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Features of Creating and Maintaining a Fruit Wall in Apple Orchard: Literature Review

Andrii Chaploutskyi*, Roman Butsyk, Oleksandra Polunina

Uman National University of Horticulture
20305, 1 Instytutska Str., Uman, Ukraine

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Abstract. The establishment of rational terms and methods of mechanised pruning of apple trees on dwarf rootstocks determine the relevance of the subject under study. The purpose of this review is to highlight the current state and issues associated with tree pruning to improve the technology of growing and increasing the productivity of plantations yielding high-quality fruit with a rational period of mechanised pruning of apple trees on a dwarf rootstock. Proceeding from the analysed literature sources, this paper highlights the current state and development trends of horticulture. A gradual increase in apple production in Europe observed, but an important factor limiting the growth of fruit production is labour productivity accompanying the laborious processes of tree trimming and harvesting. The seasonal nature of work involving numerous skilled workers leads to a shortage of labour force in horticulture. With the increase in wages and the decrease in the number of workers in agricultural production, the introduction of elements of mechanised care for plantations, namely mechanised pruning of the crown, is gaining more significance. The solution to the problem is to improve modern technology of growing apple orchards, using mechanised pruning and the formation of fruit wall in particular. This will allow balancing the available number of employees involved in fruit cultivation and orchards area, and, if necessary, moving away from seasonal work. This paper investigates the specific features of the use and the influence of different periods of mechanised pruning, in particular in winter (0 BBCH), in the pink bud phase (59 BBCH), in early summer (74 BBCH), after harvesting (93 BBCH), and considers the mechanisms used for this purpose. The study proves the positive influence of this technology on improving setting illumination of the crown and the content of chlorophyll in the leaf, optimisation of growth processes with a considerable increase in the number of formed buds. The increase in yield and its marketable quality is accompanied by reducing the size of the fruit, the ripening time of which is somewhat delayed. However, the chemical composition and taste of the fruits are not inferior to the cultivation technology involving manual pruning. The practical significance of the obtained results is to improve the technology of growing apple trees using mechanised pruning and manual maintenance of the inter-tree space, which ensures a considerable reduction in the need for skilled manual labour and increases productivity

Keywords: apple tree, mechanised pruning, pruning term, fruit formations

*Corresponding author

INTRODUCTION

Apple tree is a leading fruit crop in Europe and it is third in terms of fruit production in the world, after citrus fruits and bananas [1]. Apples are a valuable food product with high flavouring qualities, dietary, prophylactic-curative and therapeutic properties [2]. Almost half (47.8%) of world gross apple production amounts to 76 million tonnes and is produced for China, while 13.9% or 9.6 million tonnes are produced the countries of the European Union [3-7].

The main areas are concentrated in Poland, Italy, Romania, and they have doubled in the last decade [8]. The important factor limiting the growth of fruit production is labour productivity accompanying labour-intensive processes of tree pruning and yield gathering. The availability of farm labour is becoming an issue for agriculture, especially for time-sensitive and labour-intensive operations [9]. Considerable seasonality and high complexity of operations create serious roadblocks due to the lack of labour force in gardening. In the past few years, the availability of these workers has been affected negatively [10].

During 2007-2013 in the EU, the total number of workers employed in agriculture decreased by almost 20% [11]. There is a shortage of skilled workers in countries where most fruit is produced considering the low level of hourly wages [12]. The solution to improve the modern technology of growing apple orchards. It is essential to increase the productivity of fruit orchard to meet the needs of population in horticultural products. New technologies should be introduced based on the use of high-yielding varieties, orchard of intensive type, and plant care systems [13].

Pruning is of particular importance in modern fruit orchards with high tree density as one of the main agro-technological factors preventing the alternate bearing tendency and ensuring efficient fruit production. Conventional pruning methods are associated with the considerable cost of manual labour and do not ensure the annual high yields of quality fruits. Hence the urgent development and implementation of mechanised elements for the orchard maintenance, namely mechanised pruning. This allows balancing the available number of employees involved in fruit cultivation and orchards, and, if necessary, leave precise seasonal work to machines. By adjusting the parameters of the ground part, mechanised pruning achieves the best coverage of the centre of the crown, improves air circulation, making the fruiting stabilised and improving crop quality.

The purpose of this study is to determine the method and time required for mechanised pruning, which provides the optimal parameters of the crown of apple trees and increases their productivity, as well as to investigate the results of the impact of pruning apple trees on fruit yield and quality.

IMPORTANCE AND FEATURES OF PRUNING FRUIT TREES

Pruning fruit trees is an essential agrotechnical measure, which helps regulate growth and fruiting, improve fruits' quality, and also contribute to efficient maintenance of soil and plants. Even formation of generative buds and fruiting throughout the crown is achieved by pruning due to regulation of the crown size [14]. When choosing the optimal pruning method, several factors are considered, such as the garden intensity level, term of execution, cultivar-rootstock combination, planting density, garden age, crown shape, height, and size of crowns [15]. Apart from the spread, no less important factor is the type of fruiting variety [16; 17].

The most efficient use of light by all tree parts, compact sizes, high yields of qualitative fruits, as well as low labour costs for formation comprise some of the main requirements for choosing the crown shape [18]. Crown pruning is described by considerable predominance of manual labour. Pruning an apple orchard requires 80-120 hours of work. This is 1/5 of the total production cost [19]. Therefore, the leading place in modern technologies is given to such methods of pruning that offer stable yields of qualitative fruits with minimum possible labour costs and production facilities. In this connection, introduction of elements of mechanised orchard maintenance, namely mechanised crown pruning, becomes increasingly more relevant.

Since the 1960s, efforts have been made to introduce mechanical pruning on most fruit plantations. The first pruning machines were implemented in the USA for pruning citrus trees. Trees were trimmed from with cutting bars or rotational saws. Gardeners became interested in this technology and tried to apply mechanical pruning to apple, pear, and peach trees [20].

Automation technologies are now used extensively in agriculture, while production operations for tree fruit crops still largely depend on manual labour. Manual pruning is a labour-intensive and costly task in apple production. Mechanical pruning is a potential solution [21]. With the adoption of mechanisation, the agricultural sector will have witnessed a considerable increase in production efficiency [22; 23].

In California, plum trees and olives were both pruned and harvested mechanically [24]. Some robot-friendly canopy architectures such as tall spindle, V-trellis, and fruiting wall are promising for the development of mechanical pruning systems [25].

The limited availability of farm labour is a severe concern for the agricultural industry. To address this issue, mechanical pruning i.e., hedging on fruit trees has been investigated by several researchers [9; 23; 26].

THE EFFECT OF MECHANISED PRUNING ON THE FERTILITY OF APPLE TREES

Recently, mechanised pruning has successfully passed production tests in different areas of horticulture and countries of the world. Mechanised pruning becomes one of the most efficient agrarian measures concerning the influence on the growth and fertility of fruit plants by efficiently limiting the height and width of fruit trees crown.

To a greater extent, the choice of equipment depends on the phase of tree development when it is used.

In winter, mechanisms equipped with circular saws are usually used. Such technology is capable of pruning the branches of considerable diameter, but saws are frequently filled with tiny sawdust and the quality of a cut drops. In summer, working units based on segment-type knives and rotating blades are usually used, which can cut branches up to 2.5 cm in diameter.

Fruit wall is formed as a result of mechanised pruning, the lower part of which is annually pruned on both sides at a distance of 40 cm from the trunk and the upper part – at a distance of 25 cm [27]. In the first year there is a decrease in fertility due to a substantial reduction in the volume of the crown after the introduction of mechanised pruning, the previous level of which is restored next season, and then slightly exceeds the productivity of the garden for manual pruning (Table 1) [28; 29].

Table 1. *Productivity of different varieties of apple trees in different ways of pruning trees*

Variety	kg/tree		Mass (g)		Number of fruits	
	Control	Mech. pruning	Control	Mech. pruning	Control	Mech. pruning
Red Prince	32.3	35.4	192	176	168	201
Primo	32.8	32.6	185	175	181	190
Decosta	28.0	36.6	213	210	138	175
Jonagored	26.1	22.7	241	218	113	116

The mechanically pruned trees have better fertility than the manually pruned trees. This is explicable because without detailed pruning, more fruit buds are preserved in the crown [9]. To promptly achieve the optimal area of a fruit wall (13-17 thousand m^2/ha), it is important to keep a rational tree planting scheme of 0.8 m in the row for diploid varieties and 1 m for triploid ones. The width of row spacing is close to the value of crown height, and their direction is from the north to the south.

The first mechanised pruning while reformation of existing plantation should be done in winter (0 BBCH) for giving the crowns proper dimensions, and again in the beginning of summer, and then only once a year – in the beginning of summer. Depending on the region, the most optimal term for early-summer pruning is the emergence of foliage (8-12 leaves) on newly formed shoots. As a result, short shoots or rhizomes are formed in shortened growth in summer, the growth of which is weakened after several years of summer pruning.

Almost half a century ago in France, L. Lorette proposed an alternative method of pruning – with mechanised shortening of current year shoots by ¼-½ length. This way, regrowth of shoots occurs from less developed buds near the base of the shoots – growth is weaker with a greater probability of differentiation of generative buds. The best time to shorten the shoots is the period immediately before the end of shoot growth and the formation of the apical bud. Weak trees do not need summer pruning [30; 31].

The reaction of trees to pruning shoots depends on the biological characteristics of the variety, length, thickness, and their location on the branches and in the crown, orientation in space and the degree of pruning. The more the shoot is shortened (closer to the base), the lower the growth activity and the smaller the angles of formation of new shoots [32].

A. Masseron and L. Roche found that mechanised pruning in summer causes less stress for the plant, inhibits excessive growth and provides 35-40% more light in the centre of the crown, improves air circulation and stimulates the formation of generative buds for next year's harvest and stabilises fruiting [33-35]. In autumn, nutrients accumulate mainly in the trunk, main branches and root system. The stock of plastic substances remains almost unchanged after removing numerous branches during winter period. Therefore, in spring, the tree develops a considerable number of strong vertical shoots [36]. Summer removal of shoots reduces the reserve amount of carbohydrates which reduces the growth activity in the next season.

In this case, it should be reactivated by winter pruning. Good illumination of crown by mechanised pruning and weaker growth of shoots initiate formation of numerous generative buds, thereby ensuring high yields of qualitative fruits. However, mechanised pruning remains impossible without additionally treating the crown manually. All operations on formation and preparation of trees for mechanised pruning, further pruning of hard-to-reach areas of the crown are being performed manually to this day [37]. All the branches growing towards row spacing are pruned mechanically, the problem is posed only by bent branches under the crown, which cannot be mechanically removed, strong nourishing shoots in its middle part and excessive growth and thickening at the apex.

Upon contour pruning they cut out the so-called "windows" by pruning individual shoots at the top and in the centre of the crown closer to the main branch, which contributes to better illumination of the central part of the crown to improve the access of light to the centre of the crown and reduce labour costs for manual additional treatment [38]. Different illumination of the crown affects anatomical structure of the leaves. According to A. F. Kovalov, with decreasing light in the lower part of the crown, the thickness of the columnar parenchyma, where the bulk of chloroplasts is localised, is 12-30% less compared to the leaves from the upper part of the crown [39].

G. Lafer found that reaction of apple trees to mechanised pruning depends on when this procedure is performed. The strongest growth of shoots was observed after winter pruning and by one third less in early-summer. Moreover, the number of shoots with a generative bud at the end was 48% and 68%, respectively [40; 41]. The number of shoots of the current year with a top generative bud reaches 90% depending on the pomological variety and time of performing mechanised summer pruning [42].

Shoots pruning changes the correlation between fruit-bearing formations. After pruning the shoot by half (mainly on two- and three-year-old trees) the share of spurs is 36%, hastula – 23%, and brindilles – 41%, and without pruning (mainly on two- and three-year-old trees) – 60%, 12%, and 28%, respectively [43]. According to L. Roche, damage to fruits upon the mechanised pruning in the summer does not exceed 0.3% [44]. Because the fruits are located on the periphery of the crown and are exposed to direct sunlight from the beginning of formation, the fruits become "seasoned" and receive almost no damage from sunburn. Fruits become smaller after several years of mechanised pruning in summer.

According to French studies, mechanised pruning makes the fertility more stable over the years of operation of the garden, and sometimes not inferior to its manual counterpart. Golden Delicious variety, planting scheme 4×1.25 m. Thinning of flowers and sets was not performed (Fig. 1).

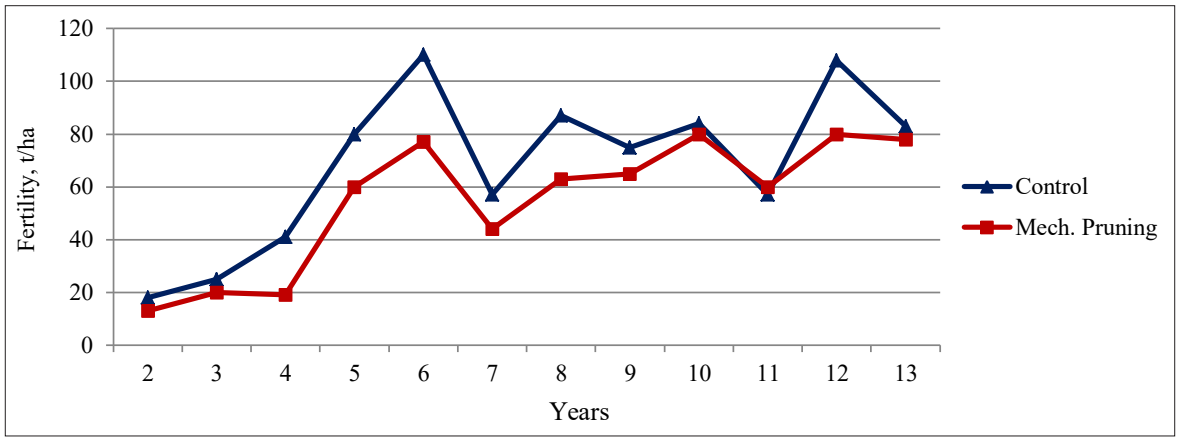

Figure 1. *Fertility of Golden Delicious trees*

Source: *[45]*

THE EFFECT OF MECHANISED PRUNING ON THE QUALITY OF APPLE FRUITS

According to G. Poldervaart and A. Urbaniec, after mechanised pruning of trees in summer for several years, the fruits starts growing smaller – their diameter becomes 2-3 mm smaller. However, this is not considered as a disadvantage for large-fruit varieties (Jonagored), as presented in Figure 2 [46].

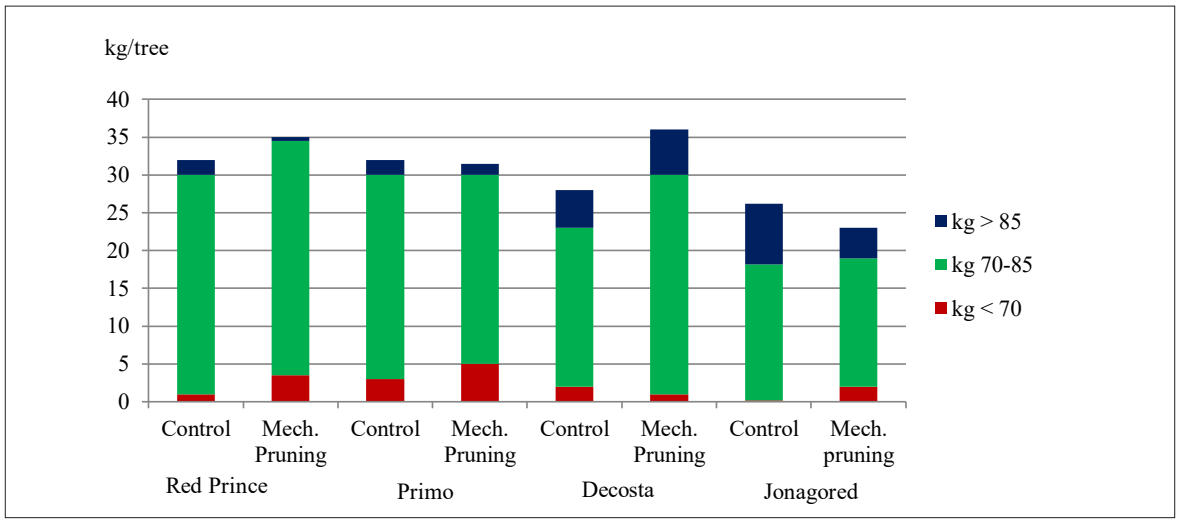

Figure 2. *Distribution of fruits by size*

Source: *[29]*

Pruning is recommended in the "pink bud" phase (59 BBCH) to stimulate tree growth activity and restore the fruit/leaf correlation, as well as form larger fruits [47]. However, pruning the garden during this period is quite difficult because this phase is short. Although similar results can be achieved by performing this operation after harvesting. With mechanised pruning, the quality of the fruit is the next best to the fruits of manually pruned crowns, except for "juiciness" and "crunchiness" for reasons not yet studied (Fig. 3).

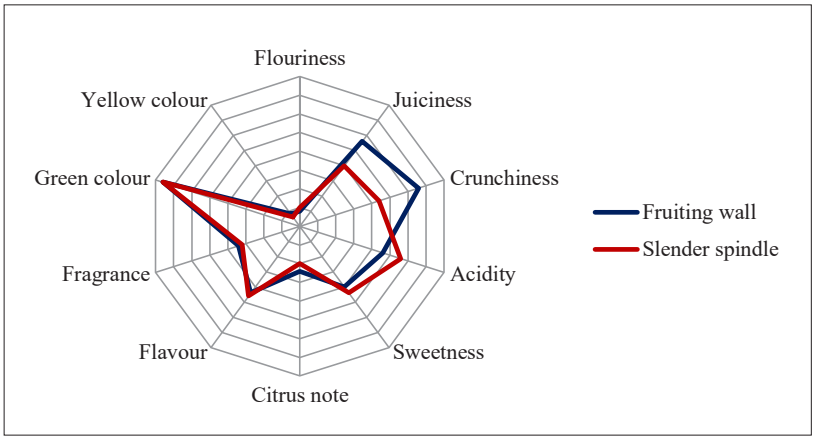

***Figure 3**. Fruit quality as a result of mechanised pruning*

***Source**: [45]*

As a result, the beginning of ripening of the crop is delayed by approximately a week (Table 2), a higher percentage of marketable fruits, especially apples of higher marketable grade, fewer fruit with sunburn.

***Table 2**. Ripeness of fruits as a result of mechanised pruning*

Variety	Hardness (kg/cm²)		Sugar content (°brix)		Starch value (1-10)	
	Control	Mech. pruning	Control	Mech. pruning	Control	Mech. pruning
Red Prince	7.8	8.1	12.3	12.8	6.7	6.4
Primo	7.7	8.2	12.6	12.5	6.6	6.2
Decosta	8.2	7.6	12.7	12.9	7.6	7.1
Jonagored	8.3	8.2	13.3	13.8	7.1	6.8

***Source**: [29]*

Contour pruning of trees requires only 2-3 hours per hectare of mechanical pruner and up to 40 hours per hectare of manual after-treatment, which is only 30-40% of labour costs compared to conventional manual pruning, which requires up to 160 labour hours per hectare [48]. Thinning of flowers becomes more efficient due to easier access to the inner part of the crown (fruiting wall), while labour productivity during harvesting increases by 17% upon shifting the fruiting zone to the periphery of the crown [29; 49-52].

CONCLUSIONS

The purpose of this study was to establish the features of mechanised pruning and its impact on fruit quality and fertility of apple trees. Mechanised pruning with fruiting wall formation is used to maintain the balance between growth and fruiting in the apple orchard as a result of the constant increase in manual labour costs and the reduction in the number of workers involved in agriculture. This cultivation technology is becoming more widespread in horticultural farms across Europe, reducing labour costs, increasing garden productivity and improving the quality of cultivated products.

It is established that to form a crown, the first mechanised pruning with a fixed width of 40 cm from the trunk in both directions at the bottom and 25 cm at the top of the tree. In subsequent years, the shoots outside the crown were pruned annually whenever 8-12 would appear on newly formed shoots. This method of pruning helps reducing labour costs and increasing orchard fertility. Yields become more stable every year and a higher number of fruits is formed. The quality of the fruits grown by mechanised pruning is the net best to the fruits grown on manual pruned crowns, although the harvest begins to ripen approximately a week later than usually.

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Особливості створення та догляду за плодовою стінкою в яблуневому саду: огляд літератури

Андрій Миколайович Чаплоуцький, Роман Миколайович Буцик, Олександра Василівна Полуніна

Уманський національний університет садівництва
20305, вул. Інститутська, 1, м. Умань, Україна

Анотація. Встановлення раціональних термінів і методів механізованого обрізування яблуні на карликових підщепах визначає актуальність теми дослідження. Метою цього огляду є висвітлення стану та проблем, пов'язаних з обрізанням дерев, удосконаленням технології вирощування та підвищення продуктивності насаджень з отриманням високоякісних плодів при раціональному терміні механізованого обрізування яблуні на карликовій підщепі. На основі проаналізованих літературних джерел висвітлено сучасний стан і тенденції розвитку садівництва. Спостерігається поступове зростання виробництва яблук у Європі, але важливим фактором, що обмежує зростання виробництва плодів, є продуктивність праці при трудомістких процесах обрізування дерев і збирання врожаю. Сезонний характер робіт із залученням великої кількості кваліфікованих робітників призводить до дефіциту робочої сили в садівництві. Із підвищенням заробітної плати та зменшенням чисельності робітників у сільськогосподарському виробництві все більшого значення набуває впровадження елементів механізованого догляду за насадженнями, зокрема механізованого обрізування крони. Вирішення проблеми полягає зокрема у вдосконаленні сучасних технологій вирощування яблуневих садів із застосуванням механізованого обрізування та формування плодової стіни. Це дасть змогу збалансувати наявну кількість працівників, зайнятих на вирощуванні плодів у садах, і, при необхідності, відійти від сезонних робіт. У статті розглянуто особливості використання та впливу різних періодів механізованої обрізки, зокрема взимку (0 BBCH), у фазі рожевого бутона (59 BBCH), на початку літа (74 BBCH), після збирання врожаю (93 BBCH), та розглянуто механізми, що використовуються для цього. Доведено позитивний вплив даної технології на покращення освітленості крони та вмісту хлорофілу в листі, оптимізацію ростових процесів зі значним збільшенням кількості утворених плодових бруньок. Підвищення врожаю та його товарної якості супроводжується зменшенням розміру плодів, термін дозрівання яких дещо затягується. Однак за хімічним складом і смаковими якостями плоди не поступаються технології вирощування при ручному обрізуванні. Практичне значення наукової роботи полягає у вдосконаленні технології вирощування яблуні з механізованим обрізуванням та ручною обробкою міждеревного простору, що забезпечить значне зниження потреби в кваліфікованій ручній праці та підвищить урожайність насаджень

Ключові слова: яблуня, механізоване обрізування, термін обрізування, плодові утворення