Ethephon as a Blossom and Fruitlet Thinner Affects Crop Load, Fruit Weight, Fruit Quality, and Return Bloom of ‘Summerred’ Apple (*Malus ×domestica*) Borkh.

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Abstract. ‘Summerred’ apples (*Malus domestica* Borkh.) are highly susceptible to biennial bearing if not properly thinned. This results in erratic yields and also affects fruit quality adversely. Between 2003 and 2005, ‘Summerred’/‘M9’ trees were treated with ethephon at concentrations of 250, 375, and 500 mg·L⁻¹ when most king flowers opened (≈20% bloom) or at concentrations of 500, 625, and 750 mg·L⁻¹ when the average fruitlet size was 10 mm in diameter. The experiment was conducted with 2.5-m height slender spindle trees sprayed to the point of runoff with a hand applicator only when temperatures exceeded 15 °C. Within 2 weeks after the second application, fruit set was reduced linearly with increasing concentrations of ethephon to less than one fruitlet per cluster at the highest concentrations used. Most thinning treatments reduced fruit set significantly compared with unthinned trees. Fruit numbers per tree decreased significantly with increasing ethephon concentrations, and the highest concentrations of ethephon applied during bloom or when the average fruitlet size was 10 mm in diameter resulted in overthinning. Yield results confirmed the fruit set response in which yield reductions were significant at the highest concentrations of ethephon (2.1 kg/tree) compared with hand-thinned trees (7.3 kg/tree) in 2005. All thinning treatments resulted in higher percentage of fruits larger than 60 mm diameter compared with unthinned control fruit. Thinning resulted in significantly higher soluble solid contents, and this was especially so for hand-thinned trees. Other fruit quality parameters like yellow–green background color did not show a clear response to thinning. Return bloom was, however, improved on all thinned trees. It is recommended that ethephon be applied at a rate of 375 mg·L⁻¹ when king flowers open or at a rate of 625 mg·L⁻¹ when the average fruitlet size is 10 mm in diameter. This thins ‘Summerred’ apples to a target of approximately five fruits/cm² per trunk cross-sectional area or 50 to 70 fruits per 100 flower clusters without impacting on fruit quality, yield, or return bloom the next year.

Biennial bearing is a major problem in many apple-producing areas of the world (Schmidt et al., 2009) and Norway is no exception. As a result of overcropping in the “on-year,” fruit size and quality are reduced. The next year, yields are markedly reduced and oversized fruit may result. This inconsistent yield pattern results in volume and quality problems both for the growers and the market.

The main horticultural practices for controlling biennial bearing are renewal pruning, growth control, and blossom or fruit thinning chemically, by hand, or a combination of the two. Blossom thinning is a standard procedure for improving fruit size, increasing return bloom, and promoting regular bearing (Byers, 2003; Jonkers, 1979). Reducing the number of fruits per tree increases the amount of leaf area per fruit and hence more photoassimilates are available to the remaining fruit. Thinning can, however, result in variable responses. Both excessive and inadequate thinning can be costly for apple growers. Consequently, it is essential to increase precision of the thinning process.

Apple seeds are a major source of gibberellic acid, which can be translocated into the tree and may inhibit flower formation for the next season (Chan and Cain, 1967; Luckwill et al., 1969). Blossom thinning results in early

removal of flowers, eliminating their competitive effects on photosynthetic assimilates or on the endogenous hormonal balance, important for flower bud induction. Blossom thinners are more effective than fruitlet thinning for encouraging consistent annual bearing (Meland and Gjerde, 1993). Blossom thinning improves fruit size and fruit quality at the same cropping level (Meland, 2011). In Norway, ethephon is the only chemical registered for blossom thinning. The only other registered product, a liquid fertilizer, ammonium thiosulphate, is, however, less effective.

For blossom thinning agents to be effective, certain minimum weather requirements must be met during the application time. In the event of unfavorable weather during bloom, growers should be afforded another opportunity for thinning during the young fruitlet stage.

In Europe, ethephon is used as a flower thinner for biennial-bearing apple trees; however, it has been shown to be risky because it can easily result in overthinning (Jonkers, 1979). Ethephon also promotes flowering the next year (Buban and Sagi, 1976; Stopar and Zadavec, 2004).

‘Summerred’ apples are highly prone to biennial bearing in Norway if not properly thinned resulting in poor fruit quality and erratic yields. Ethephon can be an effective thinner; however, results are dependent on a.i. concentration, ambient temperatures, the volume of water applied per unit area, and time of application (Jones et al., 1983, 1989, 1990; Stover and Green, 2005). The objective of this study was to investigate the effects of ethephon as a blossom and fruitlet thinning agent for ‘Summerred’ apple trees.

Materials and Methods

Field trials with the apple cultivar Summerred grafted on ‘M9’ rootstocks were conducted in a commercial orchard near Bioforsk Ullensvang, western Norway (60° N) in 2003, 2004, and 2005. Productive, 10-year-old, uniform slender spindle trees, spaced at 1.4 m × 4 m apart and pruned to a maximum height of ≈2.5 m were selected in 2003. The soil was a sandy-loam with ≈4% organic matter. Orchard floor management consisted of frequent mowing of the interrows and a 1-m wide herbicide strip was maintained in the intrarow. Trees were irrigated by drip irrigation when water deficits occurred. All trees received the same amount of fertilizers based on soil and leaf analysis. In 2003, trees were sprayed in May and June when maximum daily temperatures were 15.6 and 15.3 °C, respectively. Solar radiation on both days was ≈3900 kW·m⁻². In 2004, trees were sprayed in May and June when maximum daily temperatures were 20.8 and 18.4 °C, respectively. Solar radiation on both days was 5908 and 5665 kW·m⁻², respectively. In 2005, trees were sprayed in May and June when maximum daily temperatures were 14.1 and 16.8 °C, respectively. Solar radiation on both days was 6001 and 3812 kW·m⁻², respectively. On the days succeeding all sprays, daily temperature maxima did not exceed more than 3 °C above or

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below the maximum daily temperature on the day of application.

Blossom clusters were counted on each tree and trunk circumference was recorded at 25 cm above the soil level. The experiment was blocked by the number of blossom clusters per square centimeter trunk cross-sectional area (TCSA) each year. The experimental design was a completely randomized block design with six whole tree plots per replication. Unsprayed control and hand-thinned trees were compared against trees sprayed with ethephon at concentrations of 250, 375, and 500 mg·L⁻¹ when king flowers opened ($\approx 20\%$ bloom) or sprayed with ethephon at concentrations of 500, 625, and 750 mg·L⁻¹ when the average fruitlet size reached 10 mm in diameter. A commercial formulation of ethephon 'Cerone' 48% a.i. ethephon (w/v) (Bayer Crop Science, Monheim am Rhein, Germany) was used for this study in each of the 3 years. Ethephon was applied on the day closest to the indicated phenological stage, when conditions were considered best for chemical thinning applications, i.e., when maximum temperatures were between 15 and 20 °C, slow drying conditions, and no rain expected for at least 6 h.

Ethephon treatments were applied to whole trees as dilute sprays at different concentrations with a handgun and a small portable sprayer. Trees were sprayed to the point of runoff with ≈ 2 L/tree. No surfactants or any additives were included in the sprays. In all 3 years of the study, hand-thinning was conducted during the latter half of June and fruit were thinned to between 10 and 15 cm apart.

During the 2 first years of the trial, the numbers of flowers or fruitlets that dropped were recorded on a weekly basis for each of 10 clusters of flowers/fruitlets distributed evenly around the tree. Counting started immediately after the first application of ethephon and continued until the end of August. Fruit size measurements were taken weekly for five tagged fruits/tree. Measurements started when fruit size was between 10 and 14 mm in diameter and continued weekly until harvest.

At harvest, fruit were selectively picked on two occasions, 1 week apart. Fruit were harvested according to commercial fruit standards and the first selective pick dates were 19 Sept. 2003, 16 Sept. 2004, and 22 Sept. 2005, respectively. All the fruit from each tree were graded into two classes (greater than 60 mm diameter and less than 60 mm diameter). Total mass of each class and total number of fruit per class were recorded. Number of recently dropped fruit were recorded separately and assumed to be of average fruit weight. A sample of 10 randomly selected fruits from each tree was taken at the first selective pick and this was used to measure external and internal fruit quality [fruit weight, firmness, scores for yellow-green background color and red foreground (blush) color, soluble solids, starch content, and seed weight]. Flesh firmness was measured by a digital table penetrometer with a 11-mm probe (Penefel®; CTIFL France, Vandoeuvre-lès-Nancy, France) and percentage soluble solids was measured using a hand-held Atago® (Tokyo, Japan) refractometer

(using juice collected from the measurements of flesh firmness). The starch-iodine score was measured by spraying two apple halves with 0.1 M iodine solution and giving scores for starch content (1 = all tissues stained black to 10 = no staining or starch presents). Background color was scored on a scale from 1 to 9 in which 1 = dark green and 9 = bright yellow. Similar scores were recorded for the red foreground color in which 1 = no red color and 9 = red color covering the entire fruit surface. In the spring after the thinning treatments, the total number of flower clusters per tree was counted as a measure of return bloom.

Statistical analysis. The data were evaluated by general analysis of variance for randomized block designs using the statistical program Minitab 15 statistical software (Minitab® Inc., State College, PA) testing for differences between all crop load parameters and effects on fruit quality. The main effects of thinning time and ethephon concentration were analyzed for linear trends. Unless noted otherwise, only results significant at $P \leq 0.05$ are discussed.

Results

2003. Both the trunk section and the average number of flower clusters per tree were uniform at the start of the experiment. On average, there were approximately six flowers per cluster at bloom. Within 2 weeks after blossom application, fruit set was reduced linearly with increasing concentration of ethephon to less than one fruitlet per cluster (Fig. 1). The highest concentration of ethephon (500 mg·L⁻¹) applied during bloom resulted in overthinning. A similar result was seen with the highest ethephon concentration (750 mg·L⁻¹) when applied to young fruitlets in which initial fruit set was reduced to less than

one fruit per cluster within 2 weeks of either treatment. Natural fruit drop on the unthinned control trees continued throughout the entire growing season; however, the most severe drop occurred within 1 month after bloom to an average to 2.1 fruitlets per flower cluster.

A total of 250 mg·L⁻¹ ethephon applied at bloom, or 625 and 750 mg·L⁻¹ applied when the average fruitlet diameter was 10 mm, thinned the fruit to the desired target of approximately five fruit/cm² TCSA or a fruit set between 60 and 70 fruit per 100 clusters. Yield was reduced by half compared with unthinned control trees (19.5 kg/tree versus 42.6 kg/tree) but was comparable with hand-thinned trees (18.9 kg/tree) (Table 1).

All thinning treatments resulted in significantly higher percentages of fruit larger than 60 mm fruit size (between 89% and 100%) when compared with unthinned trees (71%) (Table 2). Average fruit weight also increased in response to all thinning treatments (between 110 g and 230 g/fruit) compared with unthinned control fruit (98 g/fruit). The largest fruit were harvested from trees with the lowest fruit set. Soluble solids content was generally low in all thinning treatments (between 9.9% and 12.9%); however, this was significantly higher than the unthinned control trees (8.7%). In the current study, ethephon applications had no effect on red foreground color (results not shown) of 'Summerred' apples but it did improve average background color of the fruit skins (between 1.4 and 1.9) compared with unthinned control trees (1.3). Neither the average number of seeds/fruit nor average seed weight was affected by fruit or flower thinning (Table 2). Except for the 500 mg·L⁻¹ ethephon applied when the average fruitlet size was 10 mm in diameter (129 flower clusters/tree), all other ethephon treatments improved return

Fig. 1. Flower/fruitlet drop of 'Summerred' apples in response to different ethephon concentrations applied either when most king flowers were open (Bloom) (19 May 2003) or when average fruitlet size reached 10 mm in diameter (Fruitlet) (13 June 2003).

bloom (between 213 to 281 flower clusters/tree) compared with hand-thinned (160 flower clusters per tree) or unthinned control trees (148 flower clusters/tree) (Table 1). Furthermore, the larger the crop load, the lower the amount of return bloom the next year, which also explains why trees sprayed with 500 mg·L⁻¹ ethephon when average fruit size reached 10 mm in diameter had the lowest return bloom. Indeed, the only negative effect of applying ethephon at all concentrations in 2003 was its effect on fruit firmness, which ranged from 5.6 to 5.9 kg in fruit treated with ethephon compared with hand-thinned trees (6.2 kg) or those on unthinned trees (6.0 kg).

2004. Fruit set was reduced significantly by ethephon and the highest concentration at bloom (500 mg·L⁻¹) (Table 3). Likewise, when the average fruitlet size reached 10 mm in diameter (750 mg·L⁻¹), it also resulted in overthinning. Similar patterns of flower/

fruitlet drop were seen as in 2003 (Fig. 2); however, the effects of ethephon were not as marked. Crop load was reduced to approximately one-third that of the unthinned control trees. The number of flower clusters per TCSA, final fruit numbers per TCSA, and final crop load on the unthinned trees were all less than the year before. Both the 375 mg·L⁻¹ and 500 mg·L⁻¹ ethephon sprays applied during bloom and the 625 mg·L⁻¹ ethephon spray when average fruitlet size was 10 mm in diameter resulted in satisfactory fruit thinning (92, 75, and 98 fruit, respectively) compared with hand-thinned trees (75 fruit) and unthinned trees (133 fruit) per 100 flower clusters at harvest. Thinning effects increased linearly with increasing ethephon concentrations and this was reflected in both yield of bigger fruit (Table 3) and fruit weight (Table 4). Increase in fruit size as a function of higher ethephon concentrations was a function of a smaller

crop load (Fig. 3). It was thus not surprising that increasing ethephon concentrations resulted in a linear increase in fruit weight and this was inversely proportional to the number of fruit/cm². In addition, the percentage of small fruits (less than 60 mm diameter) was reduced, whereas soluble solids and fruit background color were significantly improved when compared with fruit from unthinned trees. There were, however, no significant differences in fruit foreground color (results not shown) and fruit firmness. Seed weight was correlated strongly with the number of seed, but there were no significant differences in either of these parameters (Table 4).

Return bloom was significantly improved for all thinned trees [averaging between 79 and 93 flower clusters/tree (Table 3)] compared with 67 flower clusters/tree on the unthinned control trees, which was surprisingly high.

Table 1. Effects of ethephon, applied to 'Summerred' apple trees as a thinning agent, either when most king flowers were open (Bloom) or once fruit size reached an average diameter of 10 mm (Fruitlet), on mean fruit set, mean fruit number, and mean yield in 2003 and on return bloom in 2004.

Treatment	No. of flower clusters/cm ² (TCSA)	No. of fruit per 100 flower clusters at harvest	No. fruits/cm ² (TCSA)	Yield (kg/tree)	No. apples/tree	Return bloom (No. of flower clusters/tree in 2004)
Unthinned	9.0	133	11	42.6	296	148
Hand-thinned	9.1	66	5.3	18.9	131	160
Bloom (250 mg·L ⁻¹)	9.2	57	5.1	19.6	131	254
Bloom (375 mg·L ⁻¹)	9.2	36	3.3	13.8	72	213
Bloom (500 mg·L ⁻¹)	9.1	19	1.8	8.3	39	281
Fruitlet (500 mg·L ⁻¹)	8.9	135	11.2	28.1	258	129
Fruitlet (625 mg·L ⁻¹)	9.5	75	5.7	18.1	147	244
Fruitlet (750 mg·L ⁻¹)	9.9	63	5	16	112	247
Least significant difference 5%	NS	32	2.3	12.2	117	65

TCSA = trunk cross-sectional area.

NS = nonsignificant.

Table 2. Effects of different ethephon concentrations, applied to 'Summerred' apple trees in 2003 as a thinning agent either when most king flowers were open (Bloom) or once fruit size reached an average diameter of 10 mm (Fruitlet), on percentage bigger fruit, mean fruit weight, mean soluble solids, mean ground color, mean fruit firmness measured using a Penefel® firmometer, mean number of seeds per fruit, and mean seed weight.

Treatment	Percentage of yield of fruit with diam greater than 60 mm (%)	Fruit wt (g)	Soluble solids (%)	Background color	Firmness (kg)	No. seed/fruit	Seed wt (g)
Unthinned	71	98	8.7	1.3	6	2.8	0.186
Hand-thinned	99	144	10.2	1.5	6.2	2.5	0.186
Bloom (250 mg·L ⁻¹)	94	147	10.7	1.4	5.9	1.9	0.122
Bloom (375 mg·L ⁻¹)	100	206	11.9	1.7	5.6	2.4	0.173
Bloom (500 mg·L ⁻¹)	100	230	12.9	1.9	5.7	2.0	0.133
Fruitlet (500 mg·L ⁻¹)	89	110	9.9	1.6	5.6	2.7	0.190
Fruitlet (625 mg·L ⁻¹)	95	123	10.4	1.6	5.9	3.5	0.259
Fruitlet (750 mg·L ⁻¹)	99	141	11.3	1.8	5.7	2.8	0.207
Least significant difference 5%	11.0	25	0.3		0.3	0.7	

Table 3. Effects of ethephon, applied to 'Summerred' apple trees as a thinning agent either when most king flowers were open (Bloom) or once fruit size reached an average diameter of 10 mm (Fruitlet), on mean fruit set, mean fruit numbers, and mean yield in 2004 and on return bloom in 2005.

Treatment	No. of flower clusters/cm ² (TCSA)	No. of fruits per 100 flower clusters at harvest	No. of fruits/cm ² (TCSA)	Yield (kg per tree)	No. fruit/tree	Return bloom (no. of flower clusters/tree in 2005)
Unthinned	7.4	133	9.1	27.6	253	67
Hand-thinned	7.4	75	5.0	21.4	144	85
Bloom (250 mg·L ⁻¹)	7.5	92	6.1	19.5	159	79
Bloom (375 mg·L ⁻¹)	7.9	75	5.0	19.9	136	88
Bloom (500 mg·L ⁻¹)	8.1	42	3.4	12.3	84	88
Fruitlet (500 mg·L ⁻¹)	8.2	98	7.3	20.4	191	88
Fruitlet (625 mg·L ⁻¹)	8.2	47	3.7	9.9	77	92
Fruitlet (750 mg·L ⁻¹)	8.5	43	3.3	8.9	67	93
Least significant difference 5%	NS	34	2.3	8.0	71	13

TCSA = trunk cross-sectional area.

2005. Number of flower clusters/cm² of TCSA at bloom for each treatment was significantly higher than either of the 2 previous years reaching as many as 10.9 flower clusters/cm² of TCSA (Table 5). Again, the different concentrations of ethephon applied either when the king flowers opened or when the average fruit diameter reached 10 mm in size resulted in a linear reduction in the average number of fruit/cm² per TCSA (ranging from 18.5 to 8.9) compared with unthinned control trees (23.4) and hand-thinned trees (21); the average number of fruits/tree (ranging from 54 to 22) when compared with unthinned control trees (101) and hand-thinned trees (80); and average yield (ranging from 5.5 to 2.1 kg/tree) compared with unthinned control trees (10.5) and hand-thinned trees (7.3). To summarize, the two highest concentrations of ethephon applied at bloom, and all three concentrations applied when the average fruitlet size reached 10 mm in diameter, resulted in fruit over-thinning (Table 5). Again, the fruit growth pattern (Fig. 4) demonstrated that largest fruits

were found on trees with the lowest crop load and the differences were established early during fruit development. Here, fruit from unthinned control trees had the smallest fruit diameter (≈ 58 mm) on average at harvest compared with those fruit from hand-thinned trees (≈ 67 mm) or treated with ethephon (ranging from 64 to 78 mm at harvest) (Table 6).

Discussion and Conclusions

Fruit set. In this study, ethephon was an effective thinning agent for reducing fruit set of ‘Summerred’ apples when applied at different concentrations either during blossom, when most king flowers had opened, or when the average fruitlet size reached 10 mm in diameter. However, there are many additional factors that must to be taken into account before consistent thinning with ethephon may be achieved. These factors include crop load (Schmidt et al., 2009), spray volume, and spray concentration.

Several other studies on the effects of ethephon as a fruit thinner found marked effects of both daily maximum temperatures for up to 3 d after application (Stover and Green, 2005) and total solar radiation (Byers et al., 1990). In this study, we did not observe any of these effects and we believe that the cool, mesic temperate climate in Norway is responsible for this anomaly.

After the bloom application of ethephon, final fruit set was achieved within 2 weeks and little subsequent fruit drop occurred during the season. During the first month after bloom, fruit set was reduced by up to one-third. Unthinned control trees continue to drop fruit regularly throughout the growing season and the final set was approximately two fruits/cluster. No “June drop” peak was observed. Similarly, ethephon applications when the average fruitlet size reached 10 mm in diameter resulted in rapid fruit drop and final fruit set numbers were established within 2 weeks of application (Figs. 1 and 2).

In the current study, regardless of the time of application, increasing ethephon concentrations resulted in a linearly reduction in fruit set. Applying ethephon during bloom, however, had a stronger thinning effect than later applications when the average fruitlet size reached 10 mm in diameter despite higher concentrations being applied. This corresponded with the model developed by Koen and Jones (1985) for ‘Golden Delicious’ apple trees, in which trees were most sensitive to thinning during flowering but at the pink bud stage. Post-bloom applications required higher rates to achieve similar reductions in fruit set. Wertheim (1997) suggested that ethephon is most active when the natural tendency for apple fruitlet drop is highest. At petal fall, higher rates were needed than at the start of the “June drop” period. However, in the current study, flower applications were done well in advance of the “June drop,” which normally occurs in early July under Norwegian conditions. Furthermore, during all 3 years of the current study, 250 mg·L⁻¹ ethephon applied when most king flowers were open or 625 mg·L⁻¹ when average fruitlet size reached 10 mm in diameter reduced the crop load to the target of approximately five fruits/cm² TCSA, which is equally to 50 to 70 fruits per 100 clusters. This supports the study on ‘Paulared’/‘MM106’ apple trees, which found

Fig. 2. Flower/fruitlet drop of ‘Summerred’ apples in response to different ethephon concentrations applied either when most king flowers were open (Bloom) (10 May 2004) or when average fruitlet size reached 10 mm in diameter (Fruitlet) (8 June 2004).

Table 4. Effects of different ethephon concentrations, applied to ‘Summerred’ apple trees as a thinning agent in 2004, either when most king flowers were open (Bloom) or once fruit size reached an average diameter of 10 mm (Fruitlet), on percentage bigger fruit, mean fruit weight, mean soluble solids, mean ground color, mean fruit firmness measured using a Penefel® firmometer, mean number of seeds per fruit, and mean seed weight.

Treatment	Percentage of yield of fruit with diam 60 mm or greater	Fruit wt (g)	Soluble solids (%)	Background color	Firmness (kg)	No. seed/fruit	Seed wt (g)
Unthinned	83	109	10.2	3.2	4.6	2.4	0,153
Hand-thinned	96	153	11.0	2.9	4.8	2.2	0,150
Bloom (250 mg·L ⁻¹)	89	130	10.7	3.6	4.4	2.5	0,165
Bloom (375 mg·L ⁻¹)	97	153	11.6	3.6	4.7	2.0	0,132
Bloom (500 mg·L ⁻¹)	88	158	11.8	3.3	4.6	2.1	0,143
Fruitlet (500 mg·L ⁻¹)	80	113	11.2	3.3	4.8	2.7	0,17
Fruitlet (625 mg·L ⁻¹)	94	136	12.8	4.1	5.0	3.2	0,213
Fruitlet (750 mg·L ⁻¹)	95	137	12.9	4.1	5.0	3.2	0,207
Least significant difference 5%	NS	29	1.0		NS	NS	

NS = nonsignificant.

Fig. 3. Fruit growth pattern of 'Summerred' apples in response to different ethephon concentrations applied either when most king flowers were open (Bloom) on 10 May 2004 or when average fruitlet size reached 10 mm in diameter (Fruitlet) on 8 June 2004.

Table 5. Effects of different ethephon concentrations, applied to 'Summerred' apple trees as a thinning agent, either when most king flowers were open (Bloom) or once fruit size reached an average diameter of 10 mm (Fruitlet), on mean fruit set, mean fruit numbers, and mean yield in 2005 and on return bloom in 2006.

Treatment	No. of flower clusters/cm ² (TCSA)	No. of fruits per 100 flower clusters at harvest	No. fruits/cm ² (TCSA)	Yield (kg/tree)	No. fruit/tree	Return bloom (no. of flower clusters/tree in 2006)
Unthinned	9.9	255	23.4	10.5	101	80
Hand-thinned	9.9	177	21.0	7.3	80	84
Bloom (250 mg·L ⁻¹)	10.1	144	18.5	5.5	54	72
Bloom (375 mg·L ⁻¹)	10.2	84	11.7	3.5	31	76
Bloom (500 mg·L ⁻¹)	10.2	88	13.2	3.6	33	79
Fruitlet (500 mg·L ⁻¹)	10.1	83	9.6	3.6	36	76
Fruitlet (625 mg·L ⁻¹)	10.3	104	10.0	3.9	40	83
Fruitlet (750 mg·L ⁻¹)	10.9	62	8.9	2.1	22	75
Least significant difference 5%	NS	85	8.2	3.2	31	NS

TCSA = trunk cross-sectional area.

NS = nonsignificant.

that crop load of mature trees was reduced significantly when treated with 550 mg·L⁻¹ ethephon once the average fruitlet size reached 13 mm in diameter (Embree et al., 2001). However, in contrast, a previous study found that ethephon applied at 200 mg·L⁻¹ at the start of flowering reduced fruit set in 'Summerred' apple trees but did not enhance fruit weight (Stopar and Lokar, 2003). In another field experiment on 'Golden Delicious' apple trees, a 500 mg·L⁻¹ ethephon spray applied once the average fruitlet size reached 5 to 11 mm in diameter resulted in effective fruit thinning but had no effect on fruit weight (Bukovac et al., 2006).

Fruit size and quality. Reducing apple crop load usually increases fruit weights as a result of less competition for carbohydrates among the remaining fruit on the tree (Wünsche and Ferguson, 2005). In the current study, fruit weight increased significantly on hand-thinned

and all ethephon-treated trees compared with unthinned trees in all three seasons and was negatively correlated with crop load. Furthermore, fruit weight was positively correlated with the amount of fruitlet drop and fruit weight was larger when ethephon thinning took place during bloom rather than when the average fruitlet size reached 10 mm in diameter. Fruit soluble solid content was positively correlated with the amount of thinning achieved and increased with reduced fruit set. Timing of ethephon sprays, however, had no effect on the soluble solid content of the fruit in all 3 years of the study in 'Summerred' apples. Embree et al. (2001) found that ethephon applied to small fruitlets advanced fruit maturity at harvest and increased the level of fruit color and return bloom the next year. Whale et al. (2008) found that red foreground color of 'Cripps Pink' was markedly increased by applications of ethephon or aminoethoxyvinyl-

glycine followed by ethephon. In the current study, foreground color was unaffected by any of the ethephon applications; however, background color was significantly improved in 2003 and 2004. Fruit softness of 'Summerred' apples was mostly unaffected by any of the ethephon applications when compared with unthinned trees or those thinned by hand.

Return bloom. A general aspect of crop management is that heavy thinning will promote an increase in return bloom the next season. Several studies have shown that treating apple trees with ethephon during bloom or right afterward in an "on-year" will promote return bloom (Bukovac et al., 2006; McArtney et al., 2007; Meland and Gjerde, 1993; Stopar and Zadravec, 2004). This observation was also found to be true in this present study with significant effect in the 2 first years. In the last season, there was little effect on return bloom, but this was

Fig. 4. Fruit growth pattern of 'Summerred' apples in response to different ethephon concentrations applied either when most king flowers were open (Bloom) on 12 May 2005 or when average fruitlet size reached 10 mm in diameter (Fruitlet) on 21 June 2005.

Table 6. Effects of different ethephon concentrations applied to 'Summerred' apple trees in 2005 as a thinning agent, either when most king flowers were open (Bloom) or once fruit size reached an average diameter of 10 mm (Fruitlet), on mean yield, mean fruit weight, mean soluble solids, mean fruit firmness measured using a Penefel® firmometer, mean number of seeds per fruit, and mean seed weight.

Treatment	Percentage of yield with fruit of 60 mm or greater diam	Fruit wt (g)	Soluble solids (%)	Fruit firmness (kg)	No. seed/fruit	Seed wt (g)
Unthinned	58	92	10.1	7.0	2.9	0.201
Hand-thinned	92	121	10.7	7.9	3.7	0.290
Bloom (250 mg·L ⁻¹)	94	133	11.2	7.1	2.7	0.216
Bloom (375 mg·L ⁻¹)	97	144	12.0	7.3	2.8	0.217
Bloom (500 mg·L ⁻¹)	97	151	12.3	7.3	2.1	0.154
Fruitlet (500 mg·L ⁻¹)	88	111	12.7	7.0	4.3	0.293
Fruitlet (625 mg·L ⁻¹)	91	121	12.1	7.8	3.5	0.255
Fruitlet (750 mg·L ⁻¹)	98	139	13.4	7.4	3.7	0.246
Least significant difference 5%	10.6	19	1.1	0.3	0.4	

most likely the result of a balance being achieved the previous two seasons.

Under cool temperate conditions like those in Norway during bloom, daily temperature maxima do not always exceed 15 °C. Consequently, it is imperative for growers to have a second window of opportunity for fruit thinning and in 'Summerred' apples this was found when the average fruitlet size reached 10 mm in diameter. However, based on the findings of the current study, it is recommended that ethephon applications during bloom, when most king flowers were open, be favored over later applications when the average fruitlet size reached 10 mm in diameter. Furthermore, it is suggested that a full cover spray of ethephon at a rate of 250 mg·L⁻¹ be applied to 'Summerred' apples when most king flowers are open and maximum daily temperatures are

15 °C or higher on the day of application and the subsequent 2 d. If the weather does not permit this application, then a full cover spray of 625 mg·L⁻¹ ethephon should be applied to 'Summerred' apples when the average fruit size reaches 10 mm in diameter and when the daily maximum temperatures are 15 °C or greater on the day of application and the subsequent 2 d. This should achieve the desired target of approximately five fruits/cm² TCSA or 50 to 70 fruits per 100 flower clusters with little effect on the return bloom the next year

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