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Effects of Different Blossom Densities and Crop Loads of 'Aroma' Apples (*Malus x domestica* Borkh) on Yield, Fruit Quality and Return Bloom

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ABSTRACT

Ten-year-old 'Aroma' on M26 rootstock were thinned when the first flower opened and at 20 mm fruitlet diameter to establish four different crop loads ranging from heavy crop load to fully deflowered. The planting distance was 1.4 × 4 m in single rows, shaped as slender spindle trees and limited to 2 m height by pruning. The manual-adjusted crop load treatments [0, 2, 4 and 6 fruits per cm^2 trunk cross sectional area (TCSA)] were applied over three consecutive seasons on the same individual trees. At harvest, mean yield per tree thinned at bloom varied from 0 to 23 kg and the mean fruit weight ranged from 114 g in the heaviest cropping treatment thinned at fruitlet, to 233 g in the lightest cropping treatment thinned at bloom. There were significant differences between the different treatments in final fruits per cm^2 TCSA and fruit set. Thinning at bloom to different crop levels gave a significant lower fruit set than thinning at the fruitlets stages to the same levels the first year. Thinning at fruitlets gave smaller fruits at the same crop level compared to bloom thinned. Fruit weight and soluble solid contents were largest at lowest crop load and decreased with increasing crop. Light cropping trees resulted in advancing of fruit maturity as indicated by less firmness and starch content. Seed amounts per fruit increased significantly by delayed thinning. Return bloom was more promoted when thinned at bloom. In conclusion, thinning to 6 fruits per cm^2 TCSA at bloom yielded annually large fruits of high quality. By thinning at fruitlet stage, the crop load must be reduced to 4 fruits per cm^2 in order to obtain similar results.

Keywords: biennial bearing, crop density, manual blossom and fruitlet thinning
Abbreviation: TCSA, trunk cross sectional area

INTRODUCTION

The apple cultivar 'Aroma' is a cross between the cultivars 'Ingrid Marie' and 'Filippa' and was bred at the plant breeding Centre Balsgård in Sweden in 1947. This cultivar was introduced to the fruit industry in 1979, and has proved ideal for growing premium fruit for the fall season in the northerly climate. This cultivar is now one of the largest cultivars based on production volumes in Scandinavia (Tahir *et al.* 2005). The cultivar has good flavor, is productive, tolerant to apple scab and can be used for certified organic apple production. Growing this cultivar, however, presents several challenges. The cultivar demands proper tree design for optimum light interception under Nordic environment with reduced light regime and to overcome biennial bearing due to high crop loads. Excessive cropping trees give easily a cycle of alternate season bearing with heavy crop one year with a large number of fruits of small and poor quality and the opposite the next year. Proper crop load management is important for having an annual, consistent production of high quality fruit for the market.

Information on crop load manipulation and fruit quality are of particular importance to growers for optimizing the crop load levels and for achieving desired qualities. Crop load is defined as the amount of fruit produced per tree and many factors are determining the crop load. Important factors are environmental factors like light and temperature, the availability of carbohydrate and crop management practises (Wűnsche and Ferguson 2005). The most important management practises that influence crop load and fruit quality are the effects of rootstocks and flower and fruitlet thinning.

Most apple cultivars bear abundant flowers and production practises to regulate the amounts of flowers or fruitlets are necessary to overcome alternate bearing, improve regular bearing and enhance fruit quality. Palmer *et al.* (1997) established different crop loads in the range from non-cropping to heavy crop on 4- year old 'Braeburn'/M26 trees. Decreasing yield improved fruit weight and advanced fruit quality. Similar results where found by Embree *et al.* (2007), thinning 'Honeycrisp' apples to different crop loads from untreated control trees to 3-9 fruit per cm^2 TCSA. Classical biennial bearing was observed on the untreated trees and fruit quality reduced. Consistent annual production was achieved by adjusting fruitlets to 6 fruits per cm^2 TCSA.

Reducing the number of fruit per tree increases the amount of leaf area per tree, hence the availability of assimilates to the remaining fruits. Flower bud formation and return bloom will be improved and lead to more consistent annual yield (Monselise and Goldschmidt 1982; Tromp 2000). Crop load reduction can be done either by a mechanical device, by hand or by applying plant growth regulators during bloom or at the fruitlet stage. The most common is a combination of chemical thinning and later hand-thinning for final corrections to the right crop load (Meland 1997). Research has shown that blossom thinning is more effective than fruitlet thinning alone in order to increase the potential for return bloom (Tromp 2000; Byer 2003). The optimal crop load is between 5-6 fruits per cm^2 TCSA and varies between cultivars (Robinson and Watkins 2003).

The objective of this study was to determine the influence of different crop load levels for 'Aroma' apple trees in order to achieve regular annual and uniform yield of high fruit quality grown in a Nordic environment.

Received: 5 March, 2010. Accepted: 6 January, 2011.

Original Research Paper

MATERIALS AND METHODS

Plant material and design

The study was conducted during three growing seasons (2003, 2004 and 2005) on 'Aroma' trees planted in 1993. The trees were grafted on M.26 rootstock planted at a spacing of 1.4 × 4 m in single rows and trained as slender spindle trees in a commercial orchard near Bioforsk Ullensvang, Western Norway at 60°N. The tree heights were limited to 2 m by pruning. Soil management combined frequently mown grass in the alleyways with 1m wide herbicide strips along the tree rows. Standard cultural management practices were conducted in the orchard like pest controls and nutrition according to commercial standards. Fourty two trees were arranged in a 2 × 4 factorial randomized tree design with six replications and blocked by the number of flower clusters per cm^2 TCSA. The trees were thinned at two stages when first flower opened and 20 mm fruitlet diameter to four different crop load levels; 0-2-4-6 flowers/fruitlets per cm^2 TCSA. The thinning level was limited to 1 flower/fruitlet per cluster. When shortage of amounts of return bloom in the second year, the thinning levels were increased to 2 flowers/fruitlets per cluster in order get the right crop load level. The same trees received the same crop load levels in the three successive growing seasons.

The number of flower clusters was counted per tree and trunk circumference was measured at 25 cm above the soil level. The crop was adjusted at bloom on May 27, May 12, May 24 and at 20 mm fruitlet diameters on June 27, June 18 and 25 in 2003, 2004 and 2005, respectively.

Harvest, yield, quality and return bloom

Fruits on each tree were harvested at commercial harvest time all by the end of September. The number and total weight of fruit per tree, graded into two classes (> 60 mm diameter and < 60 mm) were recorded. Number of recent drops were counted and assumed to be of average fruit weight. A sample of 10 randomly selected fruits from the larger size classes from each experimental tree was used to determine maturity and inner fruit quality parameters (fruit weight, firmness, scores for background and surface colour, soluble solids, starch content and seed amounts) right after harvest. Flesh firmness was measured by a digital penetrometer with 11 mm probe (Penefel, CTIFL France) and the percentage of soluble solids by an Atago hand refractometer (using juice collected from the measurements of flesh firmness). The starch-iodine score was measured by spraying both halves of each fruit with 0.1 M iodine solution and giving scores for starch content (1 = all tissues stained black to 10 = no staining or starch present). Background colour was given as scores on a scale from 1-9 where 1 = dark green and 9 = bright yellow. Similar scores were given for % area coloured red, where1 = no red colour and 9 = red colour covering the surface completely.

Numbers of seed per apple were counted and weighted. In the springs of 2004, 2005 and 2006 the total number of flower clusters was recorded per tree as return bloom at pink bud stage in May.

Statistical analysis

The data was evaluated by using the ANOVA procedure in the statistical program Minitab 15 statistical software (Minitab Inc., USA) testing the difference between the crop loads parameters. The main effects of thinning time and tinning level were analyzed for linear trends. Regression analysis was used to examine the relationships between mean fruit weights and crop load (fruits per cm^2 TCSA). Unless noted otherwise, only results significant at $P \leq 0.05$ are discussed.

RESULTS

Fruit set, crop load and return bloom

Both the trunk girth and the average number of flower clusters per tree were uniform at the start of the experiment and no significances were found for either parameter (**Table 1**).

Flower and fruitlet thinning resulted in crop loads ranging from zero on deflowered trees to 149 fruits on the high cropping trees in the first season. The crop loads showed significant differences between the different crop load levels. The final crop level expressed as fruit set when thinned at bloom was less than when thinned at the fruitlet stage to the same level, and did not reach the final levels aimed for. The crop adjustment treatments resulted in differences between the yields. However, there were no differences between the total yields for the same levels for the two thinning times due to increasingly larger fruits when bloom thinned. The amount of class 1 fruit decreased with increasing crop load level.

In the second season there were no differences in the amount of return bloom between treatments irrespective of thinning time and crop level. All trees had enough blossoms in order to establish the different crop levels (**Table 2**). The number of flower clusters per tree doubled compared to the previous year. Thinning at bloom did not reach the final fruit number per cm^2 TCSA as planned reaching only the half level for the highest crop load. At fruitlet thinning the final crop level was more in accordance with estimated crop loads. There was no effect of the timing of thinning, but total yield increased with increasing crop loads. The highest crop load thinned at fruitlet time gave lower percentage of grade 1 fruits. For all treatments, the total yield was at the same levels as the year before.

In the third season there was a significant reduction in the amount of return bloom when thinning to the highest crop levels at the fruitlet time the year before (**Table 3**). The trees thinned at bloom had similar return bloom, independent of crop load levels the year before. However, when thinned at fruitlet stage, the amount of return bloom declined with increasing crop loads. This third season the crop loads as number apples per tree, fruit set and final number of fruits per cm^2 were in accordance with the crop levels

Table 1 The effects of handthinning at two stages when first flower opened and at 20 mm fruit diameter at different crop levels (flower/fruitlets no. cm^{-2} TCSA) on number of flower clusters and fruit number per cm^2 trunk cross sectional area, fruit set and crop load of 'Aroma' apples in 2003. Abbreviation: LSD = least significant difference.

Time	Crop level	No flower clusters per tree	No flower clusters/fruitlets per cm^2 TCSA[1)]	No apples per tree	Fruits no. per 100 clusters	Final no. fruits/ cm^2 TCSA[1)]	Yield. kg per tree	Yield. % >60 mm
Bloom	0	145	5.8	-	-	-	-	-
	2	156	6.8	51	36	2.1	10.9	100
	4	137	7.2	66	51	3.1	13.3	100
	6	157	6.7	115	74	4.6	19.3	99
Fruitlet	2	147	6.9	77	51	3.1	13.8	100
	4	138	5.5	103	64	4.2	15.2	90
	6	196	7.6	149	82	5.5	17.8	85
$LSD_{0.05\%}$		NS	NS	26	28	0.9	3.7	8
Linear time[2)]		NS	NS	***	***	***	NS	**
Linear level		NS	NS	***	***	***	***	***

[1)] TCSA: Trunk cross sectional area

[2)] NS, *,**,*** indicate no significant or significant factors at p=0.05, 0.01 or 0.001

Table 2 The effects of hand-thinning at two stages when first flower opened and at 20 mm fruit diameter at different crop levels (flower/fruitlets no. cm^{-2} TCSA) on number of flower clusters and fruit number per cm^2 trunk cross sectional area, fruit set and crop load of 'Aroma' apples in 2004.

Time	Crop level	No flower clusters/tree. Return bloom	No. flower clusters/per cm^2 TCSA[1)]	No. apples/tree	Fruit no./100 clusters	Final no. fruits/cm^2 TCSA[1)]	Yield kg/tree	Yield % >60 mm
Bloom	0	337	11.3	-	-	-	-	-
	2	331	11.9	69	21	2.4	8.8	100
	4	316	14.5	85	28	3.7	10.7	99
	6	362	13.3	82	23	3.0	14.2	100
Fruitlet	2	363	13.1	80	22	2.9	15.2	100
	4	347	13.3	101	32	3.9	13.7	98
	6	317	12.2	142	70	4.3	17.5	85
$LSD_{5\%}$		NS	NS	29	8	0.8	4.7	18
Linear time		NS	NS	**	***	NS	NS	NS
Linear level		NS	NS	***	***	***	***	***

[1)] TCSA: Trunk cross sectional area

Table 3 The effects of hand-thinning at two stages when first flower opened and at 20 mm fruit diameter at different crop levels (flower/fruitlets no. cm^{-2} TCSA) on number of flower clusters and fruit number per cm^2 trunk cross sectional area, fruit set and crop load of 'Aroma' apples in 2005 and return bloom in 2006.

Time	Crop level	No. flower clusters/tree. Return bloom	No. flower clusters/per cm^2 TCSA[1)]	No. apples/tree	Fruit no./100 clusters	Final no. fruits/cm^2 TCSA[1)]	Yield kg/tree	Yield % >60 mm	Return bloom 2006 no. flower clusters/tree
Bloom	0	237	10.0	-	-	-	-	-	93
	2	256	9.4	69	29	2.4	14.7	99	90
	4	212	9.8	96	54	4.2	18.2	99	79
	6	228	8.6	148	67	5.3	23.0	99	76
Fruitlet	2	206	8.0	80	40	3.1	14.1	100	85
	4	178	7.0	128	80	4.8	16.4	89	73
	6	162	5.2	159	106	4.9	19.8	93	62
$LSD_{5\%}$		83	3.4	14	29	1.2	5.3	10	10
Linear time		NS	NS	NS	**	NS	NS	NS	*
Linear level		*	NS	***	***	***	***	***	***

[1)] TCSA: Trunk cross sectional area

Table 4 The effects of hand-thinning at two stages when first flower opened and at 20 mm fruit diameter on fruit quality and seed weight and amount of 'Aroma' apples in 2003.

Time	Crop level	Fruit weight g	Fruit firmness	Soluble solids %	Ground colour[1)]	Surface Colour[2)]	Starch content[3)]	Seed weight g	Seed no./fruit
Bloom	2	223	5.8	12.7	1.6	6.4	7.2	0.148	2.4
	4	213	6.0	12.4	1.6	6.5	7.4	0.144	2.6
	6	163	6.0	11.2	1.6	6.3	8.1	0.103	1.4
Fruitlet	2	148	6.2	12.1	1.5	6.0	7.6	0.230	3.5
	4	146	6.4	11.8	1.9	6.8	8.0	0.244	4.2
	6	114	6.2	11.1	1.5	6.3	8.8	0.281	4.7
$LSD_{0.05\%}$		32	0.2	0.4	0.2	0.6	0.5	0.05	0.9
Linear time		***	***	***	**	NS	***	***	***
Linear level		***	**	***	**	*	***	NS	NS

[1)] Ground colour scores 1-9, where 1 = dark green and 9 = bright
[2)] Surface colour scores 1-9, where 1 = no red colour and 9 = red colour covering the surface complete.
[3)] Iodine starch test scores 1-10, where 1 = dark and 10 = white (no starch)

established at bloom and at fruitlet. Total yield increased with the crop levels established, but there was no significant differences between the timing for crop adjustments. The percentage of large fruits was reduced at the largest crop levels thinned after bloom as in previous years.

The amount of return bloom after the third cropping season (2005) was less than in previous years. However, the pattern was repeated with significantly more flower clusters on the tree which was thinned at bloom and at the lowest crop load levels.

Fruit quality and seed amount

Thinning at bloom increased significantly the fruit weights compared to thinning one month later in all the three experimental years (**Tables 4, 5, 6**). The highest crop level (6 fruits per cm^2 TCSA) correlated with the smallest fruits, which reflected the reduction in amount of class one fruits. When thinning after bloom, significant smaller fruits were recorded at harvest. The increase in the individual fruit weights at the lowest crop load adjustments did not compensate for the reduction in total yield in kg. The correlation between crop load [(fruit per cm^2 TCSA), (x)] and mean fruit weight (y) was linearly and negatively correlated, accounting for 52% of the variance (**Fig. 1**). The different harvest criteria were slightly influenced by thinning time with less firm fruits, higher soluble solid concentration and less starch content when thinned early. The soluble solid increased significantly with decreasing crop load and the fruit were less mature at the highest crop levels all the three years. Neither surface colour nor background colour was influenced by the different crop loads and time of thinning in any of the three years. In the last two years there was no starch left in the fruits and no difference between treatments found. However, there were large differences between the treatments in seed number and seed weight per fruit. Fruits thinned at fruitlet had significantly more seeds per fruit in all three cropping years. The seed numbers differed from less than one per fruit to five on average for the treatments. Seed weight reflected the seed numbers with averagely double seed weight when thinned late compared to bloom thinned.

Table 5 The effects of hand-thinning at two stages when first flower opened and at 20 mm fruit diameter on fruit quality and seed weight and amount of 'Aroma' apples in 2004.

Time	Crop level	Fruit weight. g	Fruit firmness	Soluble solids %	Ground colour[1)]	Surface Colour[2)]	Starch content[3)]	Seed weight g	Seed no./fruit
Bloom	2	200	5.2	13.0	1.4	3.6	10	0.040	0.6
	4	183	5.2	12.3	1.2	3.3	10	0.027	0.5
	6	182	5.1	12.7	1.3	3.9	10	0.048	0.7
Fruitlet	2	174	5.1	12.2	1.1	3.5	10	0.124	2.0
	4	121	5.6	11.8	1.2	4.0	10	0.118	2.2
	6	116	5.5	12.0	1.5	4.6	10	0.148	2.6
$LSD_{5\%}$		15	0.2	0.2	0.2	0.6	NS	0.46	0.8
Linear time		*	***	***	NS	*	NS	***	***
Linear level		***	***	***	NS	***	NS	NS	NS

1) Ground colour scores 1-9, where 1 = dark green and 9 = bright
2) Surface colour scores 1-9, where 1 = no red colour and 9 = red colour covering the surface complete.
3) Iodine starch test scores 1-10, where 1 = dark and 10 = white (no starch)

Table 6 The effects of hand-thinning at two stages when first flower opened and at 20 mm fruit diameter on fruit quality and seed weight and amount of 'Aroma' apples in 2005.

Time	Crop level	Fruit weight g	Fruit firmness	Soluble solids %	Ground colour[1)]	Surface Colour[2)]	Starch content[3)]	Seed weight g	Seed no./fruit
Bloom	2	219	5.6	12.7	5.2	2.9	10	0.074	1.1
	4	186	5.4	12.6	5	3.6	10	0.084	1.3
	6	151	5.4	11.8	4.8	3.9	10	0.060	0.7
Fruitlet	2	166	5.6	12.8	5.6	3.8	10	0.111	1.7
	4	123	5.8	12.2	5.5	4.4	10	0.173	2.9
	6	121	6	12	5.8	4.9	10	0.154	2.4
$LSD_{5\%}$		31	0.2	0.2	0.5	1.0		0.045	0.7
Linear time		***	***	NS	***	***	NS	***	***
Linear level		***	NS	***	NS	***	NS	NS	NS

1) Ground colour scores 1-9, where 1 = dark green and 9 = bright
2) Surface colour scores 1-9, where 1 = no red colour and 9 = red colour covering the surface complete.
3) Iodine starch test scores 1-10, where 1 = dark and 10 = white (no starch)

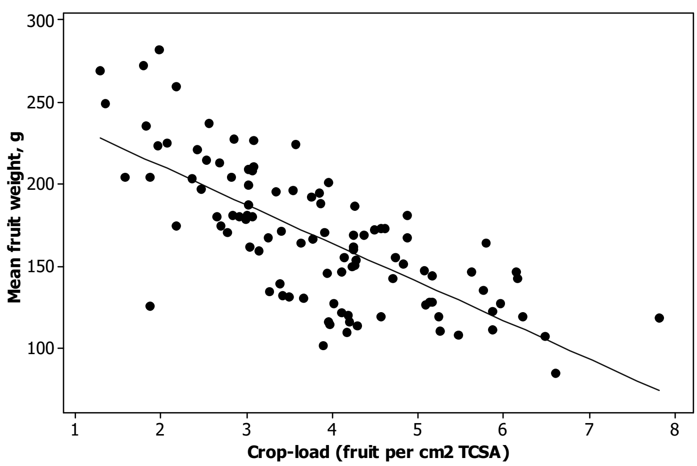

Fig. 1 Linear regression analysis (excluding deflowered controls) between crop load (fruit per cm^2 TCSA; x) and mean fruit weight (in g; y) for combined data from 2003, 2004 and 2005. y = -23.5 x +257; r^2 = 0.52.

DISCUSSION

In order to overcome biennial bearing and enhance fruit quality, thinning at blossom or fruitlet are the most important management tools growers have. Commercially thinning is done mainly by chemical applications. Mechanical devices to aid in thinning have been developed, but none has up to now proven to be highly efficient and capable of completely replacing hand thinning (Schupp *et al.* 2008). However, there is limited number of approved blossom thinning agents available on the market and research into more friendly thinning agents is still in its early stage (Embree *et al.* 2007). This study used hand-thinning to adjust blossom/fruitlet numbers which is time-consuming and costly, but the only way for adjusting crop levels accurately.

The average number of flower clusters per tree was less the first year at the start of the experiment compared to the two following years. Likely the crop load on the trees was too high the previous year and the trees were in the "off" year. However, there were enough flowers to get a sufficient fruit set at the different levels.

By thinning at bloom to a given crop load, it is more difficult to evaluate the right cropping level compared to thinning later. Not all the flowers will set and the final fruit set will be less. To obtain similar final crop level at harvest with bloom and fruitlet thinning, higher numbers of flowers have to be left on the trees. In this study the final crop levels thinned at bloom was less than when thinned at fruitlet time to the same level and did not reach the final level aimed for any of the three years. In addition the final fruit set was less to the point for the aim of thinning levels, especially for the largest crop loads at both thinning times. Likely the crop load was too high and fruitlet abscission increased. Wűnsche and Palmer (1997) have reported that bloom thinning by hand resulted in fewer final numbers of fruit at harvest compared to later thinning times. Fruit drop is therefore likely dependent on crop density and may indicate a shortage of carbohydrate supply, particular at higher crop loads during early fruit development stage. Bloom thinning should improve carbohydrate-supply and lead to less fruitlet drop.

Fruit weight at harvest was negatively correlated with crop load. Fruit weight was largest when there was a minimum competition between fruits (Palmer *et al.* 1997). This was confirmed in this study where thinning at bloom rather than at fruitlet stage, improved fruit weight and fruit quality when comparing similar crop levels.

Fruit from light cropping trees were sweeter than fruit from high cropping trees in all three years. Similar results are reported from investigations of the effect of thinning agents and crop load studies. Low cropping trees have almost always larger fruit and greater soluble solids concentrations in the flesh juice at harvest (Meland 1997; Wűnsche *et al.* 2005). However, firmness was improved by thinning at the fruitlet stage and with increasing crop load. The low cropping trees had softer fruits and the maturity was more advanced in the first season due to less starch content. Similar results were found with 'Braeburn' apples (Palmer *et al.* 1997; Wűnsche *et al.* 2000).The other seasons all the starch was converted to sugar for all the treatments by the time of harvest. Advanced maturity in light cropping trees is indicated by higher ethylene concentrations (Franscesconi *et al.* 1996) and a more yellow background and surface colour (Palmer *et al.* 1997). The improvement of fruit colour was surprisingly little, irrespective of treatments. The sugar content was high enough to meet consumer's acceptance.

Return bloom was enhanced by thinning early to a low crop load all the three years. These finding are confirmed by several other experiments finding that delaying post bloom thinning by more than one month improved alternate bearing (Harley *et al.* 1942; Jonkers 1979). These results are likely related to the carbohydrate supply. A low leaf/fruit ratio limits the carbohydrate availability for bud development and growing fruits are likely the strongest sink (Wűnsche and Ferguson 2005). Plant hormones have also an inhibitory effect on flower formation, particular gibberellins in apple seeds (Chan and Cain 1967; Luckwill *et al.* 1969). Thinning at early bloom reduces the competition for photosynthetic and favour flower initiation of next year's crop.

CONCLUSIONS

Thinning at bloom improved the fruit size and fruit quality at the same crop level compared to thinning one month later. Low crop load gave larger fruits, higher soluble solid contents and more coloured fruits. The amount of return bloom declined with increased crop loads on the trees the year before and by thinning at fruitlet stage. Thinning to 6 fruits per cm^2 TCSA at bloom gave annual yield of large fruits of high quality. By thinning at the fruitlet stage, the crop load must be reduced to 4 fruits per cm^2 in order to obtain similar results.

ACKNOWLEDGEMENTS

The author thanks the Norwegian Research Council for financing the work. Also I would like to thank Magne Eivind Moe for technical assistance in the field work, Sigrid Flatland for the fruit quality assessment work and other staff as well at Bioforsk Ullensvang for field management.

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