The growth activity of apple trees depending on the form of the crown and the time of pruning

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ABSTRACT

The apple tree is the most common fruit crop in the temperate climate zone. Modern intensive fruit cultivation involves the use of new, highly productive varieties and cultivation technologies, thanks to the creation of small-sized crown shapes with an increase in the number of trees per hectare. Reducing planting patterns and creating more dense plantations can significantly increase their yields. However, the limiting factor that can reduce tree productivity and deteriorate fruit quality is the degree of crown illumination. Ensuring uniform access of sunlight to all parts of the crown is the main task in the process of tree formation and pruning. The aim of the study was to determine the effect of crown pruning at 0 BBCH and early summer 74 BBCH of different types of crown formation on the growth activity and productivity of apple trees of two varieties Fuji and Honey Crisp. A significant decrease (20%) in the number of newly formed shoots in the form of the French axis crown compared to the ballerina and slender spindle crowns was found. However, their length and total growth were significantly higher. The formation of the ballerina crown (with the removal of overgrown wood in the 25 cm zone on the central conductor above the lower tier of semi-cross branched branches) contributed to a decrease in shoot length and total growth. The introduction of crown pruning in the summer also contributed to the improvement of crown illumination - shoot length decreased by 17%, total growth by 12%.

Key words: Apple tree, form of crown, pruning time, shoots

INTRODUCTION

The productivity of garden crops depends on the amount of light energy intercepted. In single-row plantings of intensive apple orchards with the creation of a fruit wall, the maximum light interception is about 60%. The relatively low level of light interception, according to Palmer et al. (1992), remains the main limitation for increasing the productivity of the orchard. This limitation is determined by the planning of the row direction and the shape of the crown (Tustin et al., 2022).

According to Tustin (2022a), the solution to this problem in the further intensification of horticulture should be aimed at the use of small, narrow crowns, which can increase the biological potential of fruit plants as a result of better illumination of the middle of the crown. According to Breen (2020), it is the high level of illumination inside the crown that is the key to achieving optimal yield and high quality fruit. The main determining factors are the planting scheme, crown shape and tree height (Lordan et al. (2018), which are closely correlated with the level of illumination (Musacchi, 2018).

According to Grappadelli, et al. (2007), this can be achieved through high tree density and the use of low-volume crown shapes. As a result, many different low-volume crown forms have been developed that expose most of the foliage to intense light. This allows the orchard to be adapted to robotic processes while increasing light...
interception to increase yields. Examples of such innovative systems are "Bi-baum", "UFO", "Planar cordon", "Double Guillotine" (Bortolotti et al., 2022).

The formation and subsequent pruning of tree crowns ensures the creation of a certain crown architecture that facilitates its care and maximizes the absorption of solar energy by all its parts. Therefore, according to Raig et al. (2019), the choice of crown shape is very important for increasing yields and, as a result, the profitability of the orchard. Due to the correct choice of crown shape, it is possible to achieve annual and uniform fruit formation throughout the crown (Melnyk, 2012; Melnyk and Melekhova, 2012).

The quantity and quality of the harvest are determined by the ratio between vegetative and generative processes. They compete with each other, and according to studies by Balandier et al. (2000) and Mohammadi et al. (2013), fruit production can be optimized in the case of moderate vegetative growth activity. After all, excessive vigor of tree growth leads to a decrease in the intensity of generative bud formation, fruit setting and can lead to a decrease in fruit quality (Ashraf and Ashraf, 2014). This, according to Zhang et al. (2016), depends on the shape of the crown and the location of their structural elements in space.

Tree pruning has a significant impact on the load of trees with the crop (Robinson et al., 2016). Zamani et al. (2006) found in their research that summer pruning is one of the most effective ways to control tree growth and stimulate the creation of generative buds.

Performing crown pruning during the growing season inhibits vegetative growth (Kweon and Sagong, 2022), and performing this agricultural measure after harvesting, according to Klamar and Fioravanco (2018) and Gościło (2013), increases the yield of plantations in the following year. However, according to the results of Bound and Summers (2001), summer pruning reduces the content of dry soluble substances in fruits.

Summer pruning is the main agricultural measure that increases the penetration and distribution of light in the crown (Buler and Mika, 2009). This has a positive effect on fruit size and quality. However, the timing, intensity of pruning and fruit load must be taken into account (Wertheim, 2005).

Another positive effect of summer pruning is growth regulation (Platon and Zagrai, 1997). Since summer pruning involves the removal of weak shoots and leaves with low photosynthetic activity and high respiration rate, it has a positive effect on the leaf/fruit ratio and carbohydrate distribution, thus regulating the yield load and improving fruit quality (Tahir et al., 2008). The study by Kuo-Tan et al. (2003) shows that the potential impact of reduced crown photosynthesis after summer pruning depends on the balance of supply and demand for carbohydrates. In addition, crown transpiration decreases in proportion to the intensity of pruning (Kuo-Tan et al., 2003a).

As a result of pruning, the side branches are systematically replaced, but the lower branches that produce a large number of fruits remain constant. This can be a limiting factor in a spindle-shaped crown, as with the closure of the crowns of neighboring trees, these branches are quickly shaded and the quality of the fruit deteriorates (Dallabetta et al., 2014). A partial increase in the productivity of these branches can be achieved by shortening annual growths (Mohammadi et al., 2013), but without sufficient illumination of the lower tier of branches, the quality of the fruit will deteriorate.

The aim of the study was to determine the effect of pruning time, forming different crown shapes on the productivity of apple trees in an irrigated apple orchard in the Right-Bank Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The study of the methods of formation and timing of pruning of small-sized forms of the crown of apple trees began in the spring of 2019 in the experimental garden of the Uman National University of Horticulture. The orchard was planted in the spring of 2015 with medium-sized Fuji and vigorous Honey Crisp varieties grafted onto a dwarf rootstock M.9 T337. The experiment consisted of 12 variants with four replications of 5 replicates each. The planting scheme of the studied trees is 4x1 m, the soil type is black soil sod-podzolic. The system of soil maintenance in the inter-row is sod-humus, herbicide steam in the near-stem strip, and the irrigation system is drip. The studied trees were pruned in two terms: in winter (0 BBCH) and twice during the growing season: in winter and summer after the June ovary shedding (II decade of June, 74 BBCH), forming a crown: slender spindle, ballerina (with the removal of overgrown wood on the central conductor, in the 25 cm zone above the tier of semi-complex branches) and French axis.

Phytometric records were made according to generally accepted recommendations and research methods. Growth parameters were recorded at the end of the growing season according to the methods of Kondratenko and Bagel (1999). The increase in bole diameter was recorded as the difference of values between adjacent years measured with a caliper at a bole height of 30 cm from the soil level. The length and number of annual shoots longer than 5 cm were measured after the end of growth with a measuring tape from the annual ring to the top of the shoot growth cone. The total length of the shoots was calculated by multiplying the average length of the shoots by their total number on the tree.

RESULTS AND DISCUSSION

The intensity of lateral growth of apple trees of Fuji and
Table 1: Parameters of vegetative growth of apple trees depending on the form of the crown and the term of pruning (averaged data for 2019-2022).

<table>
<thead>
<tr>
<th>Pomological variety</th>
<th>The form of the crown</th>
<th>Term of pruning</th>
<th>Increase in stem diameter, mm</th>
<th>The number of shoots, pcs./tree</th>
<th>Shoot length, cm</th>
<th>Total length of shoots, m/tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuji</td>
<td>Slim spindle</td>
<td>In winter (control)</td>
<td>4.8</td>
<td>49</td>
<td>22.1</td>
<td>10.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In winter and summer</td>
<td>4.1</td>
<td>54</td>
<td>16.0</td>
<td>8.6</td>
</tr>
<tr>
<td>French axis</td>
<td></td>
<td>In winter</td>
<td>5.2</td>
<td>36</td>
<td>28.8</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In winter and summer</td>
<td>4.6</td>
<td>41</td>
<td>27.2</td>
<td>11.0</td>
</tr>
<tr>
<td>Ballerina</td>
<td></td>
<td>In winter</td>
<td>4.4</td>
<td>49</td>
<td>20.3</td>
<td>9.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In winter and summer</td>
<td>3.8</td>
<td>54</td>
<td>14.7</td>
<td>7.9</td>
</tr>
<tr>
<td>Honey Crisp</td>
<td>Slim spindle</td>
<td>In winter</td>
<td>6.5</td>
<td>45</td>
<td>28.8</td>
<td>12.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In winter and summer</td>
<td>6.1</td>
<td>44</td>
<td>26.4</td>
<td>11.3</td>
</tr>
<tr>
<td>French axis</td>
<td></td>
<td>In winter</td>
<td>7.2</td>
<td>39</td>
<td>32.1</td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In winter and summer</td>
<td>6.9</td>
<td>39</td>
<td>29.3</td>
<td>11.4</td>
</tr>
<tr>
<td>Ballerina</td>
<td></td>
<td>In winter</td>
<td>6.5</td>
<td>43</td>
<td>25.0</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In winter and summer</td>
<td>5.8</td>
<td>50</td>
<td>17.3</td>
<td>8.6</td>
</tr>
</tbody>
</table>

LSD05 = 1.0
LSD05 = 11
LSD05 = 4.9
LSD05 = 3.0

Figure 1: Average growth of stem diameter (a), number of shoots (b), shoot length (c) and total shoot length (d) of apple trees in 2019-2022 depending on the crown shape and pruning time (results of analysis of variance).

Notes: Varieties: Fuji (F), Honey Crisp (HC); form of crown: slender spindle (SS), French axis (FA), ballerina (B); pruning period: in winter (W), winter and summer (WS).
Honey Crisp varieties during the experiment was significantly different with a predominance in favor of the latter (Table 1). Also, the introduction of different crown shapes and their pruning in winter and during the growing season had an impact on the intensity of growth of the stem diameter. In particular, as a result of winter pruning of the French axis crown, the most intensive thickening of the stem was found up to 7.2 mm per year, which was almost twice as high as the value of the indicator as a result of double pruning of the ballerina crown of Fuji trees. According to the results of the analysis of variance (Figure 1a), the activity of lateral growth of the bole during 4 years of research did not differ significantly, but significantly depended on the pomological variety with 44% prevalence of Honeyeye Crisp over Fuji. More active lateral growth of the stem was promoted by the formation of the crown of the French axis, regardless of the term of pruning (6 mm), while the formation of the ballerina crown significantly slowed down this process with an average annual value of 5.1 mm (LSD0.05=0.3). The crown formation of the slender spindle occupied an intermediate position. Pruning the crown of trees twice during the growing season (0 and 74 BBCH) contributed to a 10% slowdown in the intensity of stem thickening.

The correlation between the increase in bole diameter and shoot length \( (r=+0.74±0.14) \) and the inverse relationship with the number of shoots \( (r=-0.66±0.19) \) was found. The greatest influence on the thickening of the stem (Figure 2a) was caused by the peculiarities of the pomological variety (65%) and the introduced crown forms (8.5%).

The experiment revealed a significant effect of the studied agricultural practices on the growth activity of apple trees. In general, the most active shoot formation, as a reaction to the introduced methods and timing of pruning, was found in Fuji trees with two-time pruning of the crown of the slender spindle and ballerina in 54 newly formed shoots per tree. While the winter pruning of the French axis crown provided only the formation of 36 shoots (LSD0.05=11) (Table 1). According to the analysis of variance, during the experiment and the annual consistent growth and development of plants, there was a tendency to gradually increase the number of newly formed shoots by 11-12% compared to the previous season (Figure 1b). The shoot-forming ability of Fuji trees significantly exceeded the value of Honey Crisp variety, 47 pcs./tree vs. 43 pcs./tree, respectively (LSD0.05=2). The formation and subsequent pruning of the French axis crown contributed to a significant weakening of the growth activity of the studied trees and provided a quarter reduction in the number of annual shoots compared to other crown forms that were studied. There was no significant difference in the value of the indicator in the variants with the formation of the crown of a slender spindle and ballerina. However, a 6% increase in the number of shoots was achieved with the introduction of tree crown pruning twice during the growing season, in winter and summer in the plantations of both studied varieties.

The predominant influence on the change in the number of shoots was caused by the factor "year of research" by 22% and "crown shape" by 21%. The pomological characteristics of the variety influenced the nature of the number of shoots formation by only 5% (Figure 2a).

A strong correlation of the number of shoots was found with the total leaf area \( (r=+0.86±0.07) \), tree fruit load \( (r=+0.81±0.1) \) and yield \( (r=+0.82±0.09) \) and an inverse relationship with shoot length \( (r=-0.93±0.04) \).

An important qualitative characteristic of the crown architecture of fruit trees is the length of annual shoots. The formation of the crown by the French axis and its subsequent pruning during the dormant period activated the growth force of shoots and provided their greatest length in both studied varieties. On the other hand, two-time pruning of trees in the shape of the ballerina crown significantly reduced the growth force of the plantations, forming shoots of 14.7-17.3 cm (Table 1). During the research period, with the annual increase in the number of shoots, their length decreased (Figure 1c) with an average value of 26.8 cm at the beginning of the experiment to 22.5 cm at the time of its completion (difference was 16%). Peculiarities of the pomological variety Honey Crisp provided 26% predominance of shoot length in comparison with the corresponding indicator of the variety Fuji. Also, the increase in shoot growth force was facilitated by the introduction of the French axis crown shape and averaged 29.3 cm in the experiment, which was a quarter higher than the results obtained as a result of the formation of the crown of a slender spindle and twice as much as the formation of the ballerina crown, which recorded the lowest values of the studied indicator. Also, the repeated pruning of trees in the early summer period contributed to a significant restraint of shoot growth. Thus, two-time pruning of trees in winter and early summer provided a decrease in the length of shoots by 4.5 cm (17%), LSD0.05=1.

The decrease in shoot growth vigor was caused by the predominant influence of the studied factors: "crown shape" by 38%, "pomological variety" by 14%, and "pruning time" by 11%.

A strong direct correlation of shoot length with total shoot length and number of leaves \( (r=+0.92±0.04) \) and inverse relationships with crown volume, tree fruit load, yield \( (r=-0.81±0.1) \) and number of fruits \( (r=-0.87±0.07) \) were found.

The total length of shoots (Figure 1d) in the experiment increased with the age of the plantations and significantly depended on the pomological variety (influence of the factor 10%). In the trees of the Honey Crisp variety, the value of the indicator was 15% higher as compared with the Fuji variety. As a result of the formation of the French axis crown and the activation of growth processes, the total length of shoots increased to 11.3 m/d (influence of the factor 12%), while with an increase in yield and a decrease
Figure 2: Strength of influence (%) of the studied factors on the growth of stem diameter (a), number of shoots (b), shoot length (c) and total shoot length (d).

**Notes:**
- A - year of research; B - pomological variety; C - crown shape; D - pruning period.

**Source:** developed by the author.

### Table 2: Specific productivity of apple trees depending on the shape of the crown and the term of pruning (averaged data for 2019-2022).

<table>
<thead>
<tr>
<th>Pomological variety</th>
<th>The form of the crown</th>
<th>Term of pruning</th>
<th>Specific productivity per bole cross-sectional area, kg/cm²</th>
<th>Specific productivity per total shoot length, kg/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuji</td>
<td>Slim spindle</td>
<td>In winter (control)</td>
<td>0.40</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In winter and summer</td>
<td>0.51</td>
<td>1.44</td>
</tr>
<tr>
<td>French axis</td>
<td></td>
<td>In winter</td>
<td>0.26</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In winter and summer</td>
<td>0.33</td>
<td>0.79</td>
</tr>
<tr>
<td>Ballerina</td>
<td></td>
<td>In winter</td>
<td>0.57</td>
<td>1.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In winter and summer</td>
<td>0.68</td>
<td>2.03</td>
</tr>
<tr>
<td>Honey Crisp</td>
<td>Slim spindle</td>
<td>In winter</td>
<td>0.31</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In winter and summer</td>
<td>0.40</td>
<td>1.18</td>
</tr>
<tr>
<td>French axis</td>
<td></td>
<td>In winter</td>
<td>0.17</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In winter and summer</td>
<td>0.24</td>
<td>0.75</td>
</tr>
<tr>
<td>Ballerina</td>
<td></td>
<td>In winter</td>
<td>0.35</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In winter and summer</td>
<td>0.43</td>
<td>1.78</td>
</tr>
<tr>
<td>LSD&lt;sub&gt;05&lt;/sub&gt;</td>
<td></td>
<td></td>
<td>0.11</td>
<td>0.55</td>
</tr>
</tbody>
</table>

In shoot length, the formation of the ballerina crown, the total length of shoots decreased to 9.3 m/tree (LSD<sub>05</sub>=0.7). Weakening the growth of apple trees of both studied varieties by 12% was facilitated by the implementation of two-time crown pruning.

Correlation of total shoot length was obtained with shoot length (r=+0.92±0.04) and yield (r=-0.63±0.21).

Specific productivity per cross-sectional area of the stem prevailed in the plantations of the Fuji variety with the maximum value of the indicator, as a result of double pruning of the ballerina crown shape - 0.68 kg/cm². As a result of a decrease in the level of yield and activation of growth processes of trees of the Honeoye Crisp variety (Table 2), when forming the French axis crown and its subsequent pruning in winter, the lowest value of this indicator was obtained at the level of 0.17 kg/cm².
(LSD$_{05}$=0.11). In general, in the experiment, the value of specific productivity per cross-sectional area of the bole, during the period of research, decreased due to the activation of growth processes in older trees (Figure 3a). The increase in specific productivity per cross-sectional area of the bole contributed to an increase in the yield level of the characteristic variety (factor influence of 18.7%) during the formation of the ballerina crown (factor influence of 43.5%), in particular as a result of double pruning of trees (factor influence of 7.4%).

The value of specific productivity on the total length of shoots among the research variants significantly prevailed, as a result of double pruning of the ballerina crown in the plantations of both studied varieties (Table 2). According to the results of the analysis of variance, the trees of the Honeoye Crisp variety were characterized by more active vegetative growth, which resulted in a 15% decrease in the values of the indicator (Figure 3b). However, as a result of the predominance of fruiting processes over growth processes, a significant increase in specific productivity per total shoot length was obtained in trees with a ballerina crown that was 127% higher than the value of the French axis crown and 44% higher than the slender spindle crown. Also, on average, the increase in specific productivity by the total length of shoots by 0.4 kg/m was facilitated by the implementation of two-time pruning of trees in winter and summer (Figure 4) (influence of the factor 12. The correlation of specific productivities per cross-sectional area and per total shoot length was significant at the level of 0.05 (0.00, 0.01, 0.03, 0.02). The correlation of productsivities per cross-sectional area and per total shoot length was significant at the level of 0.05 (0.00, 0.01, 0.03, 0.02).
productivity on the total length of shoots with the level of yield ($r=0.92\pm0.4$), the number of fruits ($r=0.84\pm0.09$) and the inverse with the total length of shoots ($r=0.86\pm0.07$) was obtained.

The results of the study indicate a significant weakening of the vegetative growth of the crown as a result of summer pruning, which is confirmed by the research of Golovaty (2012). A similar dependence was obtained in the studies of Chaploutsy and Melnyk (2015) with the study of Golden Delicious and Johnveld varieties, according to which pruning of the tree crown in the early summer period causes an 11% decrease in the girth of the stem, the number of shoots - by 15, 12 - shoot length and 24% of their total length and Melnyk and Kravtsova (2019) with the varieties Gala and Jonaveld.

The increase in specific productivity per cross-sectional area of the stem and total shoot length as a result of summer pruning was also proved in the studies of Mészáros (2017).

CONCLUSIONS

The study of the influence of three methods of apple tree crown formation and their implementation in winter (0 BBCH) and early summer (74 BBCH) shows a significant impact of these agricultural practices on the growth activity of the studied trees. The manifestation of more intensive vegetative growth in the plantations of the Honey Crisp variety compared to the Fuji variety was established.

Forming the crown of the French axis increases the increase in the diameter of the stem by 11%, but by performing this agricultural measure in the lines, the period of stem thickening slowed down.

The number of formed shoots in the form of the crown of the French axis was significantly less (by 20%) compared to the crown of the ballerina and slender spindle, but their length and total growth was significantly higher. The formation of the ballerina crown contributed to a decrease in the length of the shoots and their total growth and improved the illumination of the crown, as well as the introduction of crown pruning in the summer - the length of the shoot decreased by 17%, the total growth by 12%.

Due to the peculiarities of the ballerina crown formation, the maximum value of specific productivity is achieved both per cross-sectional area of the stem and in terms of the total length of the shoots. Also, the positive effect of specific productivity is facilitated by the summer pruning of the crown.

This makes it possible to design and create intensive orchards with a smaller planting scheme, while avoiding excessive crown thickening, taking into account the varietal characteristics of apple trees, which will help to increase the productivity of plantations and the formation of high-quality fruits.

Further research can be based on expanding the range of varieties, the range of crown pruning dates and determining the optimal planting scheme, which in turn will ensure higher productivity of the plantations.

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