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# Productivity of apple leaves, depending on the shape of the crown and the pruning times

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**Abstract.**

***Aims.*** To determine the influence of pruning terms and methods of crown formation on the productivity of apple trees grown on dwarf rootstock M.9 in intensive plantations of the Right-Bank Forest-Steppe of Ukraine. ***Methods***. Field (data acquisition), statistical using Tukey's test and Pearson's correlation method (data processing and analysis). The experiment was carried out in the garden of the Uman National University of Horticulture for 4 years (2019–2022) with apple trees of 'Fuji' and 'Honey Crisp' cultivars on dwarf rootstock M.9, planted according to the 4×1 m scheme. The factors studied were crowning shape: slender spindle, ballerina, and French axis; and also the pruning times: winter (0 BBCH) and winter combined with summer (second decade of June, 74 BBCH). ***Results***. The shape of the crown and double pruning significantly affected the specific productivity per unit area of the apple tree leaf surface. A maximum value of 3.1 kg/m² was when forming the crown ballerina with pruning in winter and summer of 'Fuji' trees. A 33% higher indicator value was provided in plantations of the 'Fuji' compared to the 'Honey Crisp', with 30–33% higher crown formation by the French axis and 33% higher by double crown pruning. Specific productivity correlates with the yield and fruit load of trees. The French axis crown formation provided a threefold increase in the leaf index compared to the slender spindle and ballerina formation. Double pruning (winter and summer) increased the leaf index by 17%. The experiment showed a gradual decrease with a minimum in 2022. The main influence on the value of specific leaf area on crown volume was the crown shape (77.5%), where the formation of the 'French axis' provided three times higher values compared to other studied crowns. Double pruning (winter and summer) also contributed to an increase in this indicator by 60% compared to pruning only in winter. ***Conclusions***. As a result of the formation of the French axis crown, its dimensions were much more compact, as a result of the peculiarities of its formation, which ensured an increase in the value of the leaf index

and the specific leaf surface area per crown volume, but due to its smaller size, the value of specific productivity per leaf surface area was significantly reduced. At the same time, there was a clear tendency to increase these indicators and the introduction of double pruning — in winter and summer.

*Key words:* apple cultivars, apple leaf blade, ballerina trees, French axis, slender spindle.

## Продуктивність листків яблуні залежно від форми крони та строків обрізування дерев

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**Реферат.**

***Мета.*** З'ясування впливу строків обрізування та способів формування крони на продуктивність яблунь, вирощених на карликовій підщепі М.9 в умовах інтенсивних насаджень Правобережного Лісостепу України. ***Методи.*** Польовий (отримання даних), статистичний з використанням тесту Тьюкі і кореляційний, методом Пірсона (опрацювання та аналіз даних). Експеримент виконували в саду Уманського національного університету садівництва впродовж 4-х років (2019–2022 рр.) з деревами яблуні сортів ‘Фуджі’ та ‘Хоней Крісп’ на карликовій підщепі М.9, висадженими згідно схеми 4×1 м. Досліджували фактори: 1**)** Форма крони: струнке веретено, балерина та французька вісь; 2) Строки обрізування: зимовий (0 ВВСН) та зимове в поєднанні з літнім (ІІ декада червня, 74 ВВСН). ***Результати.*** Дослідження показали, що форма крони та дворазове обрізування істотно впливали на питому продуктивність площі листової поверхні яблунь з максимальним значенням показника в 3,1 кг/м² при формуванні крони балерина з обрізуванням взимку та влітку дерев сорту ‘Фуджі’. Вище значення показника на 33 % забезпечено в насадженнях сорту ‘Фуджі’, порівняно з сортом ‘Хоней Крісп’, на 30–33 % за формування крони французька вісь та на 33 % за дворазового обрізування крони. Питома продуктивність корелювала з урожайністю та навантаженням дерев плодами. Формування крони французька вісь забезпечило зростання листкового індексу втричі порівняно із формуванням стрункого веретена та балерини. Дворазове обрізування (зимове та літнє) додатково збільшувало листковий індекс на 17 %. Експеримент показав поступове його зниження, з мінімумом у 2022 році. Основний вплив на значення питомої площі листкової поверхні на об'єм крони мала форма крони (77,5 %), де формування французька вісь забезпечило утричі вищі значення порівняно з іншими досліджуваними кронами. Дворазове обрізування (зимове та літнє) також

сприяло підвищенню цього показника на 60 % у порівнянні з обрізуванням тільки взимку. ***Висновки.*** В результаті формування крони французька вісь її габарити були значно компактнішими, внаслідок особливостей її формування, що забезпечило зростання значення листового індексу та питомої площі листкової поверхні на об'єм крони, проте через менший її розмір значення питомої продуктивності на площі листкової поверхні суттєво зменшувалося. При цьому спостерігалася чітка тенденція щодо зростання цих показників із запровадженням двократного обрізування, взимку та влітку.

*Ключові слова:* сорти яблуні, листкова пластинка яблуні, балерина-крона, французька вісь, струнке веретено.

**Introduction.** Apple tree is one of the most common fruit crops for cultivation due to its ability to adapt to different climatic conditions (Chyzh et al., 2008). As the level of intensification of fruit production increases, it becomes important to study and implement compact crown forms along with appropriate care methods. The use of compact crown shapes will create densified gardens with smaller distances between trees (Chaploutskyi et al., 2023).

To achieve a high-quality crop, all parts of the crown must receive sufficient sunlight. Light plays a key role in photosynthesis, the synthesis of organic compounds (Pallardy, 2008). Optimal lighting conditions after pruning significantly increase photosynthetic processes (Zhao et al., 2018).

Fruits growing on well-lit parts of the tree, especially in the spindle crown, have a higher weight, higher content of dry matter, sugars and an optimal sugar to acid ratio (Flore, 1992; Chaploutskyi et al., 2023).

The timing of pruning is an important factor when pruning (Ran et al., 2012). If done too early, it is likely to affect carbon storage, and if done too late, it may delay shoot maturation as a result of growth stimulation (Stephan et al., 2008).

Summer contour pruning improves crown illumination, which increases the yield of the current year and improves the conditions for laying generative buds for the next year's harvest (Zbigniew, 2013). Summer pruning reduces shoot growth by 20–30 %, but at the same time stimulates the formation of generative buds and improves crown illumination. Pruning in mid-July increases floral bud development by 18–30 % (Khomenko et al., 2000).

The research aimed to study the effect of different terms of pruning and crown formation on the development of leaf apparatus of apple trees grown in intensive plantations on dwarf rootstock M.9 in the conditions of the Right-Bank Forest-Steppe of Ukraine.

**Materials and Methods.** The research started in the spring of 2019 in the experimental garden of the Uman National University of Horticulture. The research aimed to study the influence of different methods of crown formation and pruning time on the growth and productivity of apple tree cultivars — ‘Fuji’ and ‘Honey

Crisp' grown on dwarf rootstock M.9. The experiment was conducted on chernozem sod-podzolic soils of the Right-Bank Forest-Steppe of Ukraine.

Trees were planted in 4×1 m spacing. Two factors were studied: the shape of the crown (slender spindle, ballerina, and French axis) and the timing of pruning: in winter (0 BBCH), and in summer, after the June ovary shedding (74 BBCH). A sod-humus soil maintenance system and herbicide fallow in the trunk strips were introduced in the garden aisle.

Phytometric parameters were evaluated according to the methods of Petro Kondratenko and Mykola Bublyk (Kondratenko & Bublyk, 1996). For data processing, analysis of variance in Statistica 10, standard deviation, Tukey's test for comparing mean values between pairs of variants ($p = 0.05$), and Pearson's method for determining correlation dependencies ($p = 0.01$) were determined.

**Results and Discussion.** The state of the leaf apparatus has a key impact on the productivity of plantations because it is in the leaves that the process of photosynthesis takes place in the chloroplasts to create organic matter, which accumulates in the fruits. As a result of different crown shapes, different areas of the total leaf surface are formed, which have various degrees of illumination and receive different amounts of solar energy for photosynthesis consequently of the specifics of crown formation. According to the results of the experiments, the specific productivity per leaf surface area prevailed in the 'Fuji', with its maximum level for two crown pruning of the ballerina in winter and summer, which amounted to 3.1 kg/m$^2$ (Table 1). As a result of the formation of the crown of French News in winter and the reduction of its size due to the peculiarities of formation and, as a result, a decrease in the level of tree productivity, the lowest value of specific productivity per leaf surface area was noted at 1.2 kg/m$^2$.

The average annual values of the studied indicator, averaged over the experiment, showed a gradual increase in specific productivity per leaf surface area, and the maximum value was obtained in the season of 2022. However, no statistically significant difference was found for 2020–2022 (Fig. 1). The peculiarities of the cultivar (influence of the factor 19.2 %) influenced the value of the studied indicator, with a predominance of 33% in the plantations of the 'Fuji' compared to 'Honey Crisp'.

When forming the crown, the French axis, with the removal of part of the fruit wood due to the peculiarities of its formation, causes a decrease in the value of specific productivity on the leaf surface area (influence of the factor 32.7 %, Fig. 2), which was 33 % lower than the value of the ballerina crown and 30 % lower than the slender spindle. There was no statistically significant difference in the value of the studied indicator between the formation of a slender spindle and a ballerina. However, due to the double pruning of the crown (in winter and summer) and, as a result, the establishment of more fruit formations, despite the removal of part of the leaf surface as a result of pruning, it contributes to an increase in specific productivity per leaf surface area by 33 % (factor influence of 18.5 %).

*Table* 1. **Characteristics of the leaf apparatus of apple trees of 'Fuji' and 'Honey Crisp' depending on the shape of the crown and the term of tree pruning (2019–2022)**

| Cultivar | Crown shape | The term of pruning | Specific productivity per leaf surface area, кг/м$^2$ | Leaflet index | Specific leaf area per crown volume, м$^2$/м$^3$ |
|---|---|---|---|---|---|
| 'Fuji' | Slender spindle | In winter (control) | 2,2±0,3 cd* | 3,9±0,6 c | 2,7±0,3 c |
| | | In winter and summer | 2,8±0,2 ab | 4,7±1,2 c | 3,5±0,9 c |
| | French axis | In winter | 1,6±0,4 fg | 11,7±1,0 b | 8,0±0,5 b |
| | | In winter and summer | 2,1±0,5 cde | 13,9±3,2 ab | 9,8±2,7 ab |
| | Ballerina | In winter | 2,5±0,2 bc | 4,7±1,1 c | 3,3±0,5 c |
| | | In winter and summer | 3,1±0,3 a | 4,5±1,0 c | 3,4±0,8 c |
| 'Honey Crisp' | Slender spindle | In winter | 1,8±0,2 def | 4,5±0,7 c | 3,1±0,5 c |
| | | In winter and summer | 2,4±0,2 bc | 4,6±0,7 c | 3,2±0,8 c |
| | French axis | In winter | 1,2±0,3 g | 12,8±3,5 b | 8,4±2,2 b |
| | | In winter and summer | 1,6±0,5 efg | 16,7±7,2 a | 11,4±5,2 a |
| | Ballerina | In winter | 1,8±0,1 def | 4,5±0,6 c | 3,2±0,6 c |
| | | In winter and summer | 2,2±0,1 cd | 4,8±0,6 c | 3,4±0,6 c |

Note: * — mean values (mean ± SD) of indicators, the presence of the same letters in a pair of options indicates the absence of a statistically significant difference according to the Tukey's criterion (p = 0.05).

Specific productivity per leaf surface area is directly correlated with the fruit load of trees and yield, and an inverse correlation was found with the total shoot length and the increase in stem diameter.

The value of leaf index, which expresses the ratio of leaf surface to crown projection area, significantly depends on the studied crown forms.

Despite the peculiarities of the cultivar, in the plantations of both studied cultivars, the value of the leaf index as a result of crown formation of the French axis significantly exceeded other studied crown forms. There was also a dependence on the growth of the value of the studied index with the introduction of two crown pruning - in winter in combination with summer pruning.

During the experiment, the value of the leaf index decreased over the years, and its lowest level was reached in the season of 2022 at a level of 6.6 (see Fig. 1).

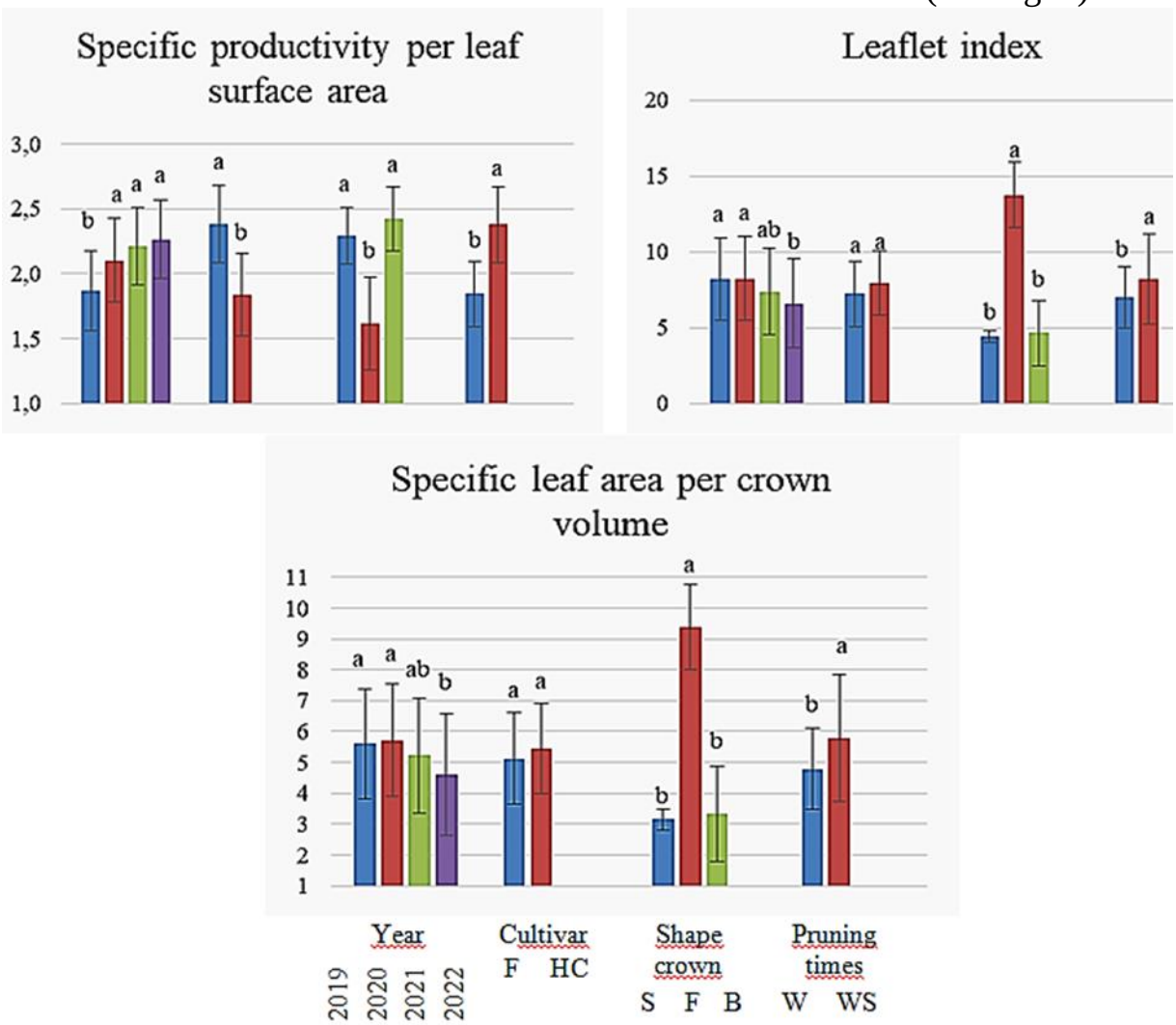


*Figure* 1. Averaged data on the factors of indicators: specific productivity per leaf blade area, leaf index, and specific leaf surface area per crown volume of apple trees, depending on the shape of the crown and the term of their pruning:
F — 'Fuji'; HC — 'Honey Crisp';
S — Slender spindle; F — French axis; B — Ballerina;
W — Winter; WS — Winter & Summer

The absence of a statistically significant difference in the average for the two studied cultivars was established. However, the formation of the French axis crown provided a threefold increase in the leaf index compared to the formation of the slender spindle and ballerina, where no statistically significant difference was found in the latter (factor influence 79.5 %, Fig. 2). The growth of the leaf index was also facilitated by the implementation of two crown pruning and its implementation in winter in combination with summer pruning, which ensured an increase in the value of the index by 17 %.

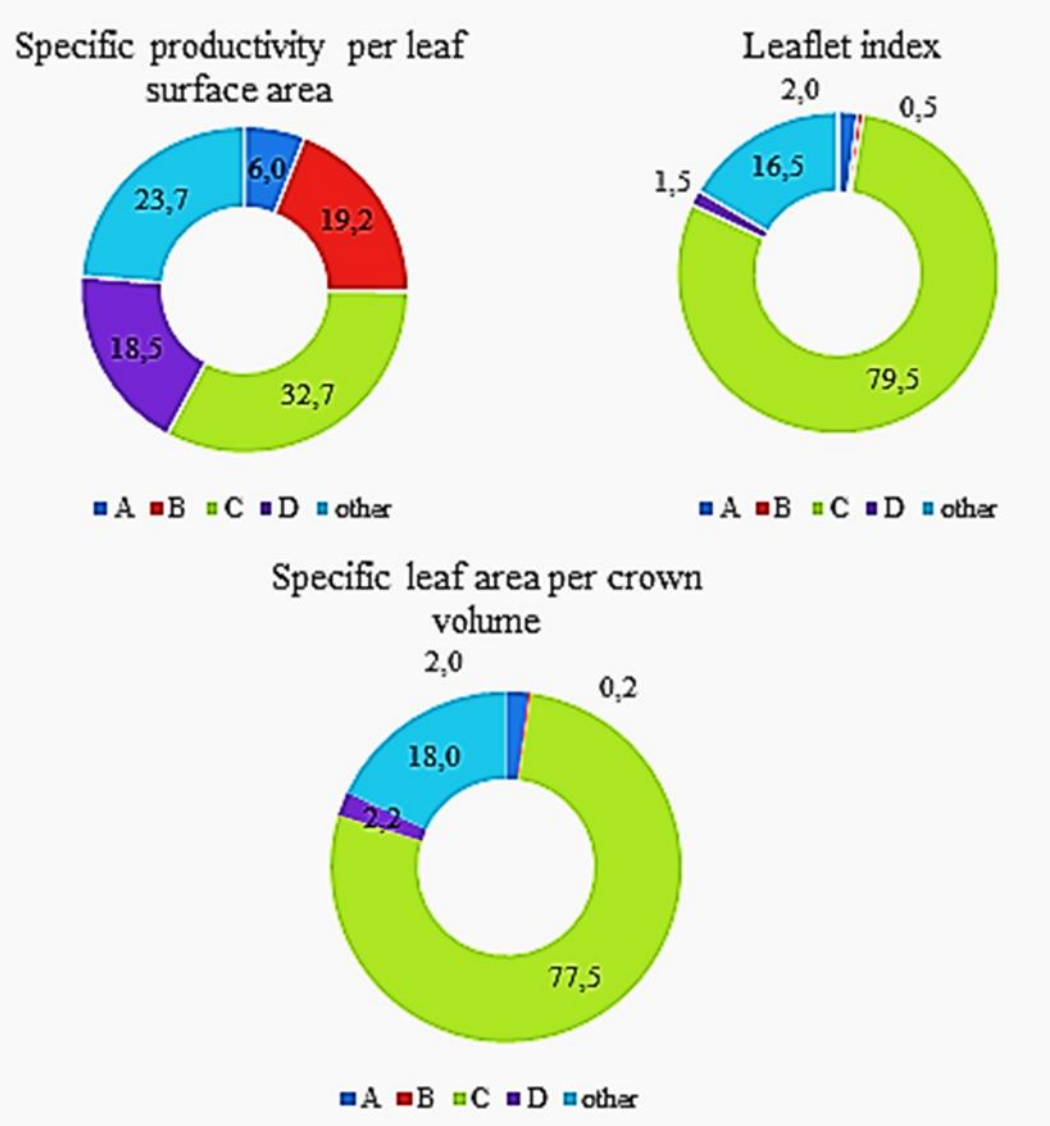


*Figure* 2. Strength of influence of the studied factors for specific productivity per leaf area; leaf index; specific leaf area per crown volume: A — year study; B —cultivar; C — crown shape; D — pruning time

The value of the leaf index is inversely correlated with the diameter and volume of the crown, as well as with the area of its projection.

During the experiment, a significant influence of the studied factors on the value of the specific leaf surface area on the crown volume was revealed. As a result of the formation of the French axis crown in winter, the value of the studied indicator was obtained at the level of 8–8.4 $m^2/m^3$, but a slightly higher value of the indicator was provided by pruning trees in winter in combination with summer at the level of 9.8 $m^2/m^3$ in the plantation of 'Fuji' and 11.4 $m^2/m^3$ of 'Honey Crisp', respectively. The formation of the crown of the slender spindle and ballerina, regardless of the term of their pruning, is distinguished by significantly lower values of the studied indicator at the level of 2.7–3.5 $m^2/m^3$ (see Table 1).

Analyzing the averaged data by factors (see Fig. 1), a gradual decrease in the

value of the studied indicator was found during the experiment, with its minimum level in the 2022 season. On the 'Honey Crisp' plantation, the value of specific leaf area per crown volume was slightly higher than that of 'Fuji', but there was no statistically significant difference between the average values of the two cultivars. The most significant influence of 77.5 % on the change in the value of the indicator was caused by the factor “crown shape”. Forming the crown, the French axis in consequence of the formation features and a significant limitation of its volume, provided a threefold advantage in terms of the specific leaf area per crown volume. The double crown pruning (in winter and summer) contributed to an increase in the value of this indicator by 60% higher than when the studied trees were pruned only in winter. The inverse correlation of the studied indicator with the diameter, crown volume, and the level of development of the feeding area was established.

**Conclusions.** The analysis of the data obtained during the experiment indicates a significant impact of different methods of crown pruning and the timing of their implementation on the characteristics of the leaf surface of apple trees of ‘Fuji’ and ‘Honey Crisp’. Studies have shown that the specific productivity per leaf surface area of apple trees was 33 % higher in ‘Fuji’ compared to ‘Honey Crisp’, 30–33 % in French axis crown formation, and 33 % in two-time crown pruning. French axis crown formation provided a threefold increase in leaf index compared to other types of crowns. Two-time pruning in winter and summer additionally increased the leaf index by 17 %. The specific leaf surface area per crown volume depended on the crown shape by 77.5 %, with the French axis predominating. Double pruning in winter and summer also contributed to a 60 % increase in the index compared to winter pruning.

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