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Parameters of apple tree crowns depending on the crown shape and pruning time

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Abstract. The apple tree is a leading fruit crop in Ukraine in terms of production volumes and planting areas and is a valuable food product with a high content of vitamins. In new modern plantings, fruit producers prefer intensive cultivation technologies that ensure the maximum amount of high-quality fruit yield per unit area. The main criterion for solving this problem is the design of plantings: a narrow-row scheme for planting trees and a low-volume crown shape. The purpose of the study was to establish the influence of the pruning period of different types of crown formations on the growth and productivity of apple trees of two varieties: Fuji and Honey Crisp. The study was conducted in the conditions of the central Forest-Steppe of Ukraine (Uman National University of Horticulture). The scheme of planting was 4x1 m, M.9 rootstock, chernozem sod-podzolic soil, drip irrigation. Field, statistical, and computational-analytical methods

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were used in the course of the study. It was identified that the growth pattern of the examined varieties differed substantially, and crown volume, projection area, and development of the feeding area prevailed in Honey Crisp trees. However, in terms of productivity, the plantings of the Fuji variety substantially exceeded the values of the Honey Crisp variety. Forming a ballerina crown with the removal of overgrown wood in a 25 cm zone on the central trunk above the lower tier of semi-cellular branches provided an increase in the growth activity of the examined trees by 3-5%. A substantial decrease in the values of crown parameters was provided by the formation of the French axis crown – there was a decrease in the crown diameter by 44%, the crown volume – by 67%, and the crown projection area and the development of the feeding area – by 69%. Performing additional summer pruning of trees also helped to reduce growth activity by 6-11%. However, the specific productivity of plantings doubled in plantings with the formation of the French axis and by 45-50% with the introduction of double pruning of trees. It is recommended that agricultural producers investigate the terms of pruning low-volume crown forms, considering varietal characteristics, to create compacted apple stands and increase the intensification of production

Keywords: apple tree; crown shape; pruning time; crown volume; summer pruning

INTRODUCTION

The apple tree is the leading fruit crop in Ukraine, which ranks third in terms of fruit production in the world, second only to citrus fruits and bananas. It is necessary to substantially increase the productivity of fruit plantations to meet the needs of the population for horticultural products. The introduction of new cultivation technologies, which will be based on the creation of efficient, intensive plant designs and plant care systems, can substantially increase the productivity of plantings and improve the quality of the grown crop. Ultimately, the intensification of gardening involves obtaining higher yields of high-quality fruits per unit area. This can be achieved by creating gardens with a smaller planting pattern and compacting the plantings. Therefore, the development of methods for the formation and subsequent care of new, small-sized crown forms, which, due to the features of their architectonics, would provide maximum interception of solar radiation, forming fruitwood and better-coloured fruits determines the relevance of these studies.

Modern intensive plantings are characterised by the rapid development of the feeding area and an increase to the physiological optimum of the leaf surface – 35-40 thousand m^2/ha or more and the early beginning of industrial fruiting. Light is important for all physiological processes in the plant. With 100% sunlight according to Laužikė *et al.* (2020), only 40% falls on plants, and 15% (out of 40%) are limited by the garden design and leaf area

The relatively low level of light use (the proportion of total photosynthetic active radiation by plant structural parts) in the intensive apple growing system remains the main limiting factor for improving garden productivity. In their studies, Tustin *et al.* (2022) and Musacchi (2018) established a close correlation between the formation and the level of illumination of all parts of the crown. According to Lordan *et al.* (2018), planting pattern, crown shape, and tree height are the main determining factors for the maximum light level of trees. These factors often set an upper limit on the productivity of plantings along with physiological ones: pomological variety, rootstock, and soil fertility. However, according to observations by Johansen *et al.* (2018), due to low or high temperatures, intense lighting, or water scarcity, photoinhibition leaf damage may occur.

Crown formation of fruit trees aims to create a specific crown architecture to improve the interception and use of light to increase yield and optimise fruit quality. Therefore, according to Raig *et al.* (2019), choosing a molding system is crucial for improving the profitability of the garden. The correct crown shape and rational pruning of the aboveground part of apple trees can achieve the uniform formation of generative buds and fruiting throughout the entire crown volume (Strnad *et al.,* 2020; Wang *et al.,* 2023).

Adjusting the parameters of the aboveground part of the crown, Siefen *et al.* (2023), were able to provide 35-40% higher illumination of its central part, improving air circulation, thus stabilising fruiting and improving the commercial quality of the crop. Pruning apple trees is a very labour-intensive agricultural measure in the apple production process (Fransen, 2016; Marini, 2020). When choosing the best pruning method, a number of factors are considered, the main ones being, according to He & Schupp (2018) and Goke *et al.* (2020), are the degree of intensity of the garden and the time of conducting, variety-rootstock combination, planting density, age, crown shape, height and dimensions of crowns.

The production of the same type of high-quality fruit is the key to successful gardening because it is the quality of fruits that is crucial for price formation, creates demand, and has the greatest impact on the potential profit of the farm. However, according to Zhang *et al.* (2016) and D'abrosca *et al.* (2017), fruit quality can be very heterogeneous within a single tree, depending on the shape of the crown and the placement of their structural elements in the space, mainly due to different lighting levels.

Attempts to control tree size by various methods, such as dwarfing rootstocks, spur varieties, tree pruning

methods, and growth inhibitors, remain the focus of scientific attention. In particular, Zahid *et al.* (2020) identified that one of the most effective ways to control tree growth and the formation of evenly eliminated crowns is to introduce summer pruning. On the recommendation of Ruiz-Sánchez *et al.* (2022) and Conesa *et al.* (2019), it consists of removing unproductive shoots and is performed mainly for controlling tree growth, reducing the need for winter pruning.

The purpose of the study was to identify the influence of the pruning period for various types of crown formation on the productivity of apple trees in an irrigated apple orchard in the conditions of the Right-Bank Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The examination of methods of care for small-sized forms of the crown of apple trees, in particular, pruning dates, started in the spring of 2019 at the Uman National University of Horticulture. An experimental apple orchard, found in the spring of 2015 had varieties of Fuji and Honey Crisp grafted on the M.9 T337 rootstock. Experimental trees are planted in the garden according to the 4x1 m scheme, the soil is sod-podzolic chernozem. In the row spacing, the soil was kept behind a sod-humus system and herbicidal steam in the trunk strip, drip irrigation. Trees were pruned in two periods: in winter and twice per season: in winter and in summer after the June shedding of the ovary (second decade of June) forming slender spindle, ballerina (with the removal of overgrown wood in 25 cm zone on the central trunk above the lower tier of semi-cellular branches), and the French axis crown shapes.

Crown parameters were assessed at the end of the growing season according to the methods of Kondratenko P.V., Bagel M.O., 1999. The crown diameter was defined as the distance between the extreme points of its width.

The area of the crown projection was calculated by the formula:

$$S=0.196*(D_1+ D_2)^2$$

where S – area of the crown projection, m^2; 0.196 – constant conversion coefficient; $D_{1,2}$ – crown width in two perpendicular directions, m;

The crown volume was determined by the following formula:

$$V=0.523*D^2*h$$

where V – crown volume, m^3; 0.523 – constant conversion coefficient; D – crown width, m; h – crown height from the bole to the top of the crown, m.

The degree of development of the feeding area was determined as the ratio of the crown projection area to the feeding area provided for by the planting scheme.

Specific productivity was defined as the ratio of tree fruit load to crown volume or crown projection area.

RESULTS AND DISCUSSION

During the experiment, a substantial dependence of the crown diameter value on both the shape of the crown and the term of its pruning was established. In general, according to the experiment, the value of the crown diameter in the plantings of the Honey Crisp variety was dominated by the corresponding indicator of the Fuji variety (Table 1) with its minimum value for twice pruning the crown of the French axis (0.62 m), which is twice lower than the value of the control option – 1.24 m (LSD_{05}=0,18).

Table 1. *Parameters of the apple tree crown depending on the shape of the crown and the time of pruning (2019-2022)*

Pomological variety	Crown shape	Pruning period	Crown diameter, m	Crown volume, m^3	Crown projection area, m^2	Development of the nutritional area, %
Fuji	Slender spindle	In winter (control)	1.24	1.71	1.22	30.6
		In winter and summer	1.12	1.32	0.99	24.8
	French axis	In winter	0.70	0.56	0.38	9.6
		In winter and summer	0.62	0.45	0.31	7.8
	Ballerina	In winter	1.20	1.60	1.15	28.7
		In winter and summer	1.21	1.52	1.17	29.2
Honey Crisp	Slender spindle	In winter	1.31	1.95	1.34	33.5
		In winter and summer	1.27	1.86	1.29	32.1
	French axis	In winter	0.75	0.69	0.46	11.4
		In winter and summer	0.66	0.52	0.35	8.8
	Ballerina	In winter	1.34	2.02	1.42	35.6
		In winter and summer	1.30	1.89	1.34	33.4
LSD_{05}			*0.18*	*0.48*	*0.33*	*8.4*

Source: *compiled by the author*

The results of the variance analysis indicate a 10% predominance of crown dimensions in Honey Crisp trees (Fig. 1a) and a 45% decrease in the indicator values as a result of crown formation. There was no substantial difference in the diameter of the crowns as a result of their formation according to the type of slender spindle and ballerina. The reduction in the indicator values was facilitated by the introduction of pruning of trees twice in winter and summer by 6%.

The greatest influence on the crown diameter value was caused by the crown shape factor by 78.6% (Fig. 2a). The greatest direct correlation of the crown diameter was identified with the crown volume (r=0.99±0.01), its projection area (r=0.99±0.01), the number of fruits (r=0.84±0.08), and the number of shoots (r=0.66±0.19).

The volume of the crown among the examined varieties prevailed in Honey Crisp plantings and was substantially inferior in the formation of the French axis (Table 1), which is explained by the absence of semi-skeletal branches in its structure. A total increase by a quarter of the indicator value in Honey Crisp trees (Fig. 1b) retained the dependence, in the plantings of both varieties, on a substantial decrease in the crown volume during the formation of the French axis – 0.55 m^3, which is 1.16-1.22 m^3 less than other types of formations examined (LSD_{05}=0,12). A decrease of 13% (0.16 m^3) in the volume of the crown is facilitated by repeated pruning of trees during the season in summer.

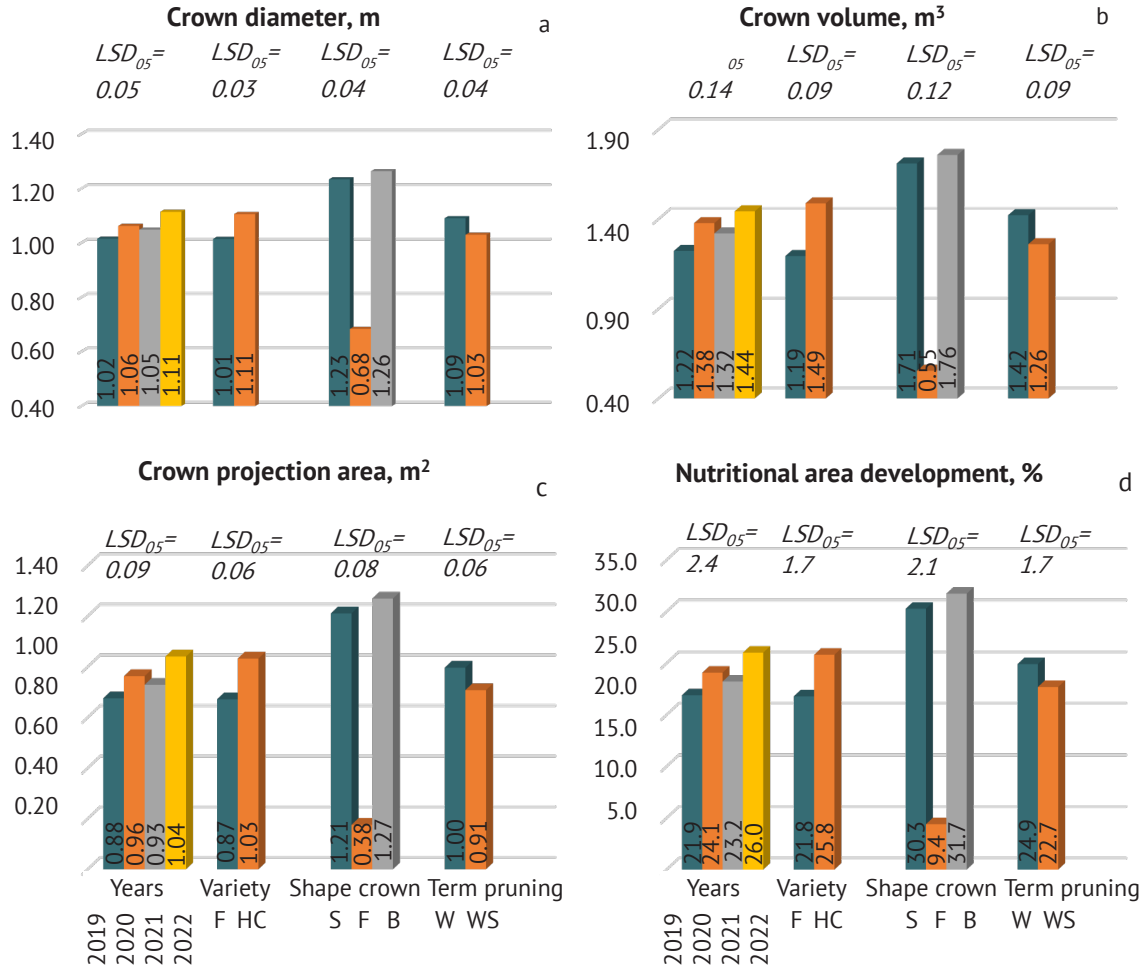

Figure 1. *The average diameter (a), volume (b), area of the crown projection (c), and level of development of the feeding area (d) of apple trees for the 2019-2022 studies, depending on the shape of the crown and the pruning period (results of variance analysis)*

Note: *Varieties: Fuji (F), Honey Crisp (HC); crown shape: slender spindle (S), French axis (F), ballerina (B); pruning term: winter (W), winter and summer (WS)*

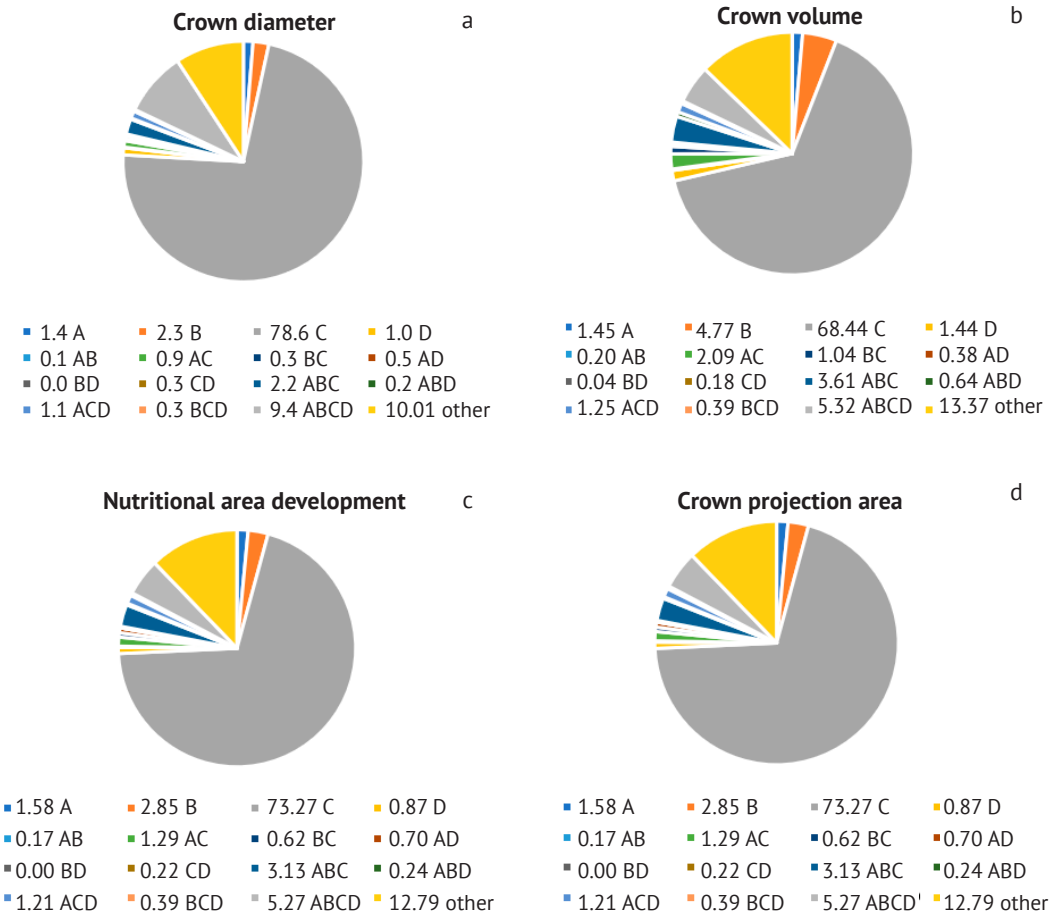

Figure 2. *The strength of the influence of the examined factors on the diameter (a), volume (b), development of the feeding area (c), and the crown projection area (d).*
Note: *A – the year of the study; B – pomological variety; C – crown shape; D – pruning period*
Source: *compiled by the author*

Change in crown volume (Fig. 2b) substantially depends on the shape of the crown (influence of the factor 68.4%) and the characteristics of the pomological variety (4.7%). Crown volume directly correlates with the number of fruits (r=0.83±0.09), yield (r=0.92±0.04), and inversely with the length of shoots (r=-0.81±0.10).

Fuji trees are substantially inferior to The Honey Crisp variety in terms of crown projection area (Table 1), with the maximum predominance of the indicator as a result of ballerina crown formation in winter (1.42 m^2). The formation of the crown of the French axis of Fuji trees and its subsequent pruning twice a season in winter and summer ensured that the lowest value of the indicator was obtained at the level of 0.31 m^2 (LSD_{05}=0.33)

On average, the experiment increases the area of the crown projection (Fig. 1b) at the level of 1.04 m^2 as of 2022 (influence of the factor – 1.6% (Fig. 2d)). Fuji trees were 18% inferior to the corresponding value of the Honey Crisp indicator. The French axis crown formation reduced the projection area by 66% (influence of the factor – 73.3%), but in trees with the ballerina crown formation, this indicator increased by 6% compared to the slender spindle option. The introduction of double pruning in winter and summer with the removal of strong-growing unproductive shoots of the current season leads to a decrease in the area of the crown projection by 6%.

The area of the crown projection directly correlates with the crown volume (r=0.99±0.01), the number of fruits (r=0.83±0.09), and the yield (r=0.79±0.11).

The development of the nutritional area, which indicates a rationally selected tree planting scheme and the level of planting intensity, somewhat prevailed (by 4%) in the planting of the Honey Crisp variety (Fig. 1f). The average value of the indicator for both examined varieties is substantially lower as a result of crown formation – 9.4% with more than 73% influence of the factor on the change in the indicator (Fig. 2c). The formation of the crowns of the slender spindle and ballerina did not differ substantially and amounted to 30.3-31.7%. The combination of winter and summer pruning reduced the value of the indicator by 9%.

A substantial influence of various methods of crown formation and the time of their pruning was obtained on the productivity indicators of trees. The-specific productivity per unit volume of the crown varied substantially with the increase in the indicator with

the introduction of a more compact, low-volume crown, which indicates an increase in the level of intensity of horticulture technology. Therewith, an increase in the specific productivity of plantings of both varieties under study was noted with the implementation of double pruning of tree crowns in winter and summer, due to an increase in the level of illumination and, as a result, an improvement in the laying of fruitwood. The maximum specific productivity per unit volume of the crown was obtained as a result of double pruning of the French axis crown – 20.7 kg/m^3 in Fuji and 17.5 kg/m^3 in Honey Crisp varieties (Table 2), by 14.7 and 12 kg/m^3 accordingly, exceeded the value for the winter pruning of the slender spindle crown, where the lowest value of the indicator (LSD_{05}=7.4).was obtained. During the formation of the ballerina crown, there was also a slight increase in the values of the indicator relative to the data of the control variant.

Table 2. *Specific productivity of apple trees depending on the crown shape and pruning period (2019-2022)*

Pomological variety	Crown shape	Pruning period	Specific productivity per unit crown volume, kg/m^3	Specific productivity per unit of nutritional area, kg/m^2
Fuji	Slender spindle	Winter (control)	6.0	8.4
		In winter and summer	9.8	13.0
	French axis	In winter	12.8	18.6
		In winter and summer	20.7	29.1
	Ballerina	In winter	9.4	13.2
		In winter and summer	11.6	15.1
Honey Crisp	Slender spindle	In winter	5.5	7.9
		In winter and summer	7.8	10.9
	French axis	In winter	10.2	15.3
		In winter and summer	17.5	25.6
	Ballerina	In winter	5.9	8.4
		In winter and summer	7.5	10.5
	LSD_{05}		*7.4*	*10.1*

Source: *compiled by the author*

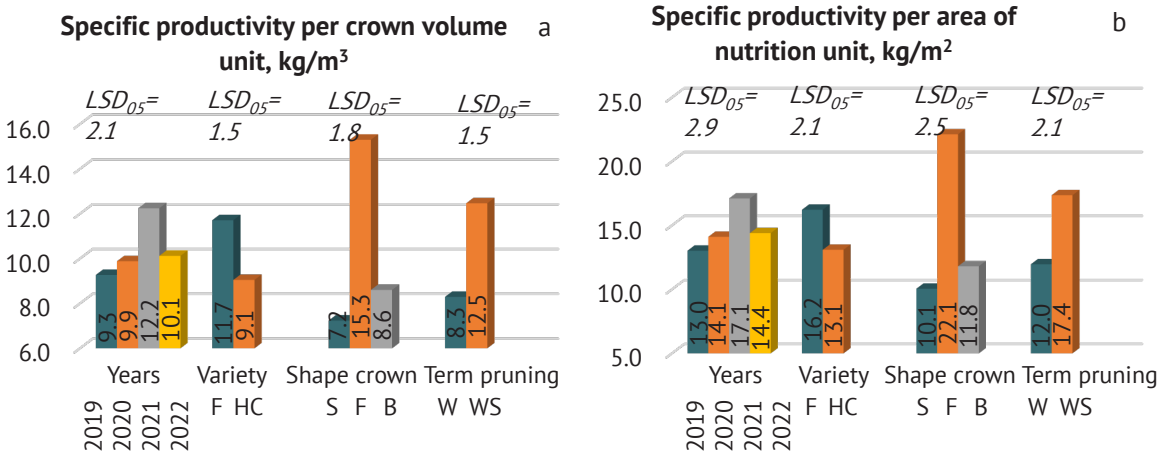

Figure 3. *Averaged data on specific productivity per volume (a) and area of nutrition (b) unit of apple trees, depending on the shape of the crown and the pruning period (results of variance analysis).*

Note: *Varieties: Fuji (F), Honey Crisp (HC); crown shape: slender spindle (S), French axis (F), ballerina (B); pruning term: winter (W), winter and summer (WS)*

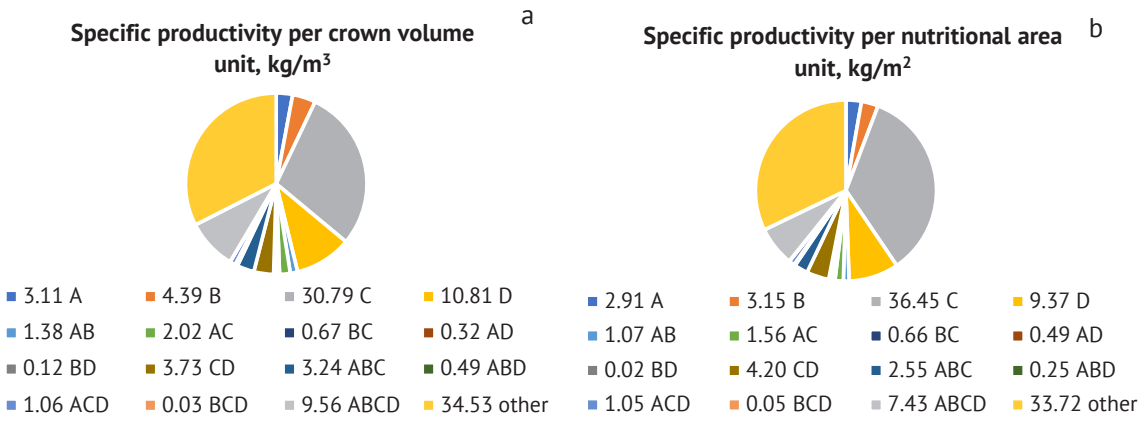

Figure 4. *The strength of the influence of the examined factors on the specific productivity per unit volume of the crown (a) and the specific productivity per unit area of the feed (b)*

Note: *A – the year of the study; B – pomological variety; C – crown shape; D – pruning period*
Source: *compiled by the author*

In general, during the experiment, according to the analysis of variance, the value of specific productivity per unit volume of the crown increased annually with the achievement of the maximum value in 2021 at the level of 12.2 kg/m^3 (Fig. 3a). On average, the specific productivity per crown volume of the Fuji variety increased by 28.5%, or 2.6 kg/m^3 exceeding the value of the Honey Crisp variety (LSD_{05}=1.5). However, the highest value of the indicator (15.3 kg/m^3) was achieved due to the introduction of a low-volume French axis crown shape, which was more than twice the value of the slender spindle crown formation (7.2 kg/m^3). In addition, the ballerina crown contributes to a 20% increase in the value of specific productivity per crown volume (8.6 kg/m^3). Additional pruning of tree crowns in summer contributed to a substantial increase in specific productivity (by 50%).

An inverse strong correlation of the specific productivity per unit crown volume was obtained with the crown diameter and volume (r=-0.86±0.07). Among the examined factors, crown shape and pruning period had the greatest influence on the change in the indicator values – by 30.8% and 10.8%, respectively (Fig. 4a).

The specific productivity per crown projection area also substantially depended on the examined crown shape and pruning time. An increase in the indicator values indicates an increase in the projected yield of plantings per unit area with an optimally selected tree planting scheme due to the influence of the examined agricultural measures. A substantial increase in the values of the specific productivity indicator during the crown projection in the plantings of both examined varieties was obtained due to the formation of the French axis crown. In addition, a substantial impact on the growth of the values of the examined indicator is caused by the introduction of additional pruning of trees in the summer. Performing winter and summer pruning of trees, in particular, the crown of the French axis, provided a maximum increase in the value of specific productivity per crown projection area to the level of 29.1 kg/m^2 in the Fuji variety and 25.6 kg/m^2 in Honey Crisp, respectively (Table 2), the difference to the control was 17.6-20.7 kg/m^2 (LSD_{05}=10.1).

Due to the relatively larger area of the crown projection in the planting of the Honey Crisp variety, the specific productivity per the area of its projection was substantially inferior to the value of the Fuji variety. The excess of the latter values is 23.6%, or 3.1 kg/m^2 (LSD_{05}=2.1) (Fig. 3b). Among the examined crown forms, the ballerina crown increased the indicator by 1.7 kg/m^2 relative to the values of the slender spindle. However, the most substantial increase in specific productivity per crown projection area is 12 kg/m^2 obtained as a result of the French axis crown formation. The implementation of additional summer pruning of trees contributed to a reduction in the size of the crown, better formation of fruitwood and, as a result, an increase in specific productivity per unit area of the crown projection by 45%, or 5.4 kg/m.^{2} (LSD_{05}=2.1).

A strong correlation of the specific productivity per unit area of the crown projection is obtained with the diameter and volume of the crown (r=-0.89±0.06). To the greatest extent, the change in specific productivity per unit area of the crown projection is caused by the crown shape and pruning period factors by 36.4% and 9.4%, respectively (Fig. 4b).

The introduction of modern small-sized crowns using the latest highly productive varieties will determine the design of plantings and, as a result, the level of intensification of the garden. According to Kolmanič *et al.* (2021) and Crassweller *et al.* (2020), summer pruning in apple orchards is a common practice to improve the illumination of the crown and reduce vegetative growth next year. It also leads to an increase in the intensity of leaf photosynthesis as a result of improved light levels after pruning, the area of which is reduced by 10-30%

(Mierowska *et al.*, 2022). The results of the study indicate a substantial decrease in the crown size as a result of summer pruning, which is confirmed by Mu *et al.* (2018) and Kolmanič *et al.* (2021). A similar relationship was obtained in the studies of Chaploutsky and Melnik (2019), Strnad *et al.* (2020), examining Golden Delicious and Jonagold varieties, according to which, winter pruning in combination with early summer pruning caused a 5% decrease in the crown diameter, a 10% decrease in its volume, and a 9% decrease in the projection area and the degree of development of the feeding area. Melnyk and Kravtsova (2018) observed a reduction in crown dimensions of the Gala and Jonagold Wilmut varieties, in particular, volume – by 15-17% and the crown projection area – 10-12%. By reducing the size of the crown, it is possible to create compacted plantings, which, when forming an axillary crown, will not affect the level of their illumination. Therewith, according to Lugaresi (2022), the percentage of more than 50% red-coloured fruits increases by 20.5% if summer pruning is introduced and the sugar content in the fruit increases (Vosnjak, 2021).

Thus, the constant updating of the assortment of fruit stands, especially in modern intensive gardens, requires research on agricultural techniques for tree care, the influence of pruning times, crown formation features, fruit wood formation, etc. Ultimately, varietal characteristics, the growth force of variety-splitting combination, shoot-forming ability, and type of fruiting substantially affect the formation of productivity of plantings and determine the features of their care.

CONCLUSIONS

The study of the influence of crown shape and tree pruning time showed that the examined varieties have different growth activity, which prevails in the Honey Crisp variety, which should be considered when choosing plantings. It was identified that the dimensions of the crown, in particular, the diameter and volume of the crown prevailed in trees of the Honey Crisp variety for the formation of the ballerina crown in winter – 1.34 m and 2.02 m^3 accordingly. The greatest influence on the reduction of crown dimensions is caused by the method of formation (influence of the factor – 68-78%), in particular, by forming the crown of the French axis, which is marked by the smallest values of diameter indicators in the Fuji variety – 0.62 m and the crown volume of 0.45 m^3. In general, according to the experiment, the formation of the crown of the French axis helps to reduce the diameter of the crown by 44% and its volume – by 54%. An additional effect of reducing the size of the crown by 6-13% in both varieties under study was achieved due to the introduction of double pruning of trees in winter and summer. These agricultural measures provided an increase in the specific productivity of apple trees of both examined varieties. The specific productivity per crown volume during the formation of the ballerina crown increased by 19%, and more than a twofold increase was achieved by forming the French axis crown (15.3 kg/m^3). In addition, the implementation of additional pruning of trees in the summer increased the specific productivity per crown volume by 50%. The same dependence was observed with the specific productivity per unit of the nutritional area. This allows for developing technologies for growing gardens with a smaller planting scheme, and therefore a larger number of trees per unit area, which will help to increase the productivity of plantings.

Considering the importance of apples as a valuable food product for fresh consumption or as a processed product, further research may be based on an extended range of crown pruning dates and determining the optimal planting scheme to ensure higher productivity of plantings.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Параметри крон дерев яблуні залежно від форми крони та строку обрізування

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Анотація. Яблуня лідируюча плодова культура в Україні за обсягами виробництва та площами насаджень та є цінним харчовим продуктом з високим вмістом вітамінів. В нових сучасних насадженнях виробники фруктів надаю перевагу інтенсивним технологіям вирощування, які забезпечують отримання максимальної кількості якісного урожаю плодів з одиниці площі. Основним критерієм вирішення даної задачі є конструкція насаджень: вузькорядна схема садіння дерев та малообʼємна форма крони. Метою досліджень було встановлення впливу строку обрізування різних типів формувань крони на ріст та продуктивність дерев яблуні двох сортів: Фуджі та Хоней Крісп. Дослідження виконувались в умовах центрального лісостепу України (Уманському національному університеті садівництва). Схема садіння досліджуваних дерев 4х1 м, підщепа М.9, ґрунт чорнозем дерново-опідзолений, зрошення краплинне. Під час виконання дослідження використано польові, статистичні та розрахунково-аналітичні методи. Виявлено, що характер росту досліджуваних сортів істотно різнився та за показниками діаметру, обʼєму крони, площі проекції та освоєнням площі живлення переважав у дерев сорту Хоней Крісп. Проте, за показниками продуктивності, насадження сорту Фуджі суттєво перевищували значення сорту Хоней Крісп. Формування крони балерина з видаленням обростаючої деревини в 25 см зоні на центральному провіднику вище нижнього ярусу напівсклетних гілок, забезпечило підвищення ростової активності досліджуваних дерев на 3-5 %. Істотного зменшення значень параметрів крони забезпечило формування крони французька вісь, на 44 % відбулось зменшення діаметра крони, на 67 % обʼєму крони, на 69 % площі проекції крони та освоєння площі живлення. Виконання додаткового літнього обрізування дерев також сприяло зменшенню активності росту на 6-11 %. Проте питома продуктивність насаджень зросла вдвічі у насадженнях з формуванням французької вісі та на 45-50 % з запровадженням двократного обрізування дерев. Рекомендовано сільгоспвиробникам досліджені строки обрізування малообємних форм крони з урахуванням сортових особливостей, з метою створення ущільнених насаджень яблуні та підвищення інтенсифікації виробництва

Ключові слова: яблуня; форма крони; строк обрізування; обʼєм крони; літнє обрізування