change in trunk parameters (Usenik *et al.*, 2008; Radomirska and Domozetova, 2017; Zec *et al*., 2020). Summer pruning decreased TCSA and canopy volume for 'Krupnoplidna' trees, in comparison with dormant pruning. This can be explained by the decreased length of the shoots in this variant, leading to more compact canopies. A similar effect was observed in other studies for sweet cherry (Blažková and Drahošová, 2012), sour cherry (Gonda, 2006), peach (Ikinci *et al.*, 2014), but not plum (Sosna, 2010).

The number of shoots formed on the tree was largely influenced by cultivars and tree age. An initial increase in shoot formation observed on 'Krupnoplidna' trees in variants with low and medium severity appeared mainly in multiple new shoots forming near the terminal end of the previous-year shoots. These types of branches with long sections of spurs and new growth only at terminal points may be problematic from an agronomic point of view, as sweet cherry spurs become less productive and die relatively quickly with age, especially in suboptimal lighting conditions, resulting in blind wood (Ayala and Lang, 2017; Bondarenko and Alekseeva, 2020). Renewing such branches by stub cutting can also be ineffective, particularly in the lower zones of the canopy and when trees are older (Stan, 2015; Hansen and Black, 2019).

Our study observed a reduction of shoot length on the trees pruned less severely, which was also documented in other studies (Usenik *et al.*, 2008; Villasante *et al.*, 2012), and may be explained by better nitrogen use efficiency by extension shoots on pruned branches (Ayala *et al.*, 2018). 'Krupnoplidna' trees also had decreased values of this indicator when pruned in late summer compared to dormancy. A similar effect was observed for peach, where shifting the pruning term further (June - July - August - September) progressively decreased both the diameter and mean length of new shoots in the subsequent season (Ikinci *et al.*, 2014).

It should be noted that the effect of pruning treatments on most of the parameters of tree vigour was more pronounced during the first and second cycles of pruning. During the third year of the research, those indices were either statistically non-significant among treatments, or, at least, less pronounced due to the trees adapting to the treatments and exhibiting their inherent growth habit. So, from an agronomic point of view, if the vigour in the orchard is excessive, shifting the pruning to late summer or removing less wood during pruning may be a valuable short-term technique in reducing tree vigour and increasing precociousness. In the long term, however, vigour is more dependent on specific rootstock and cultivar combination than on pruning measures.

Both late summer pruning and lower pruning severity positively contributed to flower formation on sweet cherry trees. In the case of the pruning term, it is reported that pruning in August led to an increase in carbohydrate content in sweet cherry flower buds in the outer and upper part of the tree canopy, compared to dormant pruning (Vosnjak *et al.*, 2021). Late summer pruning also shifts source-sink relations in the tree, promoting flower bud initiation, as there is a strong adverse correlation between bud initiation and vigour (Flore and Layne, 1999). Lower pruning severity with fewer heading cuts and no thinning cuts increased the number of flowers, which can be attributed to an overall increase in the points of growth on the trees, as well the fact that weaker, less vigorous shoots were formed in these variants. These points are supported by the fact that in the conditions of our trial, a negative correlation was observed between the mean shoot length in the previous growing season and the number of flowers per for both 'Krupnoplidna' (r= -0.623 in 2018 and r= -0.526 in 2019) and 'Melitopolska Chorna' (r = -0.550 in 2018 and r = -0.683 in 2019) cultivars. For 'Krupnoplidna', a positive correlation was also found between the number of shoots in the previous growing season and number of flowers per tree (r= 0.717 in 2018 and r = -0.593 in 2019). No such relationships were observed for other studied vigour indices.

The results of this study are consistent with other trials on sweet cherry that report a yield increase when trees were unpruned or lightly pruned (Villasante *et al.*, 2012; Claverie and Lauri, 2005). However, it should be noted that when trees enter full bearing, low pruning severity has a negative effect on fruit size and thus marketability of the yield (Gonkiewicz, 2011; von Bennewitz *et al.*, 2011; Ayala *et al.*, 2018), so more aggressive pruning may be needed to manage crop load and maintain fruit quality.

Cultivar genotype had a bigger effect on the number of flowers on the tree than any pruning treatments, further proving that a cultivar-based approach is essential for the cherry cultivation technology to be successful.

The reaction of the trees to stub cutting was more uniform among the studied cultivars compared to other treatments in this study. In general, both short and long stubs consistently produced new shoots in the subsequent season and mean shoot length was not affected by stub length. As the trees got older, the share of the dead shoots increased, mostly for short stubs, but was still minor. Another study, in which trees were grafted on a dwarfing rootstock, indicates that removing a large portion of the current year's shoots can lead to much larger proportion of dead shoots - up to 50-70% (Usenik *et al.*, 2008). Our further research of stub cutting of 1-year-old shoots will focus on the effect of this technique in different parts of the canopy (stubs in lower and upper zones of the tree, on the central leader and on lateral branches), as stubs of different length often produced mixed results depending on the shoot position in the tree.

In summary, we can conclude that pruning young sweet cherry trees in late summer and reducing pruning severity leads to a decrease in vigour, manifesting itself mostly in the reduction of 1-year-old shoot length, and has a positive effect on flower bud initiation and precociousness. The effect of pruning treatments on tree vigour was more pronounced during the first and second year of their application. Stub cutting of 1-year-old wood is a valuable alternative to thinning cuts: one can preserve more points of growth on the tree, and new shoots form more consistently in the desired locations of the canopy. The specific cultivar's growth habit should always be considered when choosing pruning strategies in the orchard.

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References

AYALA M., LANG G.A., 2017 - *Morphology, cropping physiology and canopy training*, pp. 269-304. - In: QUERO-GARCÍA J., A. LEZZONI, J. PUŁAWSKA, and G. LANG (eds.) *Cherries: Botany, production and uses*. CABI, Boston, MA, USA, pp. 533.

AYALA M., MORA L., TORREBLANCA J., 2018 - *Effect of prebloom pruning on ^{13}C and ^{15}N distribution during early spring in sweet cherry*. - HortScience, 53(6): 805-809.

BLAŽKOVÁ J., DRAHOŠOVÁ I., 2012 - *Impact of pruning time on tree vigour and productivity of three sweet cherry cultivars grown on two semi-dwarf rootstocks*. - Hortic. Sci., 39(4): 181-187.

BONDARENKO P., 2018 - *Comparative evaluation of the economic efficiency of cultivating the sweet cherry (*Cerasus avium *Moench.) orchards of different constructions in the Ukraine's Southern Steppe*. -

Sadivnytstvo (Horticulture), 73: 193-199.

BONDARENKO P., ALEKSEEVA O., 2020 - *Spur and generative bud formation as an indicator of sweet cherry precocity in the orchard*. - Innovations in Horticulture: Proc. Int. Sci. Internet Conf., 4: 18-22.

CHAPLOUTSKYY A., MELNYK O., 2015 - *Growth potency of an apple-tree depending on pruning type and term*. - Sci. Rep. NULES Ukraine, 55(6): 1-8.

CLAVERIE J., LAURI P.E., 2005 - *Extinction training of sweet cherries in France - appraisal after six years*. - Acta Horticulturae, 667: 367-372.

COLHOUN K., BUTLER R., MARRONI M., 2015 - *Pruning date affects bacterial canker of sweet cherry*. - N. Z. Plant Prot., 68: 448.

DOLYA Y., 2011 - *Formation of sweet cherry cultivar productivity in the conditions of the North Caucasus*. - PhD Thesis summary, Krasnodar, Russia, pp. 26.

ELFVING D., LANG G., VISSER D., 2003 - *Prohexadione-Ca and ethephon reduce shoot growth and increase flowering in young, vigorous sweet cherry trees*. - HortSci., 38(2): 293-298.

FAO, 2020 - *FAOSTAT* - FAO, Food and Agriculture Organization of the United Nations https://www.fao.org/faostat.

FLORE J., LAYNE D., 1999 - *Photoassimilate production and distribution in cherry*. - HortSci., 34(6): 1015-1019.

GONDA I., 2006 - *The size of the canopy of sour cherry trees depends on the time of pruning*. - Int. J. Hortic. Sci., 12(3): 49-52.

GONKIEWICZ A., 2011 - *Effect of tree training system on yield and fruit quality of sweet cherry 'Kordia'*. - J. Fruit Ornam. Plant Res., 19(1): 79-83.

HANSEN S., BLACK B., 2019 - *The response of 'Montmorency' tart cherry to renewal pruning strategies in a high density system*. - J. Am. Pom. Soc., 73(1): 53-61.

IKINCI A., KUDEN A., AK B.E., 2014 - *Effects of summer and dormant pruning time on the vegetative growth, yield, fruit quality and carbohydrate contents of two peach cultivars*. - Afr. J. Biotechnol., 13(1): 84-90.

JACYNA T., BARNARD J., WIELGUS M., 2012 - *Immediate and residual effects of prohexadione-calcium, with or without ethephon, applied in a low-pH solution on vegetative and reproductive growth in sweet cherry trees (*Prunus avium *L.).* - J. Hortic. Sci. Biotechnol., 87(6): 577-582.

KISHCHAK O., GRYNYK I., BARABASH O., KISHCHAK Y., 2020 - *Technological aspects of the creation of intensive plantations of cherries in Forest-Steppe of Ukraine*. - Bull. Agric. Sci., 98(3): 27-37.

LANG G., 2005 - *Underlying principles of high density sweet cherry production*. - Acta Horticulturae, 667: 325-336.

LONG L., LANG G., KAISER C., 2021 - *Sweet cherry training systems*, pp. 190-235. - In: *Sweet cherries: Crop production science in horticulture*. CABI, Boston, MA, USA, pp. 380.

LONG L., LANG G., MUSACCHI S., WHITING M., 2015. - *Cherry training systems*. - Pacific Northwest Extension Publication, 667: 1-63.

MELNYK O., MULIENOK Y., 2020 - *Productivity and economic evaluation of apple orchards on rootstock M.9 depending on crown pruning practices and terms*. - Sci. Rep. NULES Ukraine, 84(2).

MIKA A., 2006 - *Cięcie drzew i krzewów owocowych*. - Państwowe Wydawnictwo Roslicze I Leśne, Warszawa, Poland, pp. 192.

PAL M., MITRE V., 2016 - *Root pruning effect on growth and yield of sweet cherry*. - Agricultura - Revistă de Știință și Practică Agricolă, 1(2): 35-41.

PATYKA T.I., DUDINA T.A., PATYKA N.V., 2016 - *Peculiarities of the microbial communities development and functioning in the agrocoenoses of orchards and small fruit plantations*. - Sadivnytstvo (Horticulture), 71: 123-129.

QUERO-GARCÍA J., SCHUSTER M., LÓPEZ-ORTEGA G., CHARLOT G., 2017 - *Sweet cherry varieties and improvement*, pp. 60-94. - In: QUERO-GARCÍA J., A. LEZZONI, J. PUŁAWSKA, and G. LANG (eds.) *Cherries: Botany, Production and Uses*. CABI, Boston, MA, USA, pp. 533.

RADOMIRSKA I., DOMOZETOVA D., 2017 - *Influence of heading heights of the tree leader on growth and fruiting of sweet cherry*. - Acta Horticulturae, 1161: 165-170.

RULYEV V.A., 2003 - *Horticulture of the South of Ukraine*. - Dyke Pole, Zaporizhzhya, Ukraine, pp. 240.

SOSNA I., 2010 - *Effect of pruning time on growth, blooming and content of chemical constituents in leaves of four early ripening plum cultivars*. - J. Fruit Ornam. Plant Res., 18(2): 151-160.

SPOTTS R.A., WALLIS K.M., SERDANI M., AZARENKO A.N., 2010 - *Bacterial canker of sweet cherry in Oregon-Infection of horticultural and natural wounds, and resistance of cultivar and rootstock combinations*. - Plant Dis., 94(3): 345-350.

STAN C., 2015 - *The influence of the diameter, length and position of the stub resulting from modern pruning on growth and fructification in cherry, in high density culture*. - Sesiunea De Comunicări Ştiinţifice Studenţeşti, 8: 221.

STATE STATISTICS SERVICE OF UKRAINE, 2020 - *Areas, gross harvests and yields of agricultural crops, fruits, berries and grapes (final data) in 2019: Statistical bulletin*. - Kyiv, Ukraine, pp. 159.

USENIK V., SOLAR A., MEOLIC D., ŠTAMPAR F., 2008 - *Effects of summer pruning on vegetative growth, fruit quality and carbohydrates of 'Regina' and 'Kordia' sweet cherry trees on 'Gisela 5'*. - Eur. J. Hortic. Sci., 73(2): 62-68.

VASZILY B., GONDA I., SOLTÉSZ M., 2011 - *Summer pruning of sweet cherry trees and an inquiry of winter frost damages*. - Int. J. Hortic. Sci., 17(4-5): 41-44.

VILLASANTE M., GODOY S., ZOFFOLI J., AYALA M., 2012 - *Pruning effects on vegetative growth and fruit quality of 'Bing'/'Gisela®5' and 'Bing'/'Gisela®6' sweet cherry trees (*Prunus avium*)*. - Ciencia e Investigación Agraria, 39(1): 117-126.

VON BENNEWITZ E., FREDES C., LOSAK T., MARTÍNEZ C., HLUSEK J., 2011 - *Effects on fruit production and quality of different dormant pruning intensities in 'Bing'/'Gisela®6' sweet cherries (*Prunus avium*) in Central Chile*. - Ciencia e Investigación Agraria, 38(3): 339-344.

VOSNJAK M., MRZLIC D., USENIK V., 2021 - *Summer pruning of sweet cherry: a way to control sugar content in different organs*. - J. Sci. Food Agric., 102(3): 1216-1224.

WEBSTER A., ATKINSON C., VAUGHAN S., LUCAS A., 1997 - *Controlling the shoot growth and cropping of sweet cherry trees using root pruning or root restriction techniques*. - Acta Horticulturae, 451: 643-652.

ZEC G., MILATOVIĆ D., BOŠKOV Đ., ČOLIĆ S., ĐORĐEVIĆ B., ĐUROVIĆ D., 2020 - *Influence of pruning on biological properties of sweet cherry cultivars grafted on 'Oblačinska' sour cherry*. - Acta Horticulturae, 1289: 105-110.