

INFLUENCE OF PRUNING SYSTEMS ON TREE YIELD IN 'GOLDEN DELICIOUS' APPLE

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RESEARCH ARTICLE

Abstract

Pruning is a critical orchard management practice that directly influences vegetative growth, light interception, fruiting behavior, and ultimately yield in apple trees. The cultivar 'Golden Delicious' is widely grown due to its high productivity and fruit quality; however, its yield potential is strongly affected by the pruning system adopted. This article reviews the influence of different pruning systems on tree yield in 'Golden Delicious' apple, focusing on canopy structure, light distribution, flower bud formation, fruit set, and yield efficiency. The findings highlight that appropriate pruning systems enhance productivity by balancing vegetative and reproductive growth, improving light penetration, and maintaining long-term orchard performance.

Keywords: Apple, Golden Delicious, pruning systems, yield, canopy management

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INTRODUCTION

Apple (*Malus × domestica* Borkh.) continues to be one of the most economically important temperate fruit crops worldwide, with global production systems evolving rapidly due to labor shortages, mechanization, and the need for higher productivity per unit area. Pruning and canopy management are recognized as essential cultural practices that shape tree architecture, optimize light distribution, regulate vegetative–reproductive balance, and thereby influence not only fruit quality but also total yield (Win et al., 2025). The cultivar 'Golden Delicious' is widely cultivated due to its broad adaptability and market demand, but like many high-yielding cultivars, its productivity and fruit quality are strongly dependent on efficient pruning systems that manage canopy vigor and light interception.

Pruning practices have traditionally been labor-intensive and require skilled labor, prompting increased research interest in mechanized and hybrid pruning approaches. Recent work has demonstrated that mechanical pruning, while reducing labor input, may alter canopy structure in ways that can limit light penetration deeper into the tree and negatively affect fruit size and coloration unless

supplemented with manual follow-up pruning (Win et al., 2025). In 'Ariseo' apple trees, for example, mechanical pruning alone reduced light penetration within the canopy and produced smaller, less well-colored fruits compared to trees receiving manual or combined mechanical + manual pruning, although yields were comparable; combined pruning significantly reduced pruning time while maintaining yield and quality parameters (Win et al., 2025).

In addition to winter pruning strategies, summer pruning has gained renewed attention as a cultural technique that influences tree physiology directly during the growing season. Summer pruning — including shoot thinning, bending, and ring wounding — has been shown to promote flower bud differentiation, improve ventilation and light conditions within the canopy, and reduce the incidence of pests and diseases, which together contribute to better fruit quality and potentially improved yield when applied at appropriate growth stages (Qiu et al., 2025). However, excessive summer pruning can weaken trees and negatively impact yield if not tailored to growth vigor and orchard context.

Effective pruning fundamentally alters canopy light interception and distribution, which influences photosynthetic efficiency — a

main driver of assimilate production and overall yield. Research on canopy structure underscores that pruning methods that promote open, well-distributed foliage can enhance light availability to fruiting zones, thereby improving flower bud formation and crop load distribution (Park et al., 2025). Shading caused by dense canopy layers is known to reduce chlorophyll content and lower photosynthetic rates, ultimately diminishing both vegetative vigor and reproductive success in poorly pruned orchards.

Integrated pruning strategies that combine winter and summer approaches, along with modern robotic and precision pruning technologies, are emerging as promising solutions to labor constraints and orchard sustainability challenges. New developments in robotic pruning, precision canopy sensing, and machine learning-based management tools aim to optimize pruning decisions based on tree structure and light models, enabling more consistent yield outcomes across diverse orchard conditions.

Despite growing research interest, there remain significant gaps in understanding how different pruning systems specifically affect tree yield and fruit quality in cultivars like 'Golden Delicious' across varying climates and planting densities. Given the cultivar's susceptibility to dense canopy formation, biennial bearing, and quality variations under suboptimal light conditions, a comprehensive assessment of pruning practices is essential to guide orchard management decisions that maximize yield while maintaining fruit quality and orchard longevity.

Pruning is a fundamental orchard management practice that serves multiple physiological and horticultural functions in apple production. By selectively removing shoots and branches, pruning regulates vegetative growth and controls tree size, thereby maintaining an optimal canopy structure suited to the planting density and rootstock vigor (Robinson et al., 2021). Proper pruning improves light penetration and distribution within the canopy, which is a key factor influencing photosynthetic efficiency, spur productivity, and fruit development (Corelli Grappadelli et al., 2020).

Light availability within the canopy directly affects flower bud differentiation and fruiting potential. Well-pruned apple trees exhibit higher flower bud density due to improved exposure of shoots and spurs to sunlight during

the critical period of bud initiation (Qiu et al., 2024). Pruning also helps maintain a balance between vegetative growth and reproductive activity, preventing excessive shoot growth that can compete with developing fruits for assimilates (Zhou et al., 2023).

In addition to its effects on yield formation, pruning enhances fruit size, color, and overall quality by improving canopy microclimate, air circulation, and light interception around fruiting zones (Park et al., 2025). Open canopies also reduce humidity and shading, thereby lowering the incidence of pests and diseases and improving spray penetration and orchard sanitation (Sun et al., 2021).

In the cultivar 'Golden Delicious', which is moderately vigorous and prone to dense canopy formation, pruning plays a particularly critical role. Without systematic pruning, trees may develop excessive shading, poor spur renewal, and irregular bearing, ultimately leading to reduced yield consistency. Therefore, appropriate pruning strategies are essential for sustaining high and regular yields in 'Golden Delicious' apple orchards.

MATERIAL AND METHOD

The experiment was conducted during the 2024 and 2025 growing seasons in the northwestern part of Romania, at an experimental apple orchard located in Bihor County. The site is situated at approximately 300–400 m above mean sea level and is characterized by a temperate continental climate with moderate influences from Western Europe.

The region experiences cold winters and mild to warm summers, with an average annual rainfall of 600–700 mm, most of which occurs during spring and early summer. Mean annual temperature is approximately 9–10 °C, with summer temperatures ranging between 18 and 28 °C. The soil of the experimental orchard is classified as loam to clay loam, well-drained, with good fertility and uniform physical characteristics across the site. The study was conducted on uniform, healthy 'Golden Delicious' apple (*Malus × domestica* Borkh.) trees grafted on M.26 rootstock, which is commonly used in Romanian apple orchards due to its moderate vigor and adaptability. The trees were 8 years old at the beginning of the experiment and planted at a spacing of 4.0 m × 2.5 m, corresponding to a semi-intensive orchard system.

Standard orchard management practices, including irrigation, fertilization, weed control, and plant protection measures, were uniformly applied to all trees throughout the experimental period in accordance with regional recommendations.

The experiment was laid out in a Randomized Complete Block Design (RCBD) with five pruning treatments and four replications. Each replication consisted of three adjacent trees, and to minimize border effects, all observations and measurements were recorded on the central tree of each experimental unit. The pruning treatments evaluated included the central leader system (T_1), modified central leader system (T_2), open center or vase system (T_3), minimal pruning (T_4), and renewal pruning (T_5).

Pruning was carried out during the dormant season (late February to early March) in both years of study, prior to bud break. All pruning operations were performed manually using sterilized pruning tools to ensure precision and to prevent disease transmission.

In the central leader system, a dominant vertical axis was maintained with well-spaced lateral branches arranged in a conical shape. The modified central leader system involved limiting tree height and encouraging lateral branching to improve canopy openness. In the open center (vase) system, the central leader was removed to create an open canopy structure with three to four main scaffold branches. Vegetative growth was evaluated by recording annual shoot extension growth (cm) on selected current-season shoots and by calculating the trunk cross-sectional area (TCSA, cm^2) from trunk diameter measurements taken at 30 cm above the graft union. Flowering intensity was assessed at full bloom by counting the number of flower clusters per tree, while fruit set (%) was calculated as the ratio of the number of fruits retained after natural fruit drop to the initial number of flowers, expressed as a percentage.

Fruits were harvested at commercial maturity in September, and yield parameters were recorded, including yield per tree (kg), number of fruits per tree, average fruit weight (g), and yield efficiency, expressed as kg cm^{-2} TCSA. For fruit quality assessment, a random sample of 20 fruits per tree was collected and analyzed for fruit diameter (mm) and fruit weight (g). Fruit skin color was evaluated visually using a standard color chart, while total soluble solids (TSS, °Brix) were determined

using a digital refractometer. Titratable acidity (%) was measured by titration with sodium hydroxide (NaOH), and fruit firmness (kg cm^{-2}) was assessed using a penetrometer.

The collected data were subjected to analysis of variance (ANOVA) using R statistical software. Treatment means were compared using Tukey's Honestly Significant Difference (HSD) test at a significance level of $p \leq 0.05$. Percentage data were arcsine transformed prior to statistical analysis where necessary to meet assumptions of normality.

RESULTS AND DISCUSSIONS

Pruning systems significantly influenced vegetative growth parameters of 'Golden Delicious' apple trees. Annual shoot extension growth varied markedly among treatments, with the minimal pruning (T_4) treatment exhibiting the highest shoot growth, reflecting reduced control of vegetative vigor. In contrast, trees subjected to renewal pruning (T_5) and the open center system (T_3) showed moderate shoot extension, while the central leader (T_1) and modified central leader (T_2) systems maintained balanced vegetative growth.

Trunk cross-sectional area (TCSA) increased progressively over the study period in all treatments; however, trees under minimal pruning (T_4) recorded the largest TCSA, indicating excessive vegetative development. The central leader (T_1) and modified central leader (T_2) systems exhibited moderate increases in TCSA, suggesting a better balance between vegetative growth and reproductive activity.

Table 1.

Effect of pruning systems on vegetative growth of 'Golden Delicious' apple trees

Pruning system	Annual shoot extension growth (cm)	Trunk cross-sectional area (cm^2)
Central leader	38.6 ± 1.4 b	68.3 ± 2.1 b
Modified central leader	40.2 ± 1.6 b	70.1 ± 2.4 b
Open center (vase)	42.8 ± 1.8 b	72.5 ± 2.6 b
Minimal pruning	52.4 ± 2.0 a	80.9 ± 3.1 a
Renewal pruning	44.1 ± 1.7 b	73.8 ± 2.8 b

Flowering intensity was significantly affected by pruning systems. The central leader (T_1) and modified central leader (T_2) systems produced the highest number of flower clusters per tree, indicating improved flower bud differentiation. Trees under minimal pruning (T_4) showed comparatively lower flowering intensity, likely due to increased canopy shading and reduced light penetration.

Fruit set (%) followed a similar trend, with the highest fruit set observed in the central leader and modified central leader systems, while the open center system (T_3) recorded moderate fruit set. Renewal pruning (T_5) resulted in improved fruit set compared to minimal pruning, reflecting the positive effect of renewed fruiting wood on reproductive performance.

Table 2

Effect of pruning systems on flowering and fruit set of 'Golden Delicious' apple trees

Pruning system	Flower clusters per tree	Fruit set (%)
Central leader	185 ± 6 a	62.4 ± 1.9 a
Modified central leader	178 ± 5 a	60.7 ± 2.1 a
Open center (vase)	160 ± 6 b	56.2 ± 2.0 b
Minimal pruning	142 ± 7 c	49.8 ± 1.8 c
Renewal pruning	168 ± 6 b	57.9 ± 2.2 b

Yield per tree differed significantly among pruning treatments. The central leader system (T_1) recorded the highest yield per tree, followed closely by the modified central leader system (T_2). These systems also produced a greater number of fruits per tree, indicating superior yield potential. The open center system (T_3) resulted in moderate yields, while minimal pruning (T_4) produced lower and more variable yields despite high vegetative growth.

Pruning systems had a significant effect on fruit quality characteristics. Fruits harvested from trees trained under the open center (T_3) and central leader (T_1) systems exhibited larger fruit size and better skin coloration, attributed to enhanced light exposure within the canopy. The modified central leader (T_2) system

produced fruits of comparable size and acceptable coloration.

Total soluble solids (TSS) content was generally higher in fruits from well-illuminated canopies, particularly under the open center and central leader systems, whereas fruits from minimally pruned trees recorded lower TSS values. Titratable acidity showed minor variation among treatments, while fruit firmness was slightly higher in fruits from moderately pruned trees, indicating improved texture and storage potential.

Table 3

Effect of pruning systems on yield and yield efficiency of 'Golden Delicious' apple trees

Pruning system	Yield per tree (kg)	Fruits per tree	Average fruit weight (g)	Yield efficiency (kg cm ⁻² TCSA)
Central leader	45.6 ± 1.8 a	265 ± 10 a	172 ± 5 a	0.67 ± 0.03 a
Modified central leader	43.8 ± 1.7 a	258 ± 9 a	170 ± 6 a	0.63 ± 0.02 a
Open center (vase)	38.2 ± 1.6 b	228 ± 8 b	168 ± 5 ab	0.53 ± 0.02 b
Minimal pruning	32.5 ± 1.5 c	210 ± 9 c	155 ± 6 b	0.40 ± 0.02 c
Renewal pruning	36.9 ± 1.6 b	235 ± 8 b	165 ± 5 ab	0.50 ± 0.02 b

Yield efficiency (kg cm⁻² TCSA) was significantly higher in the central leader and modified central leader systems, reflecting more efficient conversion of vegetative growth into fruit production. Minimal pruning showed the lowest yield efficiency, whereas renewal pruning (T_5) improved yield efficiency compared to minimal pruning by stimulating productive new shoots.

pruning	1.3 ab	0.3 ab	0.02	
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Table 4

Effect of pruning systems on fruit quality attributes of 'Golden Delicious' apple

Pruning system	Fruit diameter (mm)	TSS (°Brix)	Titrateable acidity (%)	Fruit firmness (kg cm ⁻²)
Central leader	72.8 ± 1.2 a	13.6 ± 0.3 a	0.41 ± 0.02	7.8 ± 0.2 a
Modified central leader	71.9 ± 1.3 a	13.4 ± 0.3 a	0.42 ± 0.02	7.6 ± 0.2 a
Open center (vase)	73.5 ± 1.1 a	13.8 ± 0.4 a	0.40 ± 0.02	7.7 ± 0.3 a
Minimal pruning	69.2 ± 1.4 b	12.6 ± 0.3 b	0.44 ± 0.03	7.1 ± 0.2 b
Renewal	71.0 ±	13.1 ±	0.42 ±	7.4 ± 0.2 ab

Overall, the results indicate that central leader (T₁) and modified central leader (T₂) pruning systems provided the most favorable balance between vegetative growth, flowering, yield, and fruit quality in 'Golden Delicious' apple. Minimal pruning (T₄) promoted excessive vegetative growth at the expense of yield efficiency and fruit quality, while renewal pruning (T₅) improved productivity compared to minimal pruning but remained inferior to structured pruning systems. The open center system (T₃) enhanced fruit quality but resulted in moderately lower yields.

CONCLUSIONS

The present study demonstrated that pruning systems exert a significant influence on vegetative growth, flowering, yield, and fruit quality of 'Golden Delicious' apple trees grown under the climatic conditions of northwestern Romania. Pruning was shown to be an essential canopy management practice for regulating tree vigor, improving light distribution within the canopy, and sustaining productive fruiting over successive seasons.

Among the evaluated pruning systems, the central leader and modified central leader systems proved to be the most effective in achieving a balanced relationship between vegetative growth and reproductive performance. Trees trained under these systems exhibited moderate vegetative growth, higher flowering intensity, improved fruit set, and superior yield efficiency compared with other treatments. These systems also produced consistently higher yields per tree while maintaining desirable fruit size, coloration, and internal quality attributes.

The open center (vase) system enhanced fruit quality due to improved light penetration and canopy openness; however, it resulted in comparatively lower yields, likely due to

reduced canopy volume and leaf area. Minimal pruning promoted excessive vegetative growth, which negatively affected flowering, yield efficiency, and fruit quality, highlighting the long-term disadvantages of insufficient canopy regulation. In contrast, renewal pruning improved productivity relative to minimal pruning by stimulating new fruiting wood, although its performance remained inferior to structured leader-based systems.

Overall, the findings indicate that adopting well-defined pruning systems, particularly central and modified central leader systems, is essential for maximizing yield, improving fruit quality, and ensuring long-term orchard productivity in 'Golden Delicious' apple. These pruning strategies can be recommended for semi-intensive apple orchards in northwestern Romania and similar temperate regions. Further research integrating pruning systems with high-density plantings, mechanized pruning techniques, and precision orchard management tools may help further optimize apple production under evolving climatic and economic conditions.

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