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Impact of Early Cropping on Vegetative Development and Productivity of 'Golden Delicious' Apple Trees (*Malus domestica* Borkh)

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Summary

Investigations of the influence of early cropping on productivity and vegetative development of newly established 'Golden Delicious'/M.9 trees were conducted during three years after planting with the aim of determining the subsequent crop load dynamics according to different initial productivity of young trees. On the basis of the rate of natural fruit drop in the second growing year, three experimental groups were established: trees with intensive fruitlet natural June drop (group A) were further adjusted to 5 fruit tree^{-1}; medium fruitlet drop trees (group B) adjusted to 15 fruit tree^{-1}; and low fruitlet drop trees (group C) which were hand thinned to 25 fruit tree^{-1}. In the third growing year, the crop load was artificially thinned to 40, 60 or 80 fruit per tree. Trees of group A showed strong return bloom in the third growing year while weak flowering and low yield was observed in the fourth growing year (11–28 fruit tree^{-1}). In contrast to group A, trees of group C presented a constantly increasing yield tendency with no biennial bearing pattern: 66 flower clusters in the third growing year which were hand adjusted to 40, 60 or 80 fruit tree^{-1} gave nice return bloom and yield in the fourth growing year (63, 77 or 72 fruit tree^{-1}). Trees of group B adjusted to 40 or 60 fruit tree^{-1} in the third growing season responded with medium return bloom and, consequently, appropriate yield in the fourth growing year, while 80 fruit tree^{-1} adjustments or, on non-thinned trees, decreasing yield and biennial bearing tendency was observed. Trunk circumference increase on trees with higher crop load was smaller for all three bearing groups and was in the strongest negative correlation in the second year after planting the orchard.

Key words. apple – *Malus domestica* Borkh – crop load – growth – alternate bearing productivity

Introduction

Manipulation of vegetative growth/fruiting relationships in order to ensure high quality fruits and regular cropping is the objective of all apple production systems. For several decades, the use of intensive orchards has been proposed to improve early cropping and profitability (Lauri et al. 2004). Modern high-density orchards are designed to move quickly from the juvenile vegetative phase to a reproductive or fruiting phase (Luckwill 1970). It is generally accepted that all treatments which stimulate early yield can easily disrupt the delicate balance between growth and yield and lead to alternate bearing (Jones et al. 1989; Goldschmidt 2005). The problem of alternate bearing has been extensively studied (Jonkers 1979), because it affects both fruit quality and yield regularity (Buban and Faust 1982; Dennis 1986; Friderich et al. 1996).

Forshey and Elfwing (1989) and Bukovac (1981) provided an in-depth review of the close relationship between vegetative growth and fruiting in apple trees. As the crop load strongly controls the vegetative growth (Giuliani et al. 1997) and many other physiological processes in the fruit tree (Wibbe and Blanke 1995), early flowering and fruiting of dwarf trees may seriously affect the growth and cause a long term stunting of the tree, which may contribute to reduced tree size, poor tree structure and reduced yields for several years (Byers 2003). Orchard vigour, defined as the intensity of vegetative growth, is an important indicator for crop management in fruit tree cropping systems (Nesme et al. 2005).

This study was designed to examine the prospects of manipulating the vegetative/reproductive balance through regulation of early cropping in the first year after planting an apple orchard. A systematic trial was set to provide more detailed information on the influence of early cropping of apple trees with different initial productivity on vegetative development and later productivity of young trees. Based on intensity of natural spring fruitlet drop, three initial crop load groups of 'Golden Delicious'/M.9 trees were established to study the productivity and growth of trees in a newly established young orchard.

Material and Methods

Trial design

The trial took place at the Maribor Gačnik Fruit Growing Centre in Slovenia. The orchard was established in spring

2001 on new, orchard free land. The experiment was conducted over three years (2002 to 2004) using 'Golden Delicious'/M.9 (T337) at a spacing of 3.0×0.8 m. Trees were trained as slender spindles. The three-year-average of annual precipitation was 1050 mm. Nitrogen fertilizer was ground applied in the quantity of 60 kg N ha^{-1}, half in mid April and half at the beginning of May. The orchard was drip-irrigated 1–2 times weekly with the amount depending on weather situation.

The experiment was based on 156 young trees at the beginning of the second growing year. Uniform two-year-old plants were selected according to vegetative characteristics (5 lateral shoots, homogenous trunk circumference (<11 % standard deviation) and generative development (number of flower clusters = FC, number of fruitlets before June drop = CL_{BJD}) (Table 1). When counting the difference between CL_{BJD} and the crop load after the natural June drop (CL_{AJD}), trees were divided into three groups. Thirty percent of the trees had a very intensive fruitlet abscission (78 % of dropped fruit) and were selected into group A. Forty percent of the trees had a medium fruitlet abscission (60 % of dropped fruit) and were selected into group B. Thirty percent of the trees had a very low fruitlet abscission (40 % of dropped fruit) and were selected into group C (Table 1). After June drop (at a fruit diameter of 20 mm), fruit set was adjusted by hand in order to establish three levels of crop load: 5 (group A), 15 (group B) and 25 fruit $tree^{-1}$ (group C). Ten percent of randomly chosen trees in each of the groups represented non-thinned control trees (control A, control B, control C).

In the third growing year when June drop was completed, the crop load in each group was randomly adjusted to 40, 60 or 80 fruitlets $tree^{-1}$, representing about 50, 75 or 100 % of the potential crop load. The name of an individual treatment represents a combination of crop loads after fruit thinning (CL_{AFT}) in the second and the third growing year ($CL_{AFT\ 2nd}$ + $CL_{AFT\ 3rd}$) (Table 1). The fourth growing year was considered as a "control year", when no additional crop load regulation was carried out.

Data collection and statistics

Trunk circumference was measured annually 20 cm above grafting union. Cumulative trunk increase (measured from spring 2002 to fall 2004) was calculated at the end of the experiment. The yield (kg $tree^{-1}$) was recorded annually over three years and the cumulative yield per tree was calculated as a sum of the yields at the end of the experiment. The number of fruit per tree was recorded annually. Data were statistically calculated with one way analysis of variance (ANOVA with mean separations by Duncan's multiple range tests, P=0.05) using statistical package SPSS PC 14.0 for Windows.

Results

Return bloom

The crop load variants set in the 2nd growing year showed a significant effect on the return bloom data counted in the 3rd growing year (Table 1). Trees with the highest crop load adjusted in the second growing year (25 fruit $tree^{-1}$, group C) resulted with the lowest number of flower clusters (FC = 66 $tree^{-1}$) in 2003. Trees adjusted to the lowest crop load (5 fruit $tree^{-1}$, group A) resulted in the highest FC number (113 $tree^{-1}$) in the following year. Trees of group B resulted in a medium return bloom reaction (82 FC $tree^{-1}$). Also, in the fourth grow-

Table 1. The effect of tree selection in three initial cropping groups in the 2nd growing year and manual fruit thinning in the 3rd growing year on flower cluster number and crop load.

Growing year			2nd (2002)			3rd (2003)		Treatment	4th (2004)	
Year										
Parameter	FC	TC	CL_{BJD}	CL_{AJD}	CL_{AFT}	FC	CL_{AFT}	$CL_{AFT}2^{nd}$ + $CL_{AFT}3^{rd}$	FC	CL_{AJD}
Group A	25 a*	5.5 a	50 a	11 c	5	113 a	40	5–40	18 a	11 c
							60	5–60	18 a	28 a
							80	5–80	10 b	13 c
							NT=103	Control A	9 b	18 b
Group B	27 a	5.7 a	54 a	22 b	15	82 b	40	15–40	86 a	63 a
							60	15–60	59 b	52 a
							80	15–80	25 b	29 b
							NT=83	Control B	39 b	31 b
Group C	28 a	5.8 a	49 a	29 a	25	66 c	40	25–40	162 ab	63 b
							60	25–60	104 b	77 a
							80	25–80	96 b	72 ab
							NT=84	Control C	192 a	90 a

FC: flower clusters (number $tree^{-1}$), TC: trunk circumference (cm), CL: crop load (number of fruit $tree^{-1}$); BJD: before June drop; AJD: after June drop; AFT: after fruit thinning; NT: non-thinned control trees;
*different letters in a column indicate significant differences between means separated by Duncan's multiple range test (P=0.05)

ing year (control year 2004), return bloom was affected by flowering in the previous year. Trees of group A with the highest bloom in the 3rd year (113 FC) set flower clusters in the 4th year in the range of 9–18 FC tree^{-1}. Group C trees which flowered on average with 66 FC in 2003, exhibited a much higher return bloom (96–192 FC tree^{-1}). Trees of group B where medium flowering was measured in 2003 also reacted with medium return bloom in 2004 (25–86 FC tree^{-1}).

However, observing the trees inside each group, also a negative relationship between crop load adjusted in the previous year and return bloom in the fourth growing year was found. On group A trees, where crop load was adjusted to 40 or 60 fruit per tree (2003), return bloom was significantly higher (18 FC tree^{-1}) comparing to trees with 80 fruit per tree or non-adjusted (non-thinned) trees where return bloom was smaller (9 or 10 FC tree^{-1}). Also, the trees of group B exhibited better return flowering in the case of lower crop load adjustment in the previous year. Treatment 15–40 gave 86 FC while higher loaded treatments (15–60, 15–80) resulted in 25 or 59 FC tree^{-1}.

Group C trees with lower initial flower set in 2003 exhibited a very high return bloom in 2004, especially in the treatment with smaller crop load adjustment (25–40 gave 162 FC tree^{-1} while 25–80 gave 96 FC tree^{-1}). Non-thinned control trees of this group gave better return bloom than 25–60 or 25–80 trees.

Crop load and yield dynamic

In trees with the lowest initial productivity (group A), the crop load in the fourth year resulted in a very low final fruit retention number (CL_{AJD} =11–28) (Table 1). Considering the crop load in the year before (40–80 fruit tree^{-1}) this is estimated as biennial bearing pattern.

For the trees in group B, for the treatments 15–40 and 15–60, the final fruit retention in the fourth year indicated no biennial bearing pattern (CL_{AJD} = 63 and 52), while in two higher bearing treatments (15–80 and control B) a significant crop load decrease was observed (CL_{AJD} = 29 and 31).

In trees with the highest initial productivity (group C), increasing crop load dynamics was observed in almost all groups. Treatments 25–40, 25–60 and non-thinned control trees resulted in an enhanced fruit retention in the fourth year (CL_{AJD} = 63, 77 or 90, respectively). Only the treatment 25–80 showed a slight decrease of crop load from 80 fruit per tree in the 3rd growing year to 72 fruit per tree in the 4th growing year (Table 1).

Non-thinned control trees of the low or medium initial productivity group showed a strong fruit number oscillation in the 3rd and the 4th growing year (CL: 5 → 103 →18 and CL:15 → 83 →31), while non-thinned trees (control C) with high initial fruit retention potential achieved yields with increasing, non biennial bearing pattern (CL: 25 → 84 →90).

Crop load and tree development (vegetative growth)

Vegetative growth or orchard vigour is often measured with a single variable known as trunk cross-sectional area (TCSA) (Nesme et al. 2005) calculated out of trunk circumference (TC). The significance of relationships between final crop load and increase of tree trunk circumference is shown in Table 3. The influence of crop load on tree growth was the strongest in the second growing year. Trees of all three cropping groups together exhibited a strong negative correlation (R^2=0.79) between growth and final crop load probably because the differences in yield between groups A and C were the highest in the sec-

Table 2. Trunk circumference increase and yield of the 2nd to the 4th growing year.

Parameter / Treatment	TC increase (cm)			TC_{cum} (cm)	TC_{cum}AV (cm)	Yield (kg tree^{-1})			$Yield_{cum}$ (kg)	$Yield_{cum}$AV (kg)
Growing year	2nd	3rd	4th	2nd–4th		2nd	3rd	4th	2nd–4th	
5–40	2.1 a*	1.6 a	1.4 a	4.8		0.8 b	6.3 d	3.9 ab	10.7 c	
5–60	2.1 a	1.5 a	1.1 b	5.7		0.8 b	10.9 c	4.9 a	16.6 b	
5–80	2.1 a	1.2 b	1.3 a	5.6	5.4	0.8 b	12.5 b	2.6 b	15.9 b	14.4
Control A	1.8 a	1.3 b	1.3 a	5.3		2.2 a	14.7 a	3.1 b	19.9 a	
15–40	1.7 a	1.6 a	1.1 c	4.1		2.6 b	7.8 b	10.2 a	20.6 a	
15–60	1.7 a	1.8 a	1.6 ab	5.2		2.6 b	11.2 ab	8.6 b	22.6 a	
15–80	1.7 a	1.2 b	1.9 a	5.8	5.0	2.6 b	13.1 a	5.0 b	20.7 a	21.2
Control B	1.6 a	1.5 ab	1.5 b	4.5		2.9 a	12.7 a	5.6 b	21.1 a	
25–40	1.5 a	1.9 ab	0.6 c	3.7		4.0 b	7.2 c	11.3 a	22.3 a	
25–60	1.5 a	1.6 b	1.2 a	4.6		4.0 b	10.9 b	11.9 a	26.9 a	
25–80	1.5 a	1.9 ab	1.2 a	4.6	4.3	4.0 b	13.8 a	11.9 a	29.9 a	26.4
Control C	1.5 a	2.1 a	0.9 b	4.4		4.7 a	10.4 b	13.3 a	28.4 a	

TC: trunk circumference; TC_{cum}: cumulative trunk circumference (2002–2004); $Yield_{cum}$: cumulative yield tree^{-1} (2002–2004); AV: average for trees with regulated fruit number within an individual group)

*Different letters in the column of an individual group indicate significant differences between means separated by Duncan's multiple range test (P=0.05)

Table 3. Coefficients of determination (R^2) between growth and crop load of the 2nd to the 4th growing year.

Growing year	2nd	3rd			4th		
Year	(2002)	(2003)			(2004)		
Group	A, B and C	A	B	C	A	B	C
R^2	0.79	0.55	0.31	0.21	0.14	0.01	0.06

ond growing year (Table 2). In this year, trees of the medium crop load (group B) reached approximately 17 % lower TC increase and trees of the highest crop load (group C) 27 % lower TC increase comparing to the lowest crop load trees (group A) (Table 2).

In the third growing year coefficients of determination between growth and crop load were tested within each of the groups separately (Table 3). In group A and B in the 3rd growing year, trees with the highest crop load or yield (5–80; control A; 15–80; control B) exhibited a significantly smaller TC increase comparing to lower loaded trees where crop was adjusted to 40 or 60 fruit per tree (Table 2). The lowest coefficient of determination between growth and crop load was found in group C (R^2=0.21). Within this group the differences in TC increases can not be explained by crop load adjustments because of a too small correlation.

Coefficient of determination between final crop load and trunk growth was also very small for all three cropping groups in the 4th growing year (Table 3).

However, average cumulative trunk circumference increase was also higher in the group A (5.4 cm) where smaller cumulative yield (14.4 kg tree^{-1}) was observed (Table 2). By contrast, constantly higher bearing trees of group C (26.4 kg tree^{-1}) exhibited smaller cumulative TC increase (4.3 cm).

Discussion

The aim of this study was to examine the possibility of preventing alternate bearing in young apple trees by regulating crop load after natural June drop during the second and the third year after planting. In the second growing year, in spite of selecting the trees for uniformity, they showed a substantial and statistically significant difference in the degree of natural June drop, which we considered as different initial productivity. It is known, that trees have a mechanism to prevent an over crop load, but the mechanism of apple fruitlet abscission depends on many factors and their interactions, so it can not be easily predicted (Wertheim 1998). To a certain measure the difference in the initial productivity can be explained by the existing genetic variability. One of the practical consequences of these differences is that young plants at the beginning of the yield period eventually demand a highly specific crop load management approach otherwise the trees could easily get into alternate bearing.

Several authors reported that crop load significantly influenced vegetative growth (Palmer 1997), flower bud initiation and return bloom (Hansen 1971, 1987; Stopar 2000) and, consequently, the cropping regularity (Jonkers 1979; Buban and Faust 1982). The results presenting this three-year-trial indicate the importance of early crop load management in the first year after planting for further yield and growth development of young apple orchard on M.9 rootstock. When selecting the 'Golden Delicious' plants according to natural fruitlet drop in the 2nd growing year, low, medium or high natural fruit retention groups were further artificially set to 5, 15 or 25 fruit per tree, respectively. Trees of the first low bearing group (A) (5 fruit tree^{-1}) set a lot of flowers in the 3rd year and this could be one of the reasons for low return bloom and low yield in the 4th growing year. By contrast, trees of high fruit retention group C (25 fruit per plant) exhibited moderate flowering in the 3rd growing year and further good return bloom and yield in the 4th growing year. It seems that the typical alternate bearing was stimulated in the first group of trees and no alternance was observed on high initial bearing trees. The explanation of the biennial bearing apple behaviour was reported extensively by Monselise and Goldsmith (1982). The presence of flowers or fruit could inhibit flower bud induction on apples and prevent flowering in the following season; the earlier the flower/fruit is removed, the lesser inhibition of flower induction is expected. Some hormonal factors probably coming from developing apple fruitlet seeds are antagonistic to flower formation leading to alternate bearing (Tromp 2000). Trees of the first group (A) had very low flowering in the 4th year (9–18 FC tree^{-1}) because of high flower set in the previous year (113 FC tree^{-1}) while the last group of trees (C) demonstrated high flower set in the 4th year (96–192 FC tree^{-1}) because of appropriate flowering in the previous year (66 FC tree^{-1}).

Secondly, when taking into account the artificial fruit setting done in the 3rd year in each group, better return bloom was formed on trees previously thinned to lower fruit setting. Williams (1979) and Byers (2002) reported that hand fruitlet thinning in high crop years can be effective if performed sufficiently early during fruit development. Our trees were hand regulated at 15–20 mm fruit diameter and, according to Monselise and Goldsmith (1982), at the time still early enough to overtake flower inhibition produced by young fruitlets. Especially in the low initial bearing group, thinning to 40 or 60 fruit tree^{-1}in the 3rd growing year gave a significantly stronger return bloom in the 4th growing year comparing to treatment 5–80 or non-thinned control trees.

However, when flowering of the entire groups was compared, the higher initial bearing trees (group C) demonstrated much better return bloom in the 4th growing year (on all levels of fruit settings) comparing to flowering of low initial bearing trees (group A), probably because of strong involvement of flowering intensity in the previous year. Trees started with medium initial fruit set (group B) showed medium flowering in the 3rd year and also in the 4th year. Further, the return bloom in the 4th

year in this group was better for lower fruitlet setting treatment (15–40) comparing to higher loaded trees.

Therefore, the reason for strong yield oscillation in the first group, and the opposite continuously increasing yield with no alternate bearing tendency in the last group of trees is likely to be twofold: 1) prevention of flower bud induction was originated from low/medium/high flower set and 2) early enough fruitlet thinning to low/medium/high retention level can help to overcome the biennial bearing tendency.

According to the literature data, negative relationship between growth and crop load is expected (JONES et al. 1989; GIULIANI et al. 1997). Among others, WÜNSCHE et al. (2000) reported of a significant decreasing linear trend in leaf area from no crop to high-cropped trees. Our results confirm this statement partly. Negative influence of crop load on vegetative tree growth was evident for the second and partly for the third growing year, while in the fourth growing year this influence was less evident. Also, EMBREE et al. (2007) could not draw any conclusions whether current year thinning or previous year thinning was the main stimulator of vegetative growth. Three-year cumulative trunk growth in our study was smaller in groups of trees where higher cumulative yield was measured.

This study demonstrates the importance of crop load regulation immediately after planting and its influence on growth and productivity during the years of apple orchard establishment. It also raises questions about the differences in the initial productivity of the trees. It should be said that some fruit retention (25 tree^{-1}) on young trees was better than maintaining low or non-bearing trees in the second growing year. Appropriate bearing in the 2nd year inhibits excessive flowering in the 3rd year, which gave the base for good return bloom and yield in the 4th growing year. By contrast, very low fruitlet retention or too strong thinning in the year after planting could affect abundant flower formation (return bloom) in the 3rd growing year. In this case the fruitlet thinning in the 3rd year will probably not be successful enough to provide a satisfactory flower formation for the 4th year. However, a proper flower and fruitlet manipulation in the second growing year after planting is necessary to establish a continually increasing yield dynamics and good tree growth development for further seasons.

The current study also confirms the statement that heavy cropping inhibits the young tree growth, especially if they bear fruit in the second growing year; after that the relationship between growth and crop load is weaker.

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