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Impact of early cropping on vegetative development, productivity, and fruit quality of Gala and Braeburn apple trees

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Abstract: The effects of 5 crop load levels (all fruit removed and 10, 20, 30, and 40 fruit per tree) in the second growing year on vegetative growth, productivity, and fruit quality were studied in apple cultivars Gala and Braeburn on M9 rootstock in the second and the third leaf. An increase in vegetative growth was observed on the defruited trees in the second growing year. The highest crop load of 40 fruits per tree reduced average fruit weight by 18.7% in Gala compared to those obtained on the trees carrying the lowest crop load (10 fruits per tree). The reduction in average fruit weight was compensated by the increase in yields. Yield per tree in the treatment with the highest crop load was 2.4-fold higher in Gala and 2.7-fold higher in Braeburn than the treatment with the lowest crop load. Yield efficiency (kg cm^{-2} trunk cross-section area) in both tested cultivars ranked the highest on the trees carrying the heaviest crop. The highest crop load in the second growing year did not have negative consequences on the yield and fruit quality obtained in the third growing year.

Key words: Crop load, fruit characteristics, return bloom, tree growth, yield

1. Introduction

For several decades, the use of intensive orchards has been proposed to improve profitability and yield, notably of early cropping, in apple orchards (Lauri et al., 2004). Fruit yield is a function of 2 components: fruit number and fruit size. Fruit number, as the primary factor, is mainly affected by flower bud formation and final fruit set (Lakso and Wünsche, 2000). Crop load, defined as the number of fruits per tree, has a significant impact on both fruit quality and tree physiology, and thus on managing the risks associated with achieving commercial requirements for fruit size and consumer-based quality attributes (Wünsche et al., 2005; Treder et al., 2010).

Apple growers are under increasing pressure to enhance fruit size to satisfy consumer demands, but profitability in an apple orchard also depends on optimal yield and high fruit quality. Sometimes apple trees bloom abundantly and set too many fruits. Excessive cropping contributes to a cycle of alternate season bearing, which results in a large number of small, poor-quality apples on a tree in heavy bloom years (Cmelik et al., 2006; Wright et al., 2006). The fruits act as a strong carbohydrate sink and high crop loads can constrain vegetative growth, reducing the interception of light and the future productivity of the orchard (Yuri et al., 2011).

Information on crop load manipulation and fruit quality are of particular importance to growers in order to optimize the number of fruits per tree to achieve the desired fruit qualities (Treder, 2008; Meland, 2009). Fruit thinning is the most important technique in apple growing for improving fruit quality. It is important to know how many fruits should be retained to obtain optimum fruit quality and adequate storability (Treder, 2008). Overly heavy fruit thinning reduces yield and increases fruit sensitivity to many physiological disorders during storage. Lightly thinned trees bear heavier crops of smaller fruits (De Salvador et al., 2006). Well-documented consequences of high fruit load are reductions of floral returns and flowering patterns in the following season, the latter being dependent on the cultivar (Cmelik et al., 2006; Yuri et al., 2011). Flower bud production for the following spring can be negatively affected by an increase in fruit load (Palmer, 1992; Dennis, 2000). The gibberellins generated by the seeds of the small fruits are relocated to the plant and inhibit the formation of floral buds in the following season (Yuri et al., 2011).

Manipulation of vegetative growth/fruiting relationships in order to ensure high-quality fruits and regular cropping is the objective of all apple production

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systems (Lauri et al., 2004; Unuk et al., 2008). A good balance between vegetative growth and cropping is the most important in young high-density apple orchards because, over the years, the length of time for full orchard productivity has become shorter and shorter (Treder et al., 2010). When feathered nursery trees are used for establishing an apple orchard, trees in second leaf are more likely to bloom abundantly and set too many fruits to optimize yield per tree, fruit size, and return bloom. Therefore, in a young, high-density planting apple orchard, it is particularly important to know the ideal amount of fruit per tree to obtain optimum fruit quality, vegetative growth, and adequate yield.

This experiment was designed to examine the management of vegetative/reproductive balance through the regulation of early cropping levels in the first year after planting in a high-density apple orchard. To study the productivity, fruit quality, and growth of trees in the second and the third leaf, 5 crop load groups were applied to 2 cultivars, Gala and Braeburn, on M9 rootstock.

2. Materials and methods

2.1. Experimental design and plant material

The study was carried out at a Delta Group commercial orchard located in Čelarevo, Serbia, in the second and third growing years (2008/2009). The area has a temperate continental climate with an average annual rainfall of 615 mm. The orchard was established in spring 2007 with high-quality 1-year-old nursery trees that contained 7 or more lateral branches. Two apple cultivars were used on M9 rootstock (T337): Gala (Brookfield Baigent) and Braeburn (Eve® Mariri Red). Planting distance was 3.2 m between the rows and 0.8 m within the rows (3906 trees ha^{-1}) for both cultivars. Trees were trained with the slender spindle-type system. Standard cultural measures in the orchard were used, including drip irrigation.

In the winter of 2008, 80 trees per cultivar were selected according to their uniformity. The trees were assigned to 5 levels of fruit crop load, in a complete random design with 5 replicates per treatment. Each replicate included 4 trees. At the end of May in the second growing year (when fruit diameter was about 15 mm), the fruit set in both cultivars was adjusted by hand in order to establish 5 levels of crop load, as follows: all fruit removed, 10 fruits per tree, 20 fruits per tree, 30 fruits per tree, and 40 fruits per tree. The third growing year was used as a control (no treatment). In that year, all the trees from previous year were chemically thinned with carbaryl (concentration was 0.5% with 800 L solution ha^{-1}) without hand-thinning. The application of carbaryl was performed when king fruit diameter on the 2-year-old wood was 10.5 mm in Gala and 12 mm in Braeburn. The influence of crop load from previous year on yield, fruit characteristics, and vegetative growth was studied in the control year.

2.2. Vegetative growth characteristics

Trunk diameter was measured twice at the beginning of March and in late November, at 10 cm above the grafting union, in order to calculate an increase of trunk cross-section area (TCSA) during the second and third growing years. At the end of the second season, the number of long extension shoots (>5 cm in length) and short shoots (<5 cm in length) was quantified. All long shoots were measured to calculate total shoot growth.

2.3. Productivity and fruit quality characteristics

Gala fruits were harvested in August and Braeburn fruits were harvested in September in both years. The fruit from each tree was picked separately on 2 dates. The yield per tree was obtained by weighing harvested fruit, and these data were used to calculate yield per hectare (t ha^{-1}). The return bloom was recorded on each experimental tree in April of both years by counting all blossom clusters per tree. The color rating was evaluated visually as the percentage of the epidermal surface area having a red color.

To assess the fruit quality, a sample of 20 randomly selected fruits from each replicate were taken at the first picking date to determine the average fruit weight (g) using the METTLER balance (±0.01 g accuracy). Fruit diameters (mm) were also determined in the samples with the Inox Vernier scale (±0.05 mm accuracy). Soluble solids concentration (%) was assessed using a digital refractometer (Pocket PAL-1, Atago, Japan). Total acids content was measured by neutralization to pH 7.0 with 0.1 N NaOH and acidity was expressed as percent of malic acid equivalent.

2.4. Statistical analysis

A statistical analysis was performed using Statistica 6.0 for Windows. Data were calculated by ANOVA. Mean separation was done by Tukey's honestly significant difference (HSD) test at a 5% level of significance.

3. Results

3.1. Vegetative growth characteristics affected by the crop load

Different crop loads in both tested cultivars significantly influenced the increase of TCSA and total and mean shoot length (Table 1). Compared to the other 3 treatments (20, 30, and 40 fruits per tree), trees without fruit had a significantly lower rate of TCSA increase in both cultivars tested. An increase in total shoot length observed on the lower-cropping trees in our study was affected by increment of shoot length, but not by number of active shoots. This finding confirms the results obtained in Gala, where no difference was observed in the number of spurs and long shoots among the applied treatments. Conversely, Braeburn trees in the heaviest cropping treatment had significantly higher numbers of spurs and significantly lower total shoot lengths compared to the other treatments.

Table 1. Vegetative growth of Gala and Braeburn apples affected by crop load in the second growing year (2008).

Cultivar	Crop load treatment (fruit per tree)	Increase in TCSA (cm^2)	Number of spurs	Number of long shoots	Total shoot length (cm)	Mean shoot length (cm)
Gala	0	2.07 ± 0.22a	84.5 ± 7.08	58.6 ± 0.84	2190 ± 104.8a	37.5 ± 1.57a
	10	1.75 ± 0.21ab	71.8 ± 5.84	62.1 ± 2.04	1984 ± 111.1ab	32.1 ± 1.31a
	20	1.33 ± 0.11bc	87.8 ± 3.28	64.8 ± 3.53	1670 ± 74.2bc	26.3 ± 1.06b
	30	1.03 ± 0.17c	88.4 ± 8.47	66.5 ± 3.22	1646 ± 74.4bc	25.0 ± 1.50b
	40	1.33 ± 0.07bc	98.8 ± 5.91	57.5 ± 2.41	1424 ± 62.2c	24.9 ± 1.14b
F-value		*	ns	ns	*	*
Braeburn	0	2.15 ± 0.13a	148.5 ± 6.17b	53.5 ± 3.41a	1965 ± 166.9a	36.8 ± 1.01a
	10	1.55 ± 0.18ab	132.7 ± 13.70b	48.4 ± 1.13ab	1649 ± 77.8a	34.2 ± 1.17ab
	20	1.33 ± 0.12bc	143.4 ± 7.21b	55.5 ± 4.10a	1864 ± 147.0a	33.7 ± 1.02ab
	30	1.13 ± 0.11bc	141.6 ± 8.61b	50.8 ± 2.68ab	1680 ± 57.2a	33.3 ± 0.96ab
	40	0.69 ± 0.37c	214.0 ± 20.83a	36.6 ± 3.20b	1053 ± 186.7b	28.2 ± 3.42b
F-value		*	*	*	*	*

ns = Nonsignificant; * = $P < 0.05$. Data are the means of 4 replications ± standard error. For each cultivar and column, values followed by the same letter are not significantly different according to the Tukey HSD test.

3.2. Fruit quality characteristics affected by the crop load

Crop load significantly influenced fruit weight; the trees with heaviest crop load had smaller-sized fruit (Table 2). The heaviest crop load in Gala lowered fruit weight by 18.7% compared to that of the trees carrying the lowest crop. In Braeburn the heaviest crop load had a fruit weight 11.1% lower than in the treatment with 20 fruits per tree. Interestingly, the amount of best-quality fruit did not decrease in our study, although the number of remaining fruits per tree was 2- to 4-fold higher in comparison to the treatment with 10 fruits per tree. Genetically small-fruited Gala produced fruits with a diameter of greater than 75 mm in all investigated treatments, contributing to their very high market values. In Braeburn, fruits with diameters of less than 80 mm were only found on the trees carrying the heaviest crop (40 fruits); these fruits ranked as first-class. No significant differences were observed in total soluble solid (TSS) and total acid (TA) contents among the treatments in both investigated cultivars.

Trees under the highest crop load (40 fruits) of Gala expressed the lowest percentage of red color, whereas no differences were observed among other treatments. Conversely, in Braeburn, the highest percentage of red-colored fruits was recorded under the high crop load.

The effect of crop load from previous year on the fruit quality in the following (control) year was also investigated. There was no significant influence on any studied fruit quality parameters (Table 3).

3.3. Productivity and return bloom affected by the crop load

The number of remaining fruits per tree strongly influenced yield per tree achieved in the second growing year (Table 4). It was found that the highest crop load demonstrated a 2.4-fold higher yield per tree in Gala and a 2.7-fold higher yield in Braeburn, compared to the yields per tree obtained in the lowest crop load treatment. Yield efficiency (kg cm^{-2} TCSA) in both tested cultivars ranked the highest in the trees carrying the heaviest crop. Yield efficiency increased 2.9-fold in Gala and 3.3-fold in Braeburn compared to yield efficiency obtained under the lowest crop load.

Different crop loads significantly affected the uniformity of fruit ripening. In our case, fruits showed advanced maturity when their number per tree was lower. This tendency was observed in both cultivars tested, although the amount of fruit harvested in the first picking date in all treatments was greater in Gala than in Braeburn under the same crop load. No significant differences were observed in the number of flower clusters per tree among applied treatments in the second growing year.

The highest crop load in the second growing year had no negative effect on the yield obtained in the following (control) year (Table 5). Yields of Gala were not significantly different in the third growing season, whereas the highest yield per tree in Braeburn was obtained in the control year from the trees that were under the highest crop load in the previous year. That yield was 70.5% higher

Table 2. Fruit quality characteristics of Gala and Braeburn apples affected by crop load in the second growing year (2008).

Cultivar	Crop load treatment (fruit per tree)	Fruit weight (g)	Fruit diameter (mm)	TSS content (°Brix)	TA (%)	Color (% red)
Gala	10	235.2 ± 5.41a	79.3 ± 0.53	15.4 ± 0.26	0.16 ± 0.010	89.8 ± 0.64a
	20	216.5 ± 2.96b	77.9 ± 0.60	15.9 ± 0.60	0.18 ± 0.011	88.2 ± 1.78a
	30	214.0 ± 4.65bc	77.5 ± 0.84	15.7 ± 0.98	0.16 ± 0.008	88.9 ± 1.41a
	40	198.5 ± 2.71c	76.1 ± 0.98	14.2 ± 0.48	0.15 ± 0.007	80.2 ± 3.06b
F-value		*	ns	ns	ns	*
Braeburn	10	247.7 ± 5.36ab	80.0 ± 0.55a	16.3 ± 0.35	0.30 ± 0.01	78.9 ± 2.35b
	20	261.1 ± 1.70a	80.5 ± 0.77a	15.5 ± 0.29	0.30 ± 0.01	79.8 ± 0.83b
	30	251.8 ± 8.85ab	81.4 ± 0.75a	16.1 ± 0.63	0.29 ± 0.02	79.7 ± 1.13b
	40	232.1 ± 6.75b	76.7 ± 0.32b	15.4 ± 0.52	0.30 ± 0.02	86.9 ± 1.79a
F-value		*	*	ns	ns	*

ns = Nonsignificant; * = P < 0.05. Data are the means of 4 replications ± standard error. For each cultivar and column, values followed by the same letter are not significantly different according to the Tukey HSD test.

Table 3. Fruit quality characteristics of Gala and Braeburn apples affected by crop load in the control growing year (2009).

Cultivar	Crop load treatment (fruit per tree)	Fruit weight (g)	Fruit diameter (mm)	TSS (%)	TA (%)	Color (% red)
Gala	0	174.6 ± 4.01	75.0 ± 0.7	12.4 ± 0.12	0.16 ± 0.01	98.0 ± 1.52
	10	179.7 ± 5.55	74.4 ± 0.7	11.7 ± 0.13	0.17 ± 0.01	98.4 ± 0.81
	20	175.9 ± 3.42	73.4 ± 1.2	11.9 ± 0.26	0.18 ± 0.01	97.6 ± 1.03
	30	179.5 ± 2.34	74.0 ± 0.58	11.9 ± 0.31	0.16 ± 0.01	98.0 ± 1.55
	40	173.3 ± 6.63	75.3 ± 0.39	11.5 ± 0.24	0.16 ± 0.01	94.4 ± 3.39
F-value		ns	ns	ns	ns	ns
Braeburn	0	221.2 ± 7.04	79.1 ± 0.51	11.8 ± 0.30	0.29 ± 0.02	94.4 ± 0.93
	10	202.8 ± 4.95	77.6 ± 0.63	12.3 ± 0.23	0.32 ± 0.02	92.2 ± 3.43
	20	210.3 ± 9.46	77.7 ± 0.68	11.6 ± 0.40	0.28 ± 0.02	93.4 ± 2.48
	30	200.7 ± 3.22	77.5 ± 0.73	12.3 ± 0.15	0.29 ± 0.01	95.0 ± 0.55
	40	187.4 ± 10.41	75.5 ± 0.68	12.5 ± 0.15	0.31 ± 0.02	94.2 ± 1.39
F-value		ns	ns	ns	ns	ns

ns = Nonsignificant; * = P < 0.05. Data are the means of 4 replications ± standard error. For each cultivar and column, values followed by the same letter are not significantly different according to the Tukey HSD test.

than in defruited trees in the second growing season. Yield efficiency in Gala (kg cm^{-2} TCSA) in the trees carrying 30 fruits per tree was significantly higher compared to the trees without fruits, whereas Braeburn expressed the highest yield efficiency on the trees carrying 40 fruits per tree, both in the second growing season. The number of flower clusters per tree for the following production year was not significantly different among the applied treatments in both tested cultivars, suggesting a good return bloom and yield in the fourth growing year.

Table 4. Productivity and return bloom of Gala and Braeburn apples affected by crop load in the second growing year (2008).

Cultivar	Crop load treatment (fruit per tree)	Yield (t ha^{-1})	Harvest at first date (%)	Yield efficiency (kg cm^{-2} TCSA)	Flower clusters per tree
Gala	0	-	-	-	103.8 ± 7.2
	10	9.2 ± 0.21d	92.4 ± 2.29a	0.31 ± 0.01d	103.0 ± 10.5
	20	16.9 ± 0.23c	78.6 ± 3.36ab	0.64 ± 0.02c	113.6 ± 6.1
	30	25.1 ± 0.55b	66.8 ± 5.22ab	1.01 ± 0.06b	113.6 ± 9.7
	40	31.0 ± 0.42a	51.4 ± 1.10b	1.21 ± 0.02a	120.3 ± 5.4
F-value		*	*	*	ns
Braeburn	0	-	-	-	144 ± 4.9
	10	9.7 ± 0.21d	65.1 ± 11.7a	0.35 ± 0.02c	136 ± 9.4
	20	20.4 ± 0.13c	72.8 ± 2.7a	0.74 ± 0.01bc	144 ± 5.8
	30	29.3 ± 1.04b	50.2 ± 7.8ab	1.17 ± 0.06ab	144 ± 9.0
	40	36.3 ± 1.06a	23.4 ± 2.8b	1.52 ± 0.21a	156 ± 19.7
F-value		*	*	*	ns

ns = Nonsignificant; * = $P < 0.05$. Data are the means of 4 replications ± standard error. For each cultivar and column, values followed by the same letter are not significantly different according to the Tukey HSD test.

Table 5. Productivity and return bloom of Gala and Braeburn apples affected by crop load in the third (control) growing year (2009).

Cultivar	Crop load treatment (fruit per tree)	Crop load (fruit cm^{-2} TCSA)	Yield (t ha^{-1})	Harvest at first date (%)	Yield efficiency (kg cm^{-2} TCSA)	Flower clusters per tree
Gala	0	7.6 ± 0.72c	44.2 ± 3.54	75.0 ± 2.57	0.94 ± 0.10b	83.3 ± 10.6
	10	8.7 ± 0.71bc	44.4 ± 3.14	54.2 ± 6.07	1.09 ± 0.07ab	71.0 ± 9.2
	20	11.1 ± 0.92abc	53.1 ± 5.27	62.3 ± 4.56	1.43 ± 0.14ab	100.0 ± 8.5
	30	13.6 ± 1.05a	57.9 ± 2.86	56.4 ± 6.38	1.53 ± 0.09a	106.6 ± 10.7
	40	12.0 ± 1.15ab	53.9 ± 6.06	60.0 ± 9.43	1.45 ± 0.11ab	82.8 ± 11.0
F-value		*	ns	ns	*	ns
Braeburn	0	5.1 ± 0.57c	34.3 ± 0.85b	85.7 ± 4.4a	0.81 ± 0.08c	95 ± 7.1
	10	8.8 ± 0.75abc	49.1 ± 0.87ab	50.6 ± 3.8b	1.32 ± 0.11bc	85 ± 19.3
	20	7.7 ± 0.63bc	44.5 ± 1.18ab	67.9 ± 10.7ab	1.17 ± 0.10bc	90 ± 11.1
	30	10.3 ± 1.19ab	52.3 ± 1.44a	64.5 ± 9.0ab	1.52 ± 0.17ab	89 ± 20.4
	40	13.1 ± 1.85a	58.5 ± 0.72a	64.1 ± 4.4ab	1.98 ± 0.22a	64 ± 11.7
F-value		*	*	*	*	ns

ns = Nonsignificant; * = $P < 0.05$. Data are the means of 4 replications ± standard error. For each cultivar and column, values followed by the same letter are not significantly different according to the Tukey HSD test.

4. Discussion

Orchard vigor, defined as the intensity of vegetative growth, is an important indicator for crop management in fruit tree cropping systems. The obtained results of TCSA increment and shoot length in the present study confirm the general opinion that thinning results in more shoot growth than no thinning (Giuliani et al., 1997; Palmer et al., 1997; Pretorius et al., 2004). Unuk et al. (2008) concluded that heavy cropping inhibits the growth of young trees, especially if they bear fruit in the second growing year; after that, the relationship between growth and crop load is weaker. Wünsche et al. (2005) also reported that final mean bourse shoot length and TCSA in autumn were about 58% and 42% higher, respectively, in noncropping trees compared with high-cropping 7-year-old Braeburn trees. Since the fruits act as a strong carbohydrate sink, high crop loads can constrain vegetative growth. Although the results obtained in Gala showed that none of the treatments influenced the number of spurs and long shoots, an exception was found in Braeburn, whose trees with the highest crop load had more spurs and fewer long shoots in comparison to other treatments. Strong vegetative growth observed in the lower-cropping trees in Gala was affected by increment of shoot length, but not by number of active shoots. However, Wünsche and Palmer (2000) reported that reducing the number of fruits per tree increases shoot growth by increasing both the number of active shoots and their growth rate.

Strong shoot growth is unwanted in high-density apple orchards. On the other hand, heavy crops with small fruit size can lead to a decrease in tree vigor over time (Robinson et al., 2008). Crop load must be kept in balance with shoot growth to prevent ‘runting out’ of the tree in early production years, while allowing the tree to develop sufficient framework to support a commercially acceptable crop (Raines, 2000). The spur-to-shoot ratio depends mainly on rootstock/scion combination, pruning regime, and growing conditions, and it has significant implications for light distribution within the canopy and carbohydrate partitioning patterns (Lakso and Wünsche, 2000).

Fruit weight is one of the main factors determining yield level and, consequently, profitability of apple production. The negative impact of heaviest crop load on the average fruit weight observed in this study could be associated with a very high number of apples per tree. These results are in agreement with previous studies (Awad et al., 2001; Wright et al., 2006; Treder et al., 2010) in which an average fruit weight, as well as its size, signified a negative correlation with the number of apples per tree. Dussi et al. (2006) also reported that competition among fruits reduces their size if there is an excessive fruit set.

In all the treatments applied in this study, the Gala apples had diameters of greater than 75 mm, which, according to Robinson et al. (2008), contributed to their significantly higher price. This finding coincided with the study reported by Yuri et al. (2011), who found that, generally, a reduction in crop load increases the mean fruit size and the percentage of large fruits.

Chemical evaluation of the apple fruit related to different crop loads determined which of the applied treatments influenced the levels of TSS and TA in the fruits. Interestingly, none of the treatments applied in this study significantly affected TSS or TA content in the fruit of both tested cultivars, which is in accordance with the results obtained by Mpelasoka et al. (2001b) for Braeburn on MM106 rootstock and by Cmelik et al. (2006) for a young Fuji orchard grafted on M9 rootstock. De Salvador et al. (2006) also mentioned that a moderate increase in apple crop load does not affect fruit quality. However, a reduced crop load can increase TSS (Link, 2000; Mpelasoka et al., 2001a; Stopar et al., 2002) and TA (Link, 2000; Awad et al., 2001; Saei et al., 2011) content in apples.

Fruit coloration is an important external parameter contributing to consumer acceptance and higher market values. Both tested cultivars produced fruits with a good red surface color, even in the treatment with the highest crop load (which was observed only in Braeburn). Likewise, some authors (Link, 2000; Stopar et al., 2002; Wright et al., 2006) reported that decreasing crop load leads to a higher percentage of red-colored fruits. Besides that, fruit color intensity mostly depends on weather conditions during the ripening season (Stampar et al., 2002). Suitable weather conditions (colder nights and larger differences between day and night temperatures) in the period between the first and second picking dates of Braeburn grown under highest crop load contributed to better development of red color on the fruits. The quantity of fruit harvested on the second picking date was 3-fold higher than that obtained on the first picking date.

The fruit quality in the third (control) year was not influenced by crop load in the previous year. Our results are not in accordance with those reported by Unuk et al. (2008), who indicated that trees without fruit in the second growing year demonstrated an excessive fruit number per tree in the third growing year.

Manipulating the vegetative/reproductive balance through regulation of early cropping in the first year after planting an apple orchard is a very important measure. Overthinning may result in lower crops and profits, and it can easily disrupt the delicate balance between growth and yield and lead to alternate bearing. The increasing fruit number per tree leads to a linear increment of yield, so that the heaviest crop load experienced a 2.4-fold higher yield in Gala and a 2.7-fold higher yield in Braeburn than those obtained in the lowest crop load. We also observed that different crop loads affected the uniformity of fruit ripening. Trees with lower amounts of fruit per tree had accelerated fruit ripening in both tested cultivars, which was previously confirmed by Palmer et al. (1997) and Wünsche et al. (2005).

Regular productivity is one of the main goals in high-density apple orchards. In our research, none of the treatments applied in the second growing year influenced the number of flower clusters per tree, providing good yields in the control year. Crop load until 40 fruits per tree is equivalent to 7 fruits cm^{-2} TCSA. This is much higher than the results of Cmelik et al. (2006), who suggested that to achieve desirable flower density in Fuji apples during the establishment year, crop loads of about 3 fruits cm^{-2} TCSA would be required in the previous year. Palmer (1992) and Dennis (2000) also found that heavy fruiting can partially or completely inhibit flower bud initiation in some apple cultivars. The consequences of high fruit load are reductions in floral returns and flowering patterns in the following season, the latter being dependent on the cultivar (Yuri et al., 2011).

Proper flower and fruitlet manipulation in the second growing year after planting is necessary to establish continually increasing yield dynamics and good tree growth development for further seasons. Our study showed that high crop load in the second growing year did not have negative consequences on the yield in the third growing year (control year). The highest yield efficiency (kg cm^{-2} TCSA) of Braeburn on the trees with the highest crop load in the second growing season is due to not only greater fruit number per tree, but also to reduced vegetative growth. The investigation performed here indicated that the trees of both cultivars could be loaded to 13 fruit cm^{-2} TCSA in the third growing year, which provided a yield of about 50 t ha^{-1} without a negative influence on the fruit quality and potential crop in the fourth growing season. These crop loads are much higher than those reported by De Salvador et al. (2006), who determined the crop load of 6 fruits cm^{-2} TCSA as standard, whereas 8 fruits cm^{-2} TCSA is considered a high crop load.

This study shows that an appropriate balance between early cropping and vegetative growth can be achieved in high-density apple orchards of Gala and Braeburn cultivars grown on rootstock M9. A very high crop load of 30 and 40 fruits per tree resulted in a high fruit yield and good quality in the second growing year. This early high yield did not exert a negative influence on regular productivity in the following year. Furthermore, a heavier crop load induced a decrease in shoot growth, which is very important in high-density apple orchards.

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References

Awad AM, De Jager A, Dekker M, Jongen MFW (2001). Formation of flavonoids and chlorogenic acid in apples as affected by crop load. Sci Hortic-Amsterdam 91: 227–237.

Cmelik Z, Tojnko S, Unuk T (2006). Fruit quality of 'Fuji' apple as affected by crop load and rates of nitrogen. Acta Hort 721: 147–152.

Dennis FG (2000). The history of fruit thinning. Plant Growth Regul 31: 1–16.

De Salvador FR, Fisichella M, Fontanari M (2006). Correlations between fruit size and fruit quality in apple trees with high and standard crop load levels. J Fruit Ornam Plant Res 14: 113–122.

Dussi MC, Giardina G, Reeb P, De Bernardin F, Apendino E (2006). Fruit thinning effects in the apple cv. 'Royal Gala'. Acta Hort 727: 401–408.

Giuliani R, Corelli-Grappadelli L, Magnani E, Barrit BH (1997). Effect of crop load on apple photosynthetic response and yield. Acta Hort 452: 303–311.

Lakso NA, Wünsche NJ (2000). Apple tree physiology–implications for orchard and tree management. The Compact Fruit Tree 33: 82–88.

Lauri PÉ, Willaume M, Larrive G, Lespinasse JM (2004). The concept of centrifugal training in apple aimed at optimizing the relationship between growth and fruiting. Acta Hort 636: 35–42.

Link H (2000). Significance of flower and fruit thinning on fruit quality. Plant Growth Regul 31: 17–26.

Meland M (2009). Effects of different crop loads and thinning times on yield, fruit quality, and return bloom in *Malus X domestica* Borkh. 'Elstar'. J Hortic Sci Biotech ISAFRUIT Special Issue: 117–121.

Mpelasoka SB, Behboudian MH, Ganesh S (2001a). Fruit quality attributes and their interrelationships of 'Braeburn' apple in response to deficit irrigation and to crop load. Gartenbauwissenschaft 66: 247–253.

Mpelasoka SB, Behboudian MH, Green SR (2001b). Water use, yield and fruit quality of lysimeter-grown apple trees: responses to deficit irrigation and to crop load. Irrig Sci 20: 107–113.

Palmer JW (1992). Effects of varying crop load on photosynthesis, dry matter production and partitioning of Crispin/M.27 apple trees. Tree Physiol 11: 19–33.

Palmer JW, Giuliani R, Adams HM (1997). Effect of crop load on fruiting and leaf photosynthesis of 'Braeburn'/M.26 apple trees. Tree Physiol 17: 741–746.

Pretorius JJB, Wand SJE, Theron KI (2004). Fruit and shoot growth following combined girdling and thinning of 'Royal Gala' apple trees. Acta Hort 636: 401–407.

Robinson T, Osborne J, Fargione M (2008). Pruning, fertilization, chemical thinning and irrigation affect 'Gala' apple fruit size and crop value. Acta Hort 772*:* 135–142.

Saei A, Tustin DS, Zamani Z, Talaie A, Hall AJ (2011). Cropping effects on the loss of apple fruit firmness during storage: the relationship between texture retention and fruit dry matter concentration. Sci Hortic-Amsterdam 130*:* 256–265.

Stampar F, Veberic R, Zadravec P, Hudina M, Usenik V, Solar A, Osterc G (2002). Yield and fruit quality of apples cv. 'Jonagold' under hail protection nets. Gartenbauwissenschaft 67: 205–210.

Stopar M, Bolcina U, Vanzo A, Vrhovsek U (2002). Lower crop load for cv. Jonagold apples (*Malus domestica* Borkh.) increases polyphenol content and fruit quality. J Agric Food Chem 50*:* 1643–1646.

Treder W (2008). Relationship between yield, crop density coefficient and average fruit weight of 'Gala' apple. J Fruit Ornam Plant Res 16*:* 53–63.

Treder W, Mika A, Krzewińska D (2010). Relations between tree age, fruit load and mean fruit weight. J Fruit Ornam Plant Res 18: 139–149.

Unuk T, Cmelik Z, Stopar M, Zadravec P, Tojnko S (2008). Impact of early cropping on vegetative development and productivity of 'Golden Delicious' apple trees (*Malus domestica* Borkh). Europ J Hort Sci 73: 205–209.

Wright AH, Embree CG, Nichols DS, Prange RK, Harrison PA, Delong JM (2006). Fruit mass, colour and yield of 'Honeycrisp'™ apples are influenced by manually-adjusted fruit population and tree form. J Hortic Sci Biotech 81: 397–401.

Wünsche NJ, Greer HD, Laing AW, Palmer WJ (2005). Physiological and biochemical leaf and tree responses to crop load in apple. Tree Physiol 25: 1253–1263.

Wünsche JN, Palmer JW (2000). Effects of crop load on fruiting and gas-exchange characteristics of 'Braeburn'/M.26 apple trees at full canopy. J Amer Soc Hort Sci 125*:* 93–99.

Yuri JA, González Talice J, Verdugo J, del Pozo A (2011). Responses of fruit growth, quality, and productivity to crop load in apple cv. Ultra Red Gala/MM111. Sci Hortic-Amsterdam 127*:* 305–312.