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Effects of different crop loads and thinning times on yield, fruit quality, and return bloom in *Malus* × *domestica* Borkh. 'Elstar'

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SUMMARY
'Elstar' is the latest-maturing commercial apple cultivar grown in Norway, with high fruit quality when properly managed. In May 2006, an experiment with four different crop loads [2, 4 ,6, or 8 flowers or fruitlets cm^{-2} trunk cross-sectional area (TCSA), respectively] was established at two different stages [first bloom (FB), or 20-mm diameter fruitlets] and compared to unthinned control trees. Fruit growth was measured on individual fruit for each treatment throughout the season at weekly intervals. Thinning at FB gave a significantly lower final percentage fruit set than thinning to the same cropping level at the 20-mm fruitlet stage. However, fruit weights and soluble solids contents (SSC) were significantly higher, and the background fruit colour improved when trees were thinned at FB. The final number of fruit at harvest was less than the amount established at FB, or at the 20-mm fruitlet stage. There were significant differences between treatments in final fruit numbers per TCSA, which reflected the different crop loads. Fruit weights and SSC values were highest with the lowest crop load, and decreased with increasing crop loads. There was also a strong crop-load effect on the extent of return bloom per tree in the subsequent year. Trees thinned at FB had significantly more flower clusters than those thinned at the 20-mm fruitlet stage of. Untreated control trees had the lowest number of flower clusters. The amount of return bloom declined with increasing crop load. Second year crop loads and fruit weights were highest when trees were thinned at FB to two or four apples cm^{-2} TCSA in the previous year. Trees with the highest crop load had the lowest crop load in the following year. Fruit quality was generally high for all treatments.

'Elstar' is the latest maturing commercial apple cultivar (*Malus* × *domestica* Borkh) grown in Norway, which results in high quality fruit when properly maintained. Information on crop load manipulation and fruit quality are of particular importance to growers in order to optimise the number of fruit per tree to achieve the desired fruit qualities. Crop load is defined as the number of fruit produced per tree. Many factors determine crop load including environmental factors such as light and temperature, the availability of photosynthate, and crop management practices (Wűnsche and Ferguson, 2005).The most important orchard management practices that influence crop load and fruit quality are the effects of rootstock, and flower and fruitlet thinning. Rootstock has effects on tree size and crop density, which normally increase with increasing rootstock vigour. Dwarfing rootstocks such as M.9 are known for their high yield efficiency and more regular flowering than more vigorous rootstocks (Wertheim, 1998).

Most apple cultivars have an over-abundant flower density and percentage fruit set. Production practices to regulate the numbers of flowers or fruitlets are therefore necessary to overcome alternate bearing and to enhance fruit quality. Palmer *et al.* (1997) established different crop loads, from completely de-flowered to heavily fruiting, on 4-year-old 'Braeburn'/M.26 trees. A low crop load decreased fruit yield, but improved fruit weight and fruit quality. Similar results where found by Embree *et al.* (2007), who thinned 'Honeycrisp' apple trees to different crop loads, from untreated trees down to nine fruits cm^{-2} trunk cross-sectional area (TCSA). Alternate bearing was observed on untreated trees, and their fruit quality was low. Consistent annual production was achieved by thinning to six fruits cm^{-2} TCSA.

Reducing the number of fruits per tree increases the relative amount of leaf areas per fruit, and hence the availability of photo-assimilates for the remaining fruit. This also improves flower bud induction and return bloom, and leads to more consistent annual yields (Monselise and Goldschmidt, 1982; Tromp, 2000). A reduction in crop load can be achieved mechanically, by hand, or by applying plant growth regulators at first bloom (FB), or at the fruitlet stage. The most common treatment is a combination of chemical thinning followed by hand-thinning, for a final adjustment to the correct crop load (Meland, 1997).

The objective of this study was to investigate the most appropriate crop load for 'Elstar' apple trees, in order to achieve a reliable annual yield of high quality fruit grown under Nordic conditions.

MATERIALS AND METHODS

A field experiment was carried out in a commercial orchard near Bioforsk Vest Ullensvang, Norway, using the apple cultivar 'Elstar' grafted to M.9 rootstock in May 2006. The trees were planted in 1992 at a spacing of 1.24 m × 4.00 m and trained as slender-spindle trees. Tree height was limited to 2 m. Soil management consisted of frequently mown grass in the alleyways, with 1-m-wide, herbicide-treated strips along the tree rows. Standard

TABLE I

Effects of hand-thinning at first bloom (FB), or at 20-mm fruitlet diameter, on the number of flower clusters and fruits cm^{-2} trunk cross-sectional area (TCSA), fruit set, crop load, and fruit quality in 'Elstar' apple trees in 2006

Thinning treatment	No. flower clusters/ fruitlets cm^{-2} TCSA	Final no. fruits cm^{-2} TCSA	Fruit no. per 100 clusters	Yield (kg per tree)	Fruit weight (g)	Yield (% > 60 mm)	Soluble solids content (%)	Ground colour[+]	Starch content[#]
First bloom	7.6	3.8	55	19.5	147	88	12.9	4.8	3.6
20 mm-Fruitlet stage	6.6	4.3	73	20.1	130	87	12.6	4.4	4.0
F test[§]	NS	NS	**	NS	**	NS	***	***	***

[+]Ground colour scores 1-9, where 1 = dark green and 9 = bright yellow.
[#]Iodine starch test (scores 1-10), where 1 = dark and 10 = white (no starch).
[§]NS, *,**,*** indicate not significant, or significant at $P = 0.05$, $P = 0.01$ or $P = 0.001$.
All values are the average of five different crop levels.

orchard management practices such as pest and disease management control and nutrition applications were conducted according to commercial standards.

The experimental design was 2 × 5 factorial. Trees were thinned at two stages of growth: at FB when the first flowers opened (May 2 and May 10), or at the 20-mm fruitlet diameter stage (July 4 and June 14) in 2006 and 2007, respectively. Five crop levels were used, unthinned or thinned to 2, 4, 6 or 8 flowers or fruitlets cm^{-2} TCSA. Except for the lowest crop load, all trees were thinned to two flowers or fruits per cluster in 2007, due to a shortage of flower clusters per tree. In order to obtain the same crop at harvest as when thinning 20-mm fruitlets, 20% more flowers were left on the trees compared these to thinned after FB. Each treatment had six replications, thus 60 trees were included in the whole experiment.

The number of flower clusters per tree was counted and the circumference of the trunk was measured 25 cm above soil level, to calculate TCSA. The experiment was blocked by the number of flower clusters cm^{-2} TCSA. Fruit growth was measured on ten representative fruits on each tree, for each treatment, in 2006. Measurements started when the fruit were approx. 10 – 14 mm in diameter, and were carried out twice a week over the first month, then weekly until early September, with a final measurement at harvest.

Commercial harvest was on 15 October and 23 October in 2006, and 12 October and 23 October in 2007. The numbers and total weights of fruit per tree, graded into two classes (> 60 mm in diameter, and < 60 mm in diameter) were recorded. The number of recent fruit drops were also counted, and assumed to be of average fruit weight. A sample of ten fruit selected at random from each experimental tree at first harvest was used to measure both external and internal fruit quality (i.e., fruit weight, fruit firmness, visual scores for background and surface colour, SSC, starch content, and seed weight). Flesh firmness was measured using a digital table penetrometer with an 11-mm probe [Penefel; Centre Technique Interprofesionnel des Fruits et Legumes (CTIFL), Paris, France]. SSC (%) was measured using an Atago hand-held refractometer, on juice collected during the measurements of flesh firmness. Starch-iodine scores were measured by spraying two apple halves with 0.1 M iodine solution and scoring for starch content on a 10-point scale, where 1 = all tissue stained black, to 10 = no staining or starch present. Background colour scores were made on a nine-point scale, judged by one person, where 1 = dark green, and 9 = bright yellow. Similar scores where used for the percentage of the surface area coloured red, where 1 = no red colour, and 9 = fully covered with red colour. Each following Spring, the total number of flower clusters per tree was counted as return bloom.

Statistical analyses were carried out using Minitab 15 statistical software (Minitab Inc., State College, PA, USA)

RESULTS

Both TCSA and the average number of flower clusters per tree were uniform at the start of the experiment in 2006 (Table I; Table II).

Thinning at FB resulted in a significantly lower percentage fruit set than thinning at the 20-mm fruitlet stage, at both of the different thinning levels. However, there were no differences between fruit yields, or the number of Class 1 fruit. However, thinning at FB resulted in higher average fruit weights, and improved SSC and background colour value scores.

On average, for all the different thinning levels, the final numbers of fruit at harvest were less than the number established at FB, or at the 20-mm fruitlet stage (Table II). These reductions were largest for the highest

TABLE II

Effects of hand-thinning at five different crop levels (unthinned, or 2, 4, 6, or 8 flowers or fruitlets cm^{-2} TCSA) on the numbers of flower clusters and fruits cm^{-2} TCSA, fruit set, crop load, and fruit quality in 'Elstar' apple trees in 2006

Thinning treatment	No. flower clusters/ fruitlets cm^{-2} TCSA	Final no. fruits cm^{-2} TCSA	Fruit no. per 100 clusters	Yield (kg per tree)	Fruit weight (g)	Yield (% > 60 mm)	Soluble solids content (%)	Ground colour[+]	Starch content[#]
Unthinned (control)	7.3	6.8	102	25.1	97	62	12.4	3.7	5.1
2	7.2	1.8	30	12.8	175	100	13.4	5.3	2.9
4	6.8	3.0	50	20.2	158	98	12.9	5.2	3.0
6	7.1	3.8	61	19.9	132	92	12.7	4.5	3.8
8	7.2	5.0	80	21.2	128	87	12.5	4.2	4.3
F test[§]	NS	***	***	***	***	***	***	***	***

[+]Ground colour scores 1–9, where 1 = dark green and 9 = bright yellow.
[#]Iodine starch test (scores 1–10), where 1 = dark and 10 = white (no starch).
[§]NS, *,**,*** indicate not significant, or significant at $P = 0.05$, $P = 0.01$ or $P = 0.001$.
All values are the average of five different crop levels.

TABLE III

Effects of hand-thinning at first bloom or at the 20-mm fruit diameter stage on return bloom, number of flower clusters and fruit number cm^{-2} trunk cross-sectional area (TCSA), fruit set, and crop load in 'Elstar' apple trees in 2007

Thinning treatment	Return bloom (No. flower clusters per tree)	Return bloom (No. flower clusters cm^{-2} TCSA	Final no. fruits cm^{-2} TCSA	Fruit no. per 100 clusters	Yield (kg per tree)	Fruit weight (g)	Soluble solids content (%)	Ground colour[+]	Starch content[#]
First bloom	67	1.7	1.7	99	7.7	138	13.9	5.2	4.5
20 mm- fruitlet	22	0.6	0.6	90	3.2	124	14.5	5.9	4.0
F test[§]	***	***	**	NS	***	NS	***	***	*

[+]Ground colour scores 1–9, where 1 = dark green and 9 = bright yellow.
[#]Iodine starch test (scores 1–10), where 1 = dark and 10 = white (no starch).
[§]NS, *,**,*** indicate not significant, or significant at $P = 0.05$, $P = 0.01$ or $P = 0.001$.
All values are the average of five different crop levels.

TABLE IV

Effects of hand-thinning at five different crop levels (unthinned or 2, 4, 6, or 8 flowers or fruitlets cm^{-2} TCSA) on return bloom, the numbers of flower clusters and fruits cm^{-2} TCSA, fruit set and crop load in 'Elstar' apple trees in 2007

Thinning treatment	Return bloom (No. flower clusters per tree)	Return bloom (No. flowers clusters cm^{-2} TCSA)	Final no. fruits cm^{-2} TCSA	Fruit no. per 100 clusters	Yield (kg per tree)
Unthinned (control)	13	0.3	0.5	60	2.3
2	106	2.7	2.0	97	11.0
4	64	1.6	1.7	152	9.4
6	25	0.7	0.7	71	2.8
8	13	0.4	0.4	88	1.9
F test[§]	***	***	**	*	***

[§]NS, *,**,*** indicate not significant, or significant at $P = 0.05$, $P = 0.01$ or $P = 0.001$.
All values are the average of five different crop levels.

crop load. However, there were significant differences in the final numbers of fruit cm^{-1} TCSA between the different treatments, which were correlated with the different crop levels. Due to having smaller fruit at the higher crop loads, there were small differences in overall yield. The numbers of Class 1 fruit, as well as fruit weights and SSC values, decreased with increasing crop load. Fruits from untreated trees had the lowest ground-colour scores and starch contents.

Seasonal fruit growth patterns showed the effect of increased fruit size when fruit thinning was conducted early in the season (Figure 1). On average, the five cropping levels, showed the clear effect on increased fruit size during the season. As expected, the lowest crop load gave the largest fruit. Fruit diameters decreased with increasing crop load (Figure 2).

In 2007, there was a strong effect of crop load in the previous year on return bloom per tree (Table III). Trees thinned at FB had significantly more flower clusters than trees thinned at the 20-mm fruitlet stage. Untreated control trees, and those with the highest crop load (8 fruit cm^{-2} TCSA), had the lowest number of flower clusters (Table IV). Return bloom declined with increasing crop load. These trees did not have enough flower clusters or fruitlets to establish a similar level of crop load as in 2006.

On average, all the different thinning levels tested resulted in a fruitset of approx. one fruit per cluster. However, yields and fruit weights were greater when trees were thinned at FB. The highest crop load was achieved when trees were thinned to two or four apples cm^{-2} TCSA at FB. Trees with the highest crop load in

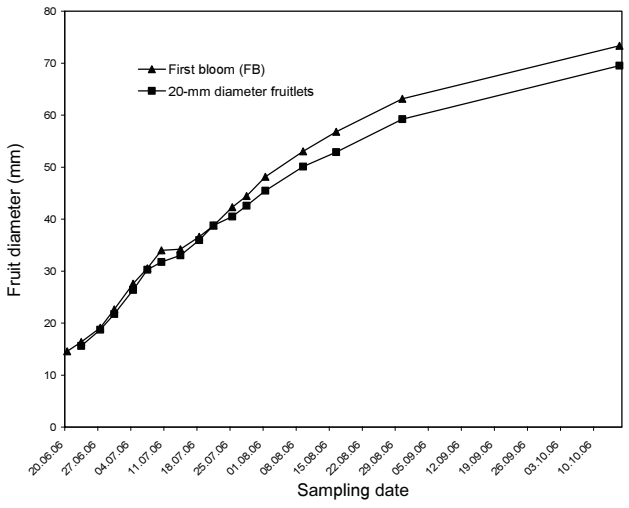

FIG. 1

Fruit growth patterns in the apple cultivar 'Elstar' when hand-thinned at first first bloom (FB) or at the 20-mm diameter fruitlet stage in 2006. Each value is the average of five different crop levels (unthinned, or 2, 4, 6, or 8 flowers or fruitlets cm^{-2} TCSA).

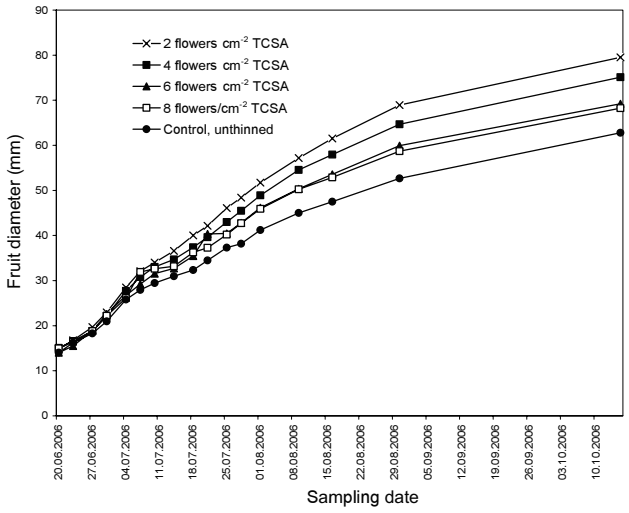

FIG. 2

Fruit growth patterns in the apple cultivar 'Elstar' when hand-thinned to four different crop levels, or unthinned, in 2006. Values are the averages of two stages of thinning [first bloom (FB) or 20-mm diameter fruitlets].

TABLE V

Effects of hand-thinning at five different crop levels (unthinned, or 2, 4, 6, or 8 flowers or fruitlets cm^{-2} TCSA) on fruit quality and seed weight per apple in 'Elstar' apple trees in 2007

Treatment	Fruit weight, (g)	Fruit firmness (kg cm^{-2})	Soluble solids content (%)	Ground colour[+]	Surface colour[‡]	Starch content[#]	Single seed weight (g)
Unthinned (control)	115	10.0	14.0	6.5	6.3	4.5	0.337
2	141	9.4	13.7	5.5	5.1	4.4	0.352
4	135	9.1	13.8	5.2	5.3	5.2	0.321
6	136	9.9	14.2	5.2	5.0	3.8	0.289
8	131	10.1	15.2	6.0	5.1	3.3	0.245
F test[§]	NS	***	***	***	*	***	*

[+]Ground colour scores 1–9, where 1 = dark green and 9 = bright yellow.
[‡]Surface colour scores 1–9, where 1 = no red colour and 9 = fully covered with red colour.
[#]Iodine starch test (scores 1–10), where 1 = dark and 10 = white (no starch).
[§]NS, *,**,*** indicate not significant, or significant at $P = 0.05$, $P = 0.01$ or $P = 0.001$. Values are the average of five different crop levels.

2006 gave only a low yield in 2007. Only 25% of unthinned control trees gave a low yield, while all other (unthinned) control trees had no flower clusters. In general, fruit quality was high due to the low crop loads, and only small differences were found (Table V).

DISCUSSION

In this study, different crop loads were established at FB, or at the 20-mm fruitlet stage. It was more difficult to adjust the crop load at FB than at the 20-mm fruitlet stage due to higher levels of fruit drop at FB. In order to obtain the same cropping level at harvest, a greater number of flowers had to be left compared to those thinned after FB (i.e., at the 20-mm fruitlet stage).

In 2006, the final percentage fruit set was less than the thinning levels achieved, especially for the largest crop loads, due to a dry season and limited water supply.

The rate of fruit growth depends primary on crop load (Palmer *et al*., 1997). When thinning at FB, the growth rate was larger compared to thinning at the 20-mm fruitlet stage. A low crop load resulted in a larger growth rate than a high crop load, due to there being less competition for available photo-assimilates. If the demand for photo-assimilates exceeded the amount available early in the season, due to a heavy crop load, this leads to decreased fruit growth (Lakso and Corelli Grappadelli, 1993). The effects of crop load on fruit growth and on final fruit weight are well-documented (Forshey and Elfing; 1989, Palmer *et al*., 1997). Fruit weight at harvest was negatively correlated with crop load, and fruit weight was greatest when there was minimum competition between fruit (Palmer *et al*., 1997). This was confirmed in this study, where thinning at FB, rather than at the 20-mm fruitlet stage, improved the mean fruit weight and fruit quality, when comparing similar crop levels.

In this study, return bloom was greater when trees were thinned early to a low crop load. These findings have been confirmed by several others who showed that delaying thinning by > 1 month increased alternate bearing (Harley *et al*., 1942; Jonkers, 1979). This result is probably related to carbohydrate supply and the hormonal status of the tree (Wűnsche and Ferguson, 2005), as plant hormones also have an effect by inhibiting flower formation. Apple seeds are an endogenous source of gibberellins which can inhibit flower formation for the next season (Chan and Cain, 1967; Luckwill *et al*., 1969). Thinning at FB caused the early removal of flowers, which reduced competition for photosynthates and favoured flower initiation for next year's crop.

CONCLUSIONS

Thinning to the same crop load at FB improved fruit size and fruit quality in 'Elstar' apple trees. Low crop loads gave larger fruit, higher SSC values, and more highly coloured fruit. The amount of return bloom declined with increasing crop load in the previous year and by thinning at the 20-mm fruitlet stage. Thinning at FB, to a level of 2 – 4 apples cm^{-2} TCSA, gave an annual crop of high quality.

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