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Apple (*Malus domestica* Borkh) Growth and Yield Response to Pruning, Training, and Time of Action at Holeta, Central Highlands of Ethiopia

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Abstract

Apple (Malus domestica Borkh) *is one of the most important temperate fruit crops globally. However, due to poor canopy management, Ethiopia's apple productivity is very low. Hence, this research was conducted to evaluate the growth and yield response of apple to pruning, training, and time of action. Variety ''Anna'' was planted in 2018 at Holeta using a randomized complete block design with three replications. A total of seven treatment combinations were applied for the study, and data on growth and yield were collected for two consecutive years. The result showed that, pruned + trained and unpruned + trained during summer had received the tallest trees (1.63 and 1.58 m, respectively) with statistical parity. Similarly, the highest trunk cross sectional area (7.48 cm^2) was obtained in summer pruned + trained trees. Besides, summer unpruned + trained trees had the highest annual growth (0.37 m), canopy volume (3.30 m^3), marketable (4.31 t ha^{-1}) and total yield (4.70 t ha^{-1}). Overall, apple producers are advised to implement efficient dormant or summer season training since fruit trees that were trained and left unpruned in the summer performed better on most metrics.*

Keywords: Pruning; summer; training; trunk; winter

Introduction

The apple (*Malus domestica* Borkh.) is one of the most important temperate fruit crops, accounting for half of the world's temperate fruit production (FAOSTAT, 2022). China was the largest producer of apple fruit in the world with 46 million tonnes from 2.10 million hectares, followed by Turkey (4.49 million tonnes using 0.17 million hectares) and United States (4.47 million tonnes on 0.12 million hectares) in 2021. Whereas, South Africa, Egypt and Morocco were the largest apple producers of Africa in the same year (FAOSTAT, 2022). However, in Ethiopia, it is cultivated in the highland areas with unspecified total area coverage and production quantity. Apple provides a number of benefits including a source of income. It has also high nutritional values, such as vitamins, minerals and micronutrients that are rarely available in daily foods, particularly in many developing nations (Fetena *et al*. 2014). Besides, it significantly contributes to soil conservation in the highlands, soil fertility management, carbon sequestration, expanding intercropping systems, enhancing economic benefits, intensifying agroforestry practices (Boyer and Liu, 2004; Girmay *et al*. 2014) and meeting dietary needs (Bellow *et al*. 2008).

There is an enabling government policy to increase fruit production in Ethiopia (Nigussie *et al*. 2019), along with diverse agro-ecologies that are allowing for the production of many temperate fruits, including apples. Despite this, the majority of fruit cultivation is done on a small scale by smallholders (Bekele *et al*. 2016) using conventional orchard management practices. Moreover, the management knowledge and skills of apple production were not yet familiarized, resulting in low yield (Tamirat and Muluken, 2018). Instead of that, pruning and training techniques were highly influential in all aspects of apple production.

Pruning is among the most crucial orchard management practices in temperate fruit production. It can be classified as summer and winter pruning based on time of action (Demirtas *et al*. 2010). This technique aims to control the tree canopy to a manageable size, and balance the plant's vegetative and reproductive growth, and enhances productivity (Singh and Bal, 2008; Maughan *et al*. 2017; Canon *et al*. 2014). It also increases photosynthetic translocation to fruits and roots that regulates flower bud formation. Besides, reduces the over-shading of the interior canopy and promote light and air penetration (Tombesi and Tombesi, 2007). Pruning also helps to maintain a right relationship among shoot growth, leaf area, photosynthesis, annual building of storage reserves and good yield (Lang, 2001). Indeed, apple productivity is relied on optimization of sunlight spectrum and synchronization of canopy management techniques that can improve sunlight interception (Hampson *et al*. 2002; Peck *et al*. 2006; Bastias and Corelli, 2012). Trees are typically pruned during their dormancy period since it helps for promoting tree growth (Marini and Barden, 2004; Tahir *et al*. 2007). Moreover, temperate fruit production is becoming increasingly reliant on summer pruning that helps to control the tree canopy, improve light penetration and availability (Autio and Cooley, 2011; Ashraf and Ashraf, 2014). Summer pruning also serves to maintain a good yield (Cline *et al*. 2008), and promotes an accumulation of carbohydrates (Demirtas *et al*. 2010b). Overall, the time of pruning affects the apple yield (Wertheim, 2005).

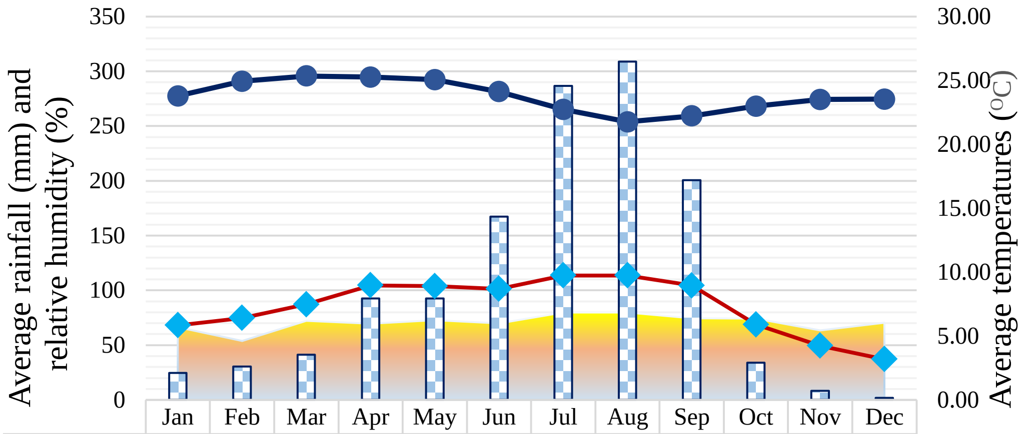
Similarly, training aids to establish a desired shape of the trees by controlling their growth habit. Its major objectives include, promoting favorable growth pattern, bringing trees in to production earlier and developing strong structural framework that will allow heavy crop loads, promote good sun light penetration, and make the trees easier to manage (Hassan *et al*. 2010). Creating a strong framework of scaffolding branches also enables successive annual bearing, expose maximum sunlight interception and promote early production (Kaith *et al*. 2011). Training has been recognized as the most important horticultural practices that is used to increase the yield (Ara *et al*. 2007), since it provides better light distribution and efficiency in the canopy (Hampson *et al*. 2002a; Hampson *et al*. 2004).

In general, tree canopy management practices such as pruning and training determine tree shape and sunlight distribution in the canopy, and directly affect the critical balance between fruiting and vegetative growth (Iannini *et al*. 2002). Currently, intensive apple production is based on the use of a number of cultural practices such as pruning and training (Milosevic and Milosevic, 2017). Various studies showed that, these techniques are usually applied to many temperate fruit crops and are commonly used by modern producer countries. However, apple is conventionally cultivated using poor orchard and canopy management practices in Ethiopia; and low productivity is common, which has likely confined its adoption and expansion. Furthermore, an appropriate time for apple tree canopy management is not well identified and thus, affects its productivity in the country. Hence, this research was conducted to evaluate the growth and yield response of apple to pruning, training, and time of action.

Materials and Methods

Experimental site description

This study was conducted at Holeta Agricultural Research Center, which is situated at 9° 00’ N latitude, 38° 30' E longitude, and 2400 m. a.s.l., central highlands of Ethiopia (EIAR, 2017). The soil type in the area was predominantly *Nitosol* with a pH of 6.04. The area received an average annual rainfall of 1287.82 mm and the relative humidity of 70.5 percent. Whereas, the average annual minimum and maximum temperatures were 7.3 and 23.8 ^{o}C, respectively (Figure 1).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RH	66.34	53.6	72.08	69.42	72.74	69.8	79.6	79.6	74.38	74.1	63.34	70.4
RF	24.54	30.28	41.18	92.62	92.66	167.18	286.56	308.74	200.36	33.96	8.06	1.68
TMAX	23.78	24.94	25.34	25.26	25.06	24.12	22.74	21.75	22.22	22.99	23.51	23.54
TMIN	5.83	6.41	7.47	8.96	8.90	8.69	9.73	9.74	8.95	5.89	4.24	3.18

Months of the years

Figure 1. Climate data of the testing site (2018-2022)

Treatment setup

The field experiment composed of seven systematically arranged treatment combinations was established using RCBD with three replications during the 2018 cropping season. There were seven treatment combinations; namely, summer pruned + trained, summer pruned + untrained, summer unpruned + trained; winter pruned + trained, winter pruned + untrained, winter unpruned + trained and control (unpruned + untrained). In the study area, summer means the dormant or coolest season, while, winter is the period when there is an active growing season and the driest period. The variety "Anna" grafted with MM106 rootstocks were selected and used as a planting material because of its low chilling hours below 7.2 °C requirement and shows mitigations in peripheral tissues, which preserves internal cellular homeostasis (Voronkov *et al*. 2019); and thus, enables to cultivate at Holeta and similar areas. All the pruning and training practices were done once at a specified time. The summer pruning was conducted before bud break started, while, winter pruning was done immediately after fruit harvest. Pruning of heading back and thinning cuts that are commonly applied in apple orchard were done for all pruned trees equally, while central leader training was applied for trained fruit trees, uniformly. Other orchard management practices such as irrigation, cultivation and pest management were conducted for all treatments consistently.

Data collection

Data were collected on the vegetative growth parameters such as tree height, above and below trunk diameters, annual growths and canopy volume. The tree height (m) was measured from the ground to longest shoot tip of the tree using a height meter. The caliper readings of above and below trunk diameters were also taken at 10 cm from the graft union; and the average trunk diameter was used to calculate the trunk-cross sectional area (TCSA) by the following formula;

$$TCSA = \frac{\pi D^2}{4}$$

Where; π = 3.14, D = the mean trunk diameter.

The annual growth (cm) was also measured using four current season grown shoots from four directions and averaged thereafter. On the other hand, the east to west and north to south directions of the tree canopy were recorded using tape meters, and the average readings were used as a canopy spread (m). The tree height above the first scaffolding branch was also measured. Then, the canopy volume was calculated according to Thorne *et al*. (2002) by the following formula;

$$\text{Canopy volume } (m^3) = 4/3\pi HW$$

Where H = tree height, W = width or canopy spread.

The yield parameters such as marketable yield, disease reaction, damaged and small fruits were also recorded succeeding the growth parameter's data collection season using an electronic balance. Then, their sum was taken as total yield (t ha^{-1}).

Statistical data analysis

The collected data were subjected to analysis of variance (ANOVA) using SAS software version 9.0 and the mean separations were done using the least significance test with 5% level of significance (Gomez and Gomez, 1984).

Results and Discussion

Vegetative growth parameters

The results analysis of variance showed that the tree height, trunk cross-sectional area (TCSA), annual growth, and canopy volume of apples were highly significant ($P<0.001$) in response to pruning, training, and time of action (Table 1 and 2). The tree heights of pruned + trained and unpruned + trained during summer had showed statistical parity and recorded the tallest trees (1.52 and 1.57 m, consecutively) among others, during 2021 cropping season. Conversely, winter unpruned + trained fruit trees were the shortest (1.30 m) among others, irrespective of statistical similarity with winter pruned + trained, summer pruned + untrained and winter pruned + untrained in the same year. During 2022, pruned + trained and pruned + untrained during summer had showed the tallest trees (1.73 and 1.77 m, consecutively) with statistical equivalence. Overall, the tree height combined over 2021 and 2022 showed that pruned + trained and unpruned + trained trees in summer had obtained the tallest with non-significantly ($P<0.05$) different values of

1.63 and 1.58 m by statistics, sequentially. However, winter unpruned + trained plus the control apple trees were statistically at par and received the shortest heights of 1.45 and 1.47 m. Comparable result was also reported by Ikinci *et al*. (2014) on peach fruits. The tallness of the trees might be because of the dormant or summer pruning combined with training had altered the shoot auxin level and enhanced its growth since pruning helps to stimulate metabolism and growth (Gucci and Cantini, 2000). The dormant pruning can result in vigourous regrowth (Wilson, 2009). This could also be due to dormant pruning allows more time for plants to accumulate reserves as well as balances the vegetative and reproductive growth, and enhance light penetration into the canopy (Moatamed, 2012; Mohammadi *et al*. 2013; Ashraf and Ashraf, 2014). Pruning also maintains the growth and vigour of shoots, letting fewer growing points grow vigourously and regulating the tree canopy, in addition to restoring the balance between the shoot and root systems (Myriam *et al*. 2005). Similarly, summer pruned + trained apple trees had recorded the highest TCSA over years of 2021 and 2022, while the lowest was observed from the control. Correspondingly, Ikinci *et al.* (2014) reported agreeable results using two peach cultivars, as did Tustin (2003). The highest TCSA could be related to summer pruning with training had altered the lateral bud's hormonal status and stimulated their growth. On the other hand, the annual growth of apple trees was highest in summer unpruned + trained (0.32 cm) and summer pruned + trained (0.51 cm) during 2021 and 2022, respectively. Moreover, the combined data over two years showed that summer unpruned + trained apple trees recorded the highest annual growth of 37 cm, while the lowest of 0.28 cm was measured from the control. There was also a statistically non-significant ($P<0.05$) variation and lowest annual growth values of 0.28 and 0.30 m between the control and winter unpruned + trained apple trees, consecutively. This might also be due to the dormant season training, which enhanced the light interception into the canopy, increased the number of buds, and ultimately influenced the shoot growth. The shoot growth result is contrary to Tustin's (2003) finding that summer pruning for three cultivars of apple trees reduced the total shoot length. The canopy volume of apple trees was also highly varied ($P<0.001$) because of pruning, training and time of action. During 2021, summer pruned + trained and summer unpruned + trained apple trees had recorded the highest with statistically at par canopy volume of 2.02 and 2.36 m^3, respectively, while the combined data over two years showed that summer unpruned + trained apple trees had received the highest canopy volume of 3.30 m^3. Contrarily, the lowest canopy volume of 1.79 m^3 were obtained from winter pruned + trained apple trees. Likewise, the highest canopy could be related to the spreading of lateral shoots and minimising apical dominance. Pruning and training during the winter or active growth season might also drain the stored energy available for rehabilitation of the wounded part and suppress the overall shoot growth. This could be because the efficacy of pruning might be dependent on environmental factors such as temperature as well as time of action (Wunsche and Lakso, 2000; Li *et al*. 2003).

Table 1. Mean squares of apple growth performance due to pruning, training, and time of action during 2021 and 2022 cropping seasons at Holeta.

Source	DF	Tree heights (m)		TCSA (cm^2)		Annual growth (cm)		Canopy volume (m^3)	
		2021	2022	2021	2022	2021	2022	2021	2022
Treatment	6	0.0320**	0.0595***	2.9661***	4.0482***	0.0059***	0.0097***	0.7458***	2.2988***
Error	12	0.0062	0.0017	0.0374	0.3099	0.0005	0.0002	0.0293	0.0994

Where DF= degree of freedom; TCSA= trunk cross sectional area (cm^2); *** = very highly significant at $P < 0.001$; and ** = highly significant at $P < 0.01$ probability level.

Table 2. Apple growth performance due to pruning, training, and time of action during 2020 and 2021 cropping seasons at Holeta.

Treatments	Tree height (m)			TCSA (cm^2)			Annual growth (m)			Canopy volume (m^3)		
	2021	2022	Comb	2021	2022	Comb	2021	2022	Comb	2021	2022	Comb
Summer pruned + trained	1.52^{ab}	1.73^{a}	1.63^{a}	1.27^{a}	9.10^{a}	7.48^{a}	0.19^{d}	0.51^{a}	0.35^{b}	2.02^{a}	3.50^{b}	2.76^{b}
Summer pruned + untrained	1.33^{c}	1.77^{a}	1.55^{b}	4.25^{bc}	8.83^{a}	6.54^{b}	0.23^{c}	0.47^{b}	0.35^{ab}	1.01^{d}	4.54^{a}	2.78^{b}
Summer unpruned + trained	1.57^{a}	1.59^{b}	1.58^{ab}	3.95^{cd}	7.10^{c}	5.52^{cd}	0.32^{a}	0.42^{c}	0.37^{a}	2.36^{a}	4.23^{a}	3.30^{a}
Winter pruned + trained	1.33^{c}	1.37^{d}	1.35^{d}	4.37^{b}	7.40^{bc}	5.88^{c}	0.23^{c}	0.39^{d}	0.31^{cd}	1.37^{c}	2.21^{d}	1.79^{d}
Winter pruned + untrained	1.37^{c}	1.47^{c}	1.42^{cd}	3.67^{d}	8.37^{ab}	6.02^{c}	0.27^{b}	0.38^{de}	0.33^{c}	1.33^{c}	2.86^{c}	2.10^{c}
Winter unpruned + trained	1.30^{c}	1.60^{b}	1.45^{c}	3.17^{e}	7.40^{bc}	5.28^{d}	0.22^{cd}	0.38^{d}	0.30^{de}	1.19^{cd}	3.57^{b}	2.38^{c}
Control	1.41^{bc}	1.52^{bc}	1.47^{c}	3.74^{d}	5.73^{d}	4.74^{e}	0.21^{cd}	0.35^{e}	0.28^{e}	1.92^{b}	2.46^{cd}	2.19^{c}
Mean	1.41	1.58	1.49	4.20	7.70	5.95	0.24	0.42	0.33	1.60	3.34	2.47
LSD (5%)	0.14	0.07	0.07	0.34	0.99	0.50	0.04	0.03	0.02	0.30	0.56	0.30
Sig. level	**	***	***	***	***	***	***	***	***	***	***	***
CV	5.59	2.62	4.06	4.61	7.23	7.05	9.31	3.63	5.90	10.70	9.44	10.17

*Means followed by the same letter within a column are not significantly different at 5% level of significance. Where *** = very highly significant at $P < 0.001$; ** = highly significant at $P < 0.01$ level of significance; Comb = combined mean; TCSA= trunk cross sectional area (cm^2); LSD= least significant difference; and CV= Coefficient of Variation.*

Yield parameters

The ANOVA result showed that the marketable and total yield of apples had a highly significant (P<0.001) response to pruning, training, and time of action during the 2021 and 2022 cropping seasons (Table 3 and 4). Based on the combined data over two years, the highest marketable (4.31 t ha^{-1}) and total (4.70 t ha^{-1}) yields were recorded from summer unpruned + trained apple trees, regardless of a statistical equity (P<0.05), with summer pruned + trained and winter pruned + untrained for marketable yield. Similarly, the total yield was statistically at par (P<0.05) with winter unpruned + trained (4.43 t ha^{-1}) and winter pruned + untrained (4.42 t ha^{-1}) trees. However, winter pruned + trained, summer pruned + untrained, and the control were statistically at par and received the lowest marketable and total yields. The highest yield might be related to the reduction of apical dominance through bending and pruning shoot tips, which stirred fruiting. The stored energy present during dormancy might also stimulate flower and fruit buds' initiation. It could also be related to the formation of strong and productive scaffolding branches, particularly through training. Coinciding results were reported by Hampson (2004) and Arsov *et al.* (2013) on apple fruits. The yield of fruit trees mainly depends on the leaves's light energy capture efficiency and the operation and distribution of photosynthates (Iglesias *et al*. 2010). A high level of light energy inside the canopy is key to achieving optimal yield (Breen *et al.* 2020). The use of appropriate canopy training and pruning for high-light conditions allows for obtaining high yields (Buler and Mika, 2004; Hrotko, 2005; Sosna and Marta, 2008). Training with various pruning and bending techniques was also emphasised for obtaining the proper tree yield (Wunsche and Lakso, 2000; Robinson, 2003). Training of branches helps to reduce nutrient growth, enhance light interception in the canopy, and ultimately improve fruit yield (Jung and Choi, 2010; Jung *et al*. 2012; Lakso and Robinson, 2014). It also aids in the formation of a good canopy structure that can intercept high levels of light and increase apple tree productivity (Buler and Mika, 2009).

Table 3. Mean squares of apple marketable and total yield response to pruning, training, and time of action during 2021 and 2022 cropping seasons at Holeta.

Sources	DF	Marketable yield (t ha^{-1})		Total yield (t ha^{-1})	
		2021	2022	2021	2022
Treatment	6	0.7523***	3.0411***	0.8107***	3.7441***
Error	12	0.0517	0.1437	0.0503	0.1434

Where DF = degree of freedom; and *** = very highly significant at P < 0.001 probability level.

Table 4. Apple marketable and total yield response to pruning, training, and time of action during 2021 and 2022 cropping seasons at Holeta.

Treatments	Marketable yield (t ha^{-1})			Total yield (t ha^{-1})		
	2021	2022	Comb	2021	2022	Comb
Summer pruned + trained	3.93^{cd}	4.03^{ab}	3.98^{ab}	4.37^{c}	4.27^{b}	4.32^{b}
Summer pruned + untrained	4.18^{bc}	2.03^{c}	3.11^{c}	4.60^{bc}	2.34^{c}	3.47^{c}
Summer unpruned + trained	4.71^{a}	3.91^{b}	4.31^{a}	5.22^{a}	4.17^{b}	4.70^{a}
Winter pruned + trained	3.77^{d}	2.41^{c}	3.09^{c}	4.21^{c}	2.54^{c}	3.37^{c}
Winter pruned + untrained	4.40^{ab}	3.84^{b}	4.12^{ab}	4.82^{b}	4.02^{b}	4.42^{ab}
Winter unpruned + trained	3.16^{e}	4.67^{a}	3.92^{b}	3.58^{d}	5.29^{a}	4.43^{ab}
Control	3.80^{cd}	2.51^{c}	3.16^{c}	4.25^{d}	2.61^{c}	3.43^{c}
Mean	3.99	3.34	3.67	4.44	3.61	4.02
LSD (5%)	0.40	0.67	0.36	0.40	0.67	0.36
Sig. level	***	***	***	***	***	***
CV	5.69	11.34	8.24	5.06	10.50	7.46

*Means followed by the same letter within a column are not significantly different at 5% level of significance. Where *** = very highly significant at P < 0.001 level of significance; Comb = combined mean; LSD= least significant difference; and CV= Coefficient of Variation.*

Conclusions

In general, the growth and yield of apples had a significant response to pruning, training, and time of action. Summer training alone as well as summer pruning combined with training were better in enhancing the vegetative growth of apple fruit trees. There were also a few inconsistencies among the cropping seasons on most of the vegetative growth and yield parameters. Similarly, summer training alone had received better marketable and total fruit yields. Therefore, it may be advised that all apple producers use dormant or summer season training effectively, as it has sufficiently created strong scaffolding branches and stimulated the inactive buds for flowering and fruiting rather than pruning at this tree age. However, the response of tree age, pruning intensities, and training types should be assessed for apple production.

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Contribution of Authors

All the authors were involved in proposal development, orchard management, data collection and analysis, as well as the interpretation of results and manuscript writing. Although the coauthors contributed tirelessly to every area of the study, the corresponding author received the lion's share of the work. The authors would also like to affirm that this manuscript is accurate, honest, and through all ethical practices, and declare that there is no conflict of interest in this research.

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