

# A New Insight into Pruning Strategy in the Biennial Cycle of Fruiting: Vegetative Growth at Shoot and Whole-tree Level, Yield and Fruit Quality of Apple

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## Abstract

Knowledge of the growth dynamics of young and mature trees contributes to development of efficient orchard management practices. In this experiment, the aim was to provide apple growers with practical information on how vegetative growth (at both shoot and whole-tree level), yield and fruit quality change during the transition period, from young to mature trees. The experiment orchard was planted at 3.5 m × 1 m inter-row and intra-row spacings, respectively, with 'Golden Delicious'/M.9 trees. Trees were trained since planting as modified vertical axis. Vegetative growth at shoot level reacted differently to yield load than that at the whole-tree level. The yield, yield efficiency and annual canopy volume increase and decrease (a vegetative growth indicator at the whole-tree level) showed a positive correlation with shoot length. TCSA (annual increase and actual TCSA), as another vegetative growth indicator at whole-tree level in the experiment, correlated negatively with shoot length. The yield varied biennially and, was greatest in the seventh year after planting (21.76±8.46 kg tree<sup>-1</sup>, corresponding to an orchard yield of ~62 t ha<sup>-1</sup>) that is an acceptable tonnage in the region of the experiment. To maintain the balance between vegetative growth and fruiting, orchard management practices should be conducted considering yield. No pruning or light pruning is recommended in the 'off-year' of biennial cycle of fruiting as a result of this study.

**Keywords:** *Malus × domestica*, irregular bearing, minimal pruning, non-plastic cultivars, plastic cultivars

## Introduction

Considerable vegetative growth with minimal pruning is desirable to fill the allocated spaces of trees in the rows in the young orchards (Robinson, 2003). As trees age, a moderate or reduced vegetative growth is preferred (Atay and Lauri, 2013). Under a given set of conditions, fruit trees can show different vegetative growth reactions at shoot and whole-tree level (Lauri *et al.*, 2010). The expectation from a bearing tree is to maintain regular yields of marketable fruit (Pellerin *et al.*, 2012). However, getting a 'regular bearing' in a given orchard is not possible with all commercial apple cultivars due to intrinsic biennial bearing patterns, and fruit growers lack effective strategies to maintain regular bearing from year to year (Smith and Samach, 2013). Biennial bearing results from the balance between vegetative growth and fruiting, and how to optimize the two is one of the goals of modern fruit growing (Lauri and Lespinasse, 2000). The role of hormone/signals (e.g. gibberellin, auxin and abscisic acid) originating from developing fruit seems the main reason for this biennial cycle of fruiting in many fruit species (Chan and Cain, 1967; Monselise and Goldschmidt, 1982; Smith and Samach, 2013), but the susceptibility to biennial bearing is highly dependent on the genotype (Atay *et al.*, 2013). In contrast to the regular bearing

cultivars (e.g. Pink Lady<sup>TM</sup> 'Rosy Glow' and 'Granny Smith'), the others (e.g. 'Golden Delicious' and 'Fuji') generally show an irregular bearing pattern with a low frequency of bourse-over-bourse that is the one of the most important aspects of regular bearing in apple (Lauri *et al.*, 1995). The regular bearing trait of 'plastic' cultivars (e.g. 'Golden Delicious' and 'Gala') can be improved by sophisticated pruning techniques such as artificial extinction (Lauri *et al.*, 1995; Tustin *et al.*, 2012), which is less efficient for 'non-plastic' cultivars (e.g. 'Fuji') (Lauri and Corelli-Grappadelli, 2014). The objective of this work was to provide apple growers with practical information on changes, during the transition period from young to mature trees, first on vegetative growth (at both shoot and whole-tree levels), second on yield, and third on fruit quality in an intensive apple orchard on a deep fertile soil containing an irregular bearing cultivar. Thus, the meaning of vegetative growth remains obscure for fruit growers, and existing knowledge does not provide fruit growers which pruning strategies that can avoid biennial bearing.

## Materials and Methods

### Plant material

The experiment was conducted at an experimental plot of Fruit Research Institute (MAREM; <http://arastirma.tarim.gov>).

tr/marem), located in the West Mediterranean Region of Turkey. One-year-old unbranched nursery trees of 'Golden Delicious'/M.9 combination were planted on a clay-loom soil at 3.5 m × 1 m inter-row and intra-row spacings, respectively, delivering an overall orchard tree density of 2857 ha<sup>-1</sup>. Trees were supported by a 2.2 m trellis system and trained to a modified vertical axis system, in which renewal cuts were performed rather than shortening cuts. The orchard had drip irrigation with fertigation. 'Red Delicious' as pollinator cultivar was planted in the orchard. There were no pollination issues during the experiment and no blossom chemical thinning was applied. Hand-thinning following the physiological drop was managed according to local conditions to ensure commercial fruit quality.

#### Data collection

Data were collected over four subsequent years, from the fifth year to the eighth year after planting using the same trees. Trunk cross-sectional area (TCSA) and canopy volume measurements were started one year prior (i.e. in the fourth year following planting). Shoots length was measured in the seventh year and eighth year after planting.

Trunk diameter was measured by a digital caliper at 15 cm above the budding point, and converted into TCSA by the following formula:

$$TCSA = \pi (\text{trunk diameter}/2)^2 (\text{Zhao et al., 2016}).$$

Canopy volume, assuming trees to be represented by prolate spheroid, was calculated by the equation:

$$\text{Volume} = 4/3 \pi ab^2,$$

where  $a=1/2$  canopy height from the lowest scaffold branch and  $b=1/2$  canopy width (Westwood, 1993). The length of all shoots ending the scaffold branches was measured on four shoots per tree at breast height that were randomly chosen. The scaffold branches studied were kept with no heading cut back to old wood. Most of the shoots were in the bourse shoot category, i.e. they were generated from axils of spur leaves beneath the flower cluster, and have sympodial and sylleptic character (Costes and Guedon, 2002; Lauri et al., 2010). All measurements for vegetative growth (i.e. TCSA, canopy volume and shoot length) were performed in the dormant season before pruning.

Yield at harvest was calculated in terms of t per ha. Biennial bearing index (BBI) was calculated using the following formula (Hoblyn et al. 1936; Monselise and Goldschmidt, 1982):

$$BBI = 1 / (n-1) \times [ | (a_2 - a_1) | / (a_2 + a_1) + | (a_3 - a_2) | / (a_3 + a_2) \dots + | (a_n - a_{(n-1)}) | / (a_n + a_{(n-1)}) ],$$

where  $n$ =the number of year and  $a$ =yield in kg tree<sup>-1</sup>.

BBI values are between '0' (no biennial bearing) and '1' (no yield in one of the years) (Pearce and Dobersek-Urbanc, 1967; Smith and Samach, 2013). Yield efficiency was computed as kg cm<sup>-2</sup> TCSA (YE<sub>TCSA</sub>), kg cm<sup>-2</sup> annual TCSA increase (YE<sub>TCSAinc</sub>), and kg m<sup>-3</sup> canopy volume increase (YE<sub>Vol</sub>). Soluble solids content (SSC) of fruit juice was measured by a digital refractometer (HANNA, HI 96801, USA). Fruit flesh firmness (kg cm<sup>-2</sup>) was measured on two opposite sides of the fruit by a hand-held penetrometer (Model FT 011, Effegi, Italy) fitted with an 11.1 mm probe. For titratable acidity, 10 ml of fruit juice were titrated with 0.1 M NaOH to pH 8.15, using a digital buret (Isolab Digirate, UK) and malic acid content was calculated (Atay et al., 2010). Fruit weight was measured by a digital scale sensitive to 0.01 g. Fruit skin colour, b\* value here, was recorded by using a colorimeter (Minolta CR-400, Japan). The values of b\* can be positive ('+' = yellow) or negative ('-' = blue) (Alcobendas et al.,

2012). The pH of fruit was measured using a digital pH meter (HANNA, HI 2211, USA).

#### Data analysis

All variables were subjected to analysis of variance (ANOVA), considering year as the main factor. When the  $F$ -test statistics were significant, means were separated using Least Significant Difference (LSD) multiple comparison test. Correlation analyses were performed to investigate relationships among the variables studied. Data were analyzed using SAS-JMP software version 7.0 (<http://www.jmp.com/software>).

#### Results and Discussion

Actual TCSA increased gradually over the years (Fig. 1A). Canopy volume increased gradually between the fourth year and seventh after planting. Afterwards, it decreased (Fig. 1B). This decrease in canopy volume is likely a result of the effect of the high yield in the previous years (See Fig. 3A). In an intensive apple orchard with M.9 rootstock, canopy volume of trees must be compatible with tree spacing and a decrease in the annual canopy volume between the years six and eight after planting is crucial to keep trees within their allotted space. Thus, in the location of this experiment, often growers having an intensive apple orchard on highly fertile soils are facing an unbalanced tree canopy with too many long extension shoots,

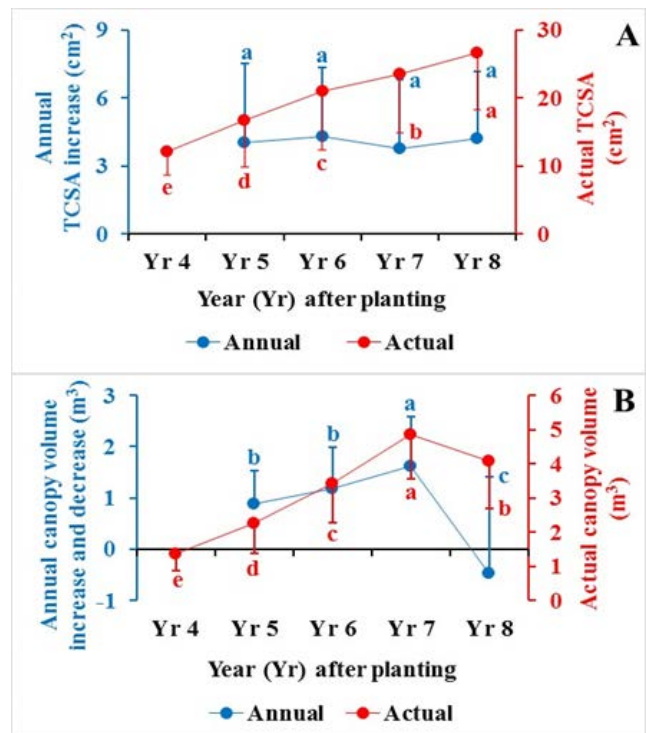


Fig. 1. Trunk cross-sectional area (TCSA) and canopy volume values of 'Golden Delicious'/M.9 trees trained to Vertical Axis system, from the fifth to the eighth year after planting (A) annual TCSA increase, and actual TCSA ( $n=96$ ), and (B) annual canopy volume increase and decrease, and actual canopy volume ( $n=96$ ). Different letters indicate statistical difference between years at  $P < 0.05$ . The values shown are means  $\pm$  standard deviation (sd)

Table 1. Pairwise correlations between shoot length and other variables studied of 'Golden Delicious'/M.9 trees trained to Vertical Axis system in the seventh and eighth year after planting

Variable	By variable	Correlation
Annual TCSA increase (cm <sup>2</sup> )	Shoot length (cm)	-0.82*
Actual TCSA (cm <sup>2</sup> )	Shoot length (cm)	-0.31*
Annual canopy volume increase and decrease (m <sup>3</sup> )	Shoot length (cm)	0.73*
Actual canopy volume (m <sup>3</sup> )	Shoot length (cm)	0.25
Yield (kg tree <sup>-1</sup> )	Shoot length (cm)	0.71*
YE <sub>TCSA</sub>	Shoot length (cm)	0.79*
YE <sub>TCSAInc</sub>	Shoot length (cm)	0.71*
YE <sub>Vol</sub>	Shoot length (cm)	0.69*
Soluble solids content (SSC) (%)	Shoot length (cm)	-0.82*
Fruit flesh firmness (kg cm <sup>-2</sup> )	Shoot length (cm)	0.21
Titrateable acidity (%)	Shoot length (cm)	0.47*
Fruit weight (g)	Shoot length (cm)	-0.04
Fruit skin colour (b* value)	Shoot length (cm)	-0.81*
pH	Shoot length (cm)	0.83*

\*Correlation significant at  $P < 0.05$ . TCSA: Trunk cross-sectional area. YE<sub>TCSA</sub>: Yield efficiency (kg cm<sup>-2</sup> TCSA). YE<sub>TCSAInc</sub>: Yield efficiency (kg cm<sup>-2</sup> annual TCSA increase). YE<sub>Vol</sub>: Yield efficiency (kg m<sup>-3</sup> canopy volume)

particularly in the top of a tree, in the seventh onwards. Carrying out similar cultural practices such as pruning and fertilization each year without considering the yield of trees may reveal this type of negative situations.

Shoot length was longer in the seventh year than in the eighth year after planting (Fig. 2). Most of the variables studied correlated significantly with shoot length (Table 1). The yield, YE<sub>TCSA</sub>, YE<sub>Vol</sub> and annual canopy volume increase and decrease showed a positive correlation to shoot length. TCSA (annual increase and actual) correlated negatively with shoot length. Shoot growth in spring (i.e. spring flush) is preformed in the winter buds, i.e. dependent on reserves stored in the tree (Sabatier and Barthelemy, 2001; Lauri, 2007). Although bourse shoots are neofomed vegetative growth units developed as sylleptic axillary shoots generated from the axils of preformed spur leaves (Costes and Guedon, 2002), results in the current study suggest that the growth potential of bourse shoots might be established in the previous year (as in the other shoots). In this experiment, heading cuts back to old wood were not used on the scaffold branches studied, and a successive flush of growth (i.e. summer flush) did not occur. In this case, it can be put forward that there is no negative subsequent-year effect of low yield ('off-year') on vegetative growth at shoot level on trees if no pruning takes place. Early data of Lauri *et al.* (2010) suggest that high yield interacts with secondary (cambial) growth later in the season (when primary growth is ceased), especially on old tree portions, and, eventually, reduces secondary growth. Thus, according to the 'coordination theory', in which there is a linear correlation between shoot growth and root growth, primary growth (shoot length here) is not affected by yield, and competition mainly is of fruit and roots, decreasing the vegetative growth at whole-tree level (Genard *et al.*, 2008; Lauri *et al.*, 2010). In contrast, a high yield (in the 'on-year') may not cause a reduction in vegetative growth at shoot level. However it is not a common strategy, keeping the trees with no pruning may be more favorable in the 'off-year' of biennial cycle of fruiting. This strategy may prevent the generation of long reaction shoots in the subsequent-year ('off-year'), leading to an imbalance between vegetative growth at shoot level and fruiting. Thus, severe heading cuts have been shown to stimulate vegetative growth at shoot level while decreasing trunk and root growth (Mika *et al.*, 2003; Atay and Koyuncu, 2013; Atay and Koyuncu, 2016).

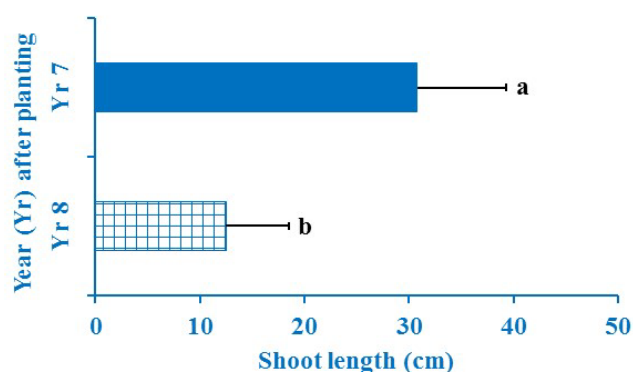


Fig. 2. Shoot length values of 'Golden Delicious'/M.9 trees trained to Vertical Axis system in the seventh and eighth years after planting ( $n=96$ ). Different letters indicate statistical difference between years at  $P < 0.05$ . The values shown are means  $\pm$  sd

Titrateable acidity and pH correlated positively with shoot length, while SSC, fruit weight and fruit skin colour were negatively correlated (Table 1). During the cell division stage which determines final fruit quality, developing shoots have priority for limited nutrients over the fruit (Quinlan and Preston, 1971; Breen *et al.*, 2015). In the current experiment, relatively low SSC, fruit weight and fruit skin colour values, accompanied by longer shoots, appeared to be associated with yield (See Fig. 3A). High yield penalizes fruit quality especially SSC, size and skin colour (Robinson *et al.*, 2009; Atay, 2016; Serra *et al.*, 2016).

The value for BBI was determined as  $0.62 \pm 0.23$  that meant yield varied biennially (Fig. 3A). The degree of biennial bearing characterized by a year of high yield ('on-year') is followed by a year of no fruit, or low yield ('off-year') varies with cultivar (Chan and Cain, 1967; Monselise and Goldschmidt, 1982). 'Golden Delicious', the plant material of this study, has been found susceptible to biennial bearing in the local conditions of the study (Atay *et al.*, 2013). By diminishing competition between flower initiation and fruit formation, fruit growers can diminish the adverse effects of high yield on next year's flowering (Guitton *et al.*, 2012; Smith and Samach, 2013). However, in the current experiment, neither blossom thinning

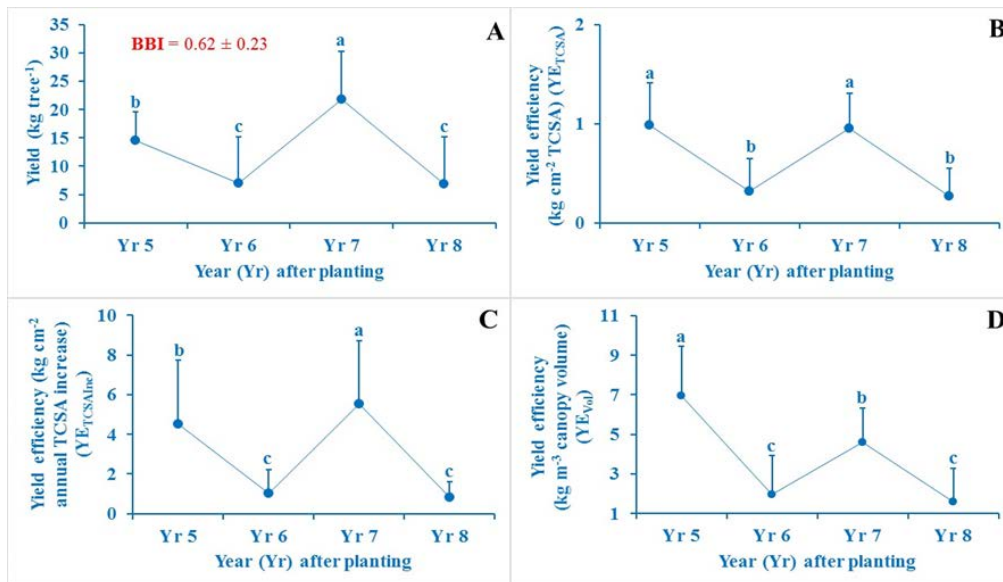


Fig. 3. Yield and yield efficiency values of 'Golden Delicious'/M.9 trees trained to Vertical Axis system, from the fifth to the eighth year after planting (A) yield, (B)  $YE_{TCSA}$  (yield efficiency as  $kg\ cm^{-2}$  TCSA) ( $n=96$ ), (C)  $YE_{TCSAinc}$  (yield efficiency as  $kg\ cm^{-2}$  annual TCSA increase) ( $n=96$ ), and (D)  $YE_{Vol}$  (yield efficiency as  $kg\ m^{-3}$  canopy volume) ( $n=96$ ). Different letters indicate statistical difference between years at  $P < 0.05$ . The values shown are means  $\pm$  standard deviation (sd). BBI: Biennial bearing index

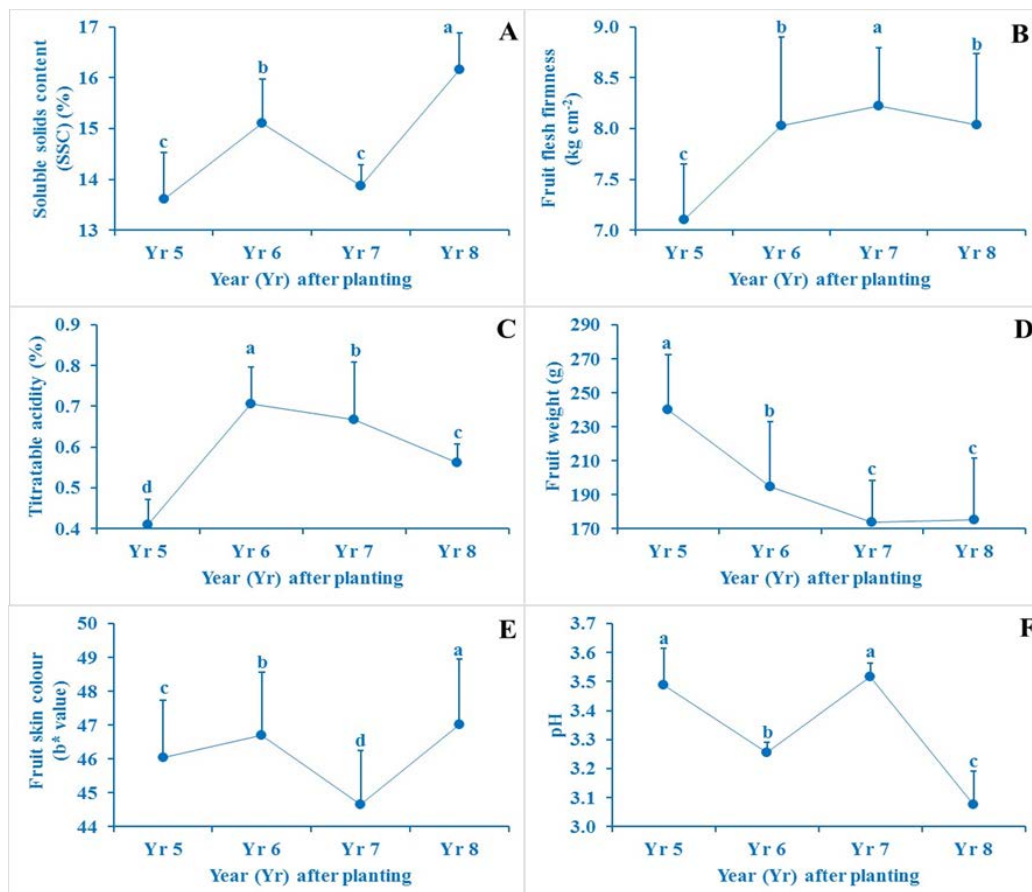


Fig. 4. Fruit quality characteristics of 'Golden Delicious'/M.9 trees trained to Vertical Axis system, from the fifth to the eighth year after planting (A) soluble solids content ( $n=24$ ), (B) fruit flesh firmness ( $n=240$ ), (C) titrateable acidity ( $n=24$ ), (D) fruit weight ( $n=240$ ), (E) fruit skin colour ( $b^*$  value) ( $n=240$ ), and (F) pH ( $n=24$ ). Different letters indicate statistical difference between years at  $P < 0.05$ . The values shown are means  $\pm$  sd

Table 2. Correlation among vegetative growth, yield and fruit quality characteristics of 'Golden Delicious'/M.9 trees trained to Vertical Axis system, from the fifth to the eighth year after planting

Variable	v1	v2	v3	v4	v5	v6	v7	v8	v9	v10	v11	v12	v13	v14
Ann.TCSA <sub>inc</sub> (v1)	1.00	0.52*	-0.79*	0.33*	-0.24*	-0.42*	-0.44*	-0.40*	0.65*	0.20	-0.09	-0.36*	0.43*	-0.66*
Actual TCSA (v2)		1.00	-0.24*	0.83*	0.23*	-0.31*	-0.15	-0.36*	0.31*	0.37*	0.25*	-0.45*	0.13	-0.28*
Ann.Can.Vol. <sub>IncDec</sub> (v3)			1.00	0.01	0.45*	0.46*	0.42*	0.36*	-0.54*	-0.02	0.22*	0.14	-0.49*	0.68*
Actual Can.Vol. (v4)				1.00	0.46*	-0.06	0.05	-0.28*	0.14	0.52*	0.35*	-0.57*	-0.23*	-0.06
Yield (v5)					1.00	0.81*	0.61*	0.66*	-0.46*	-0.02	0.01	-0.01	-0.62*	0.54*
YE <sub>TCSA</sub> (v6)						1.00	0.65*	0.91*	-0.58*	-0.32*	-0.26*	0.30*	-0.63*	0.66*
YE <sub>TCSAinc</sub> (v7)							1.00	0.58*	-0.63*	-0.20*	-0.13	0.23*	-0.61*	0.67*
YE <sub>Vol</sub> (v8)								1.00	-0.58*	-0.56*	-0.42*	0.52*	-0.42*	0.60*
SSC (v9)									1.00	0.39*	0.31*	-0.32*	0.52*	-0.72*
Firmness (v10)										1.00	0.60*	-0.75*	-0.05	-0.29*
Acidity (v11)											1.00	-0.43*	-0.04	-0.18
F. weight (v12)												1.00	0.12	0.32*
Colour (b*) (v13)													1.00	-0.54*
pH (v14)														1.00

\*Correlation significant at  $P < 0.05$ . v1: annual TCSA (trunk cross-sectional area) increase ( $\text{cm}^2$ ); v2: actual TCSA ( $\text{cm}^2$ ); v3: annual canopy volume increase and decrease ( $\text{m}^3$ ); v4: actual canopy volume ( $\text{m}^3$ ); v5: yield ( $\text{kg tree}^{-1}$ ); v6: YE<sub>TCSA</sub>: yield efficiency ( $\text{kg cm}^{-2}$  TCSA); v7: YE<sub>TCSAinc</sub>: yield efficiency ( $\text{kg cm}^{-2}$  annual TCSA increase); v8: YE<sub>Vol</sub>: yield efficiency ( $\text{kg m}^{-3}$  canopy volume); v9: soluble solids content (SSC) (%); v10: fruit flesh firmness ( $\text{kg cm}^{-2}$ ); v11: titratable acidity (%); v12: fruit weight (g); v13: fruit skin colour (b\* value); v14: pH

nor artificial extinction (Lauri *et al.*, 1995; Tustin *et al.*, 2012; Atay and Lauri, 2013) carried out, and fruit thinning by hand was applied after the physiological drop. At this stage of fruit development (i.e. after physiological drop), thinning has no or little effect on biennial bearing because flower initiation is already established (Westwood, 1993). When yield was the highest ( $21.76 \pm 8.46 \text{ kg tree}^{-1}$ ) (i.e. in the seventh year after planting) (Fig. 3A), annual TCSA increase was relatively low ( $3.75 \pm 3.06 \text{ cm}^2$ ) (see Fig. 1A). A tree with low or no yield has a relatively high vegetative growth at whole-tree level (Smith and Samach, 2013). There were significant year-to-year fluctuations in YE<sub>TCSA</sub> (Fig. 3B), YE<sub>TCSAinc</sub> (Fig. 3C) and YE<sub>Vol</sub> (Fig. 3D).

The values for SSC ( $13.61 \pm 0.92\%$ ) (Fig. 4A), fruit flesh firmness ( $7.13 \pm 0.61 \text{ kg}$ ) (Fig. 4B) and titratable acidity ( $0.41 \pm 0.06\%$ ) (Fig. 4C) were lower in the fifth year after planting with the highest fruit weight value ( $240.08 \pm 32.54 \text{ g}$ ) (Fig. 4D). Fruit skin colour (Fig. 4E) was higher ( $47.02 \pm 1.93$ ) in the sixth year after planting with the lowest pH value (Fig. 4F) ( $3.08 \pm 0.11$ ). These results for fruit quality may be bound up with the yield. Thus, SSC, fruit flesh firmness, titratable acidity and skin colour negatively, fruit weight and pH positively correlated with yield efficiency (Table 2). A high yield affects SSC and skin colour value negatively due to a shortage of carbohydrate supply for fruit (Robinson *et al.*, 2009; Atay *et al.*, 2010; Atay, 2016; Serra *et al.*, 2016). A relatively high pH value in the fruit was observed in the high cropping years which can be attributed to delayed fruit ripening. High yield ('on-year') extends maturity (Wünsche and Ferguson, 2004). Fruit weight correlated negatively with fruit flesh firmness. Unexpectedly, the positive correlation between fruit weight and yield efficiency can be postulated to an extreme fruit weight value in the fifth year after planting.

## Conclusions

This study showed that vegetative growth at shoot level reacted differently to yield than the vegetative growth at the whole-tree level, here quantified by TCSA and canopy volume. The biennially variation of yield was within an acceptable tonnage ( $\sim 55\text{-}65 \text{ t ha}^{-1}$ ) for the experimental area of Bogazova Valley of Egirdir, Isparta, Turkey in the seventh year after planting. The yield affected fruit quality. Orchard management

practices (e.g. pruning, fruit load adjustments and nitrogen-based fertilization) between the years six and eight after planting should be conducted with caution to maintain the equilibrium between the vegetative and the reproductive functions in the tree. This study supported the idea that cultural practices such as pruning should not be conducted without considering the actual yield. To maintain orchard management effectively, keeping the trees with no pruning or light pruning is recommended in the 'off-year' of biennial bearing cycle.

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