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Effects of Hydrogen Cyanamide, Ammonium Thiosulfate, Endothalic Acid, and Sulfcarbamide on Blossom Thinning, Fruit Quality, and Yield of Apples

Esmaeil Fallahi[1], Curt R. Rom[2], and Bahar Fallahi[3]

Abstract

Effects of rates and/or timings of hydrogen cyanamide (Dormex™), ammonium thiosulfate (ATS), endothalic acid (Endothal), and/or sulfcarbamide (Wilthin®) on blossom thinning (fruit set), fruit quality, and yield of 'Delicious', 'Law Rome Beauty ', 'Fuji' and 'Jonathan' apples (*Malus x domestica* Borkh.) were studied. In 'Delicious', application of Dormex™ at 1.56 or 2.34 $mL.L^{-1}$ (v/v) or ATS at 16 or 24 $mL.L^{-1}$ (v/v) reduced fruit set and increased fruit size. In 'Delicious', reduction of fruit set with application of Dormex™ at 1.56 $mL.L^{-1}$ (v/v) resulted in a significant increase in yield. In 'Law Rome Beauty', application of Dormex™ at 3.12 $mL.L^{-1}$ (v/v) or ATS at 16 or 24 $mL.L^{-1}$ (v/v) reduced fruit set in two years. Also, application of Endothal once at 1.88 $mL.L^{-1}$ or twice at 1.25 $mL.L^{-1}$ (v/v) reduced fruit set in 'Law Rome Beauty'. One application of ATS at 25 or 30 $mL.L^{-1}$ (v/v) or two applications of ATS at 15 or 25 $mL.L^{-1}$ (v/v) reduced fruit set of 'Fuji'. In 'Jonathan', one or two applications of ATS at 25 $mL.L^{-1}$ (v/v) reduced fruit set.

Introduction

Flower and fruit thinning of apples (*Malus x domestica* Borkh.) is an important cultural practice affecting fruit size in the year of application and flower bud initiation for the following year's crop. For many years, growers have been spraying chemical thinners to reduce the labor cost. Several post-bloom fruit thinners have been used on apple trees including 1-naphthyl-*N*-methylcarbamate (carbaryl, Sevin), naphthalene acetic acid (NAA), gibberelin (GA_{4+7}), and 6-benzylamino purine (2, 11, 12, 17).

The blossom thinner sodium dinitro-ortho-cresol (DNOC, Elgetol) was used for many years on apple (9, 19). Elgetol was removed from the market in 1989 because of regulatory issues. The loss of Elgetol resulted in renewed research efforts to find blossom thinners that may act similarly by damaging pistils and thereby preventing ovule fertilization. Since 1989, several new materials, including ammonium thiosulfate (ATS), hydrogen cyanamide (Dormex™), endothalic acid (Endothal), perlargonic acid (Thinex®), and sulfcarbamide (Wilthin®) have been tested as blossom thinners (4, 6, 8, 9). Fallahi et al. (5) initially used Dormex™ to reduce dormancy in peaches under climatic conditions of Southwestern Arizona. They found that the late application (late December-January) of chemical reduced fruit set. Following that observation, Dormex™ was found effective for blossom thinning of apples and stone fruit in Idaho (3, 4, 6, 7, 8, 9). Some of these thinners have been reported to cause fruit marking (russeting) (3).

The objective of this study was to evaluate various rates and/or application frequency of Dormex™, ammonium thiosulfate, Endothal,

[1] Professor and Research Director of Pomology, University of Idaho, Parma Research and Extension Center, 29603 U of I Lane, Parma, ID 83660, USA.
[2] Professor of Pomology, University of Arkansas, Department of Horticulture, 316 Plant Sciences Building, Fayetteville, AR 72701, USA.
[3] Scientific Aide Senior, Pomology Program, University of Idaho, Parma research and Extension Center, 29603 U of I Lane, Parma, ID 83660, USA
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and Wilthin® on blossom thinning, fruit set and fruit quality of 'Delicious', 'Law Rome Beauty', 'Fuji', and 'Jonathan' apples.

Materials and Methods

General descriptions and cultural practices. The experimental orchards were located in Canyon County in southwest Idaho. Soil in all orchards was sandy loam with pH of approximately 7.3. Other than blossom and post-bloom thinning treatments, all cultural practices were performed according to the commercial orchard standards. All blossom and post-bloom thinners were applied by air blast sprayers with a spray volume of 1871 $L.ha^{-1}$.

Treatments for each study are described in their corresponding Tables (1-5). We conducted a preliminary experiment which showed that application of either modified phthalic glycerol alkyd resin spreader-sticker (Latron B-1956, a.i. 77%) or Polyoxyethylenepolypropoxypropanol (Regulaid, a.i. 90.6%) alone did not affect blossom or fruit thinning. Thus, we used one of these surfactants with some treatments in our experiments without having any confounding effects from the use of two different surfactants. The unit for all blossom thinners and surfactants in the text and Tables 1-5 is in $mL.L^{-1}$ (volume of chemical formulation per liter of water or v/v), but the abbreviation "v/v" is not mentioned from this point on.

The experimental design in all experiments was randomized complete block with 3 blocks blocked by location in the orchard. Each block consisted of two adjacent rows with 8 trees per treatment. To avoid overspraying across treatments, the four trees in the middle of the 8-tree plot in each row were selected for sampling, although the entire 8 trees received the treatment. Thus, a total of 24 data trees were used per treatment in each experiment. Each block was isolated by at least two guard or buffer rows to prevent spray drift.

The number of flower clusters (mixed buds) before bloom and number of fruits after June drop were counted on three limbs of 1.2-m to 1.5-m length on each tree. The diameter of each limb was measured at its base using a digital caliper (Digimatic Model CD-6, Mitutoyo, Tokyo, Japan), and cross sectional area of that limb base was calculated. Fruit set was calculated as the number of fruit, counted after "June drop", divided by number of blossoming clusters x 100 (reported as number of fruit per 100 mixed buds), or as the number of fruit, counted after "June drop", divided by limb cross-sectional area. In the experiments where "hand thinning" was practiced, fruits from the whole tree in all treatments including control, were counted after "June drop" for fruit set calculation, and then hand thinned to maintain 13 to 15 cm spacing between fruits.

Thirty fruits were randomly sampled from each tree at harvest each year, weighed, and the average fruit weight was calculated. Fruit russeting (marking) was assessed visually, and percentage of fruit russeting was calculated as: [(number of fruit with russeting)/ total number of fruit sampled] x 100. The amount of fruit surface covered with red was rated visually on a scale of 1 to 5, with 1 = 20% red progressively to 5 = 100% red. Yield per tree (kg fruit) was recorded at harvest of each year.

'Top Red Delicious' Experiments in 1998. A 12-year-old 'Top Red Delicious'/ M.7 EMLA apple orchard at the University of Idaho Parma Research and Extension Center near Parma, Idaho with 3.7 x 6 m tree spacing was used. Treatments for this experiment are described in Table 1. These trees received Dormex™ and ATS blossom thinners at different rates. Blossom thinners were sprayed on April 25, when approximately 87% to 90% of all blooms were open. The temperature during blossom thinning application was about 6°C, reaching a maximum of 16°C that day. No hand thinning was applied to control or any other treatments.

'Law Rome Beauty' Experiments in 1998. A 10-year-old orchard of 'Law Rome Beauty'/M.7 EMLA near Parma, Idaho with 3 x 5.5 m tree spacing was used. The treatments are listed in Table 2. Dormex™ or ATS at different rates were applied on April 30, when 87 to 92% of blooms were open. 'Law Rome Beauty' trees with blossom thinning treatments did not receive any post-bloom thinner.

'Law Rome Beauty' Experiment in 1999. An 11- year-old orchard of 'Law Rome Beauty'/M.7 EMLA near Fruitland, Idaho with 3 x 5.5 m tree spacing was used. Treatments are listed in Table 3. Trees with the double Endothal treatment received their first application on May 1, when 85% of blooms were open, and temperature during thinning applications was about 2°C, reaching a maximum of 18°C about 4 hours after applications of blossom thinners. The second Endothal application was sprayed on May 5. Dormex™ and ATS were also applied on May 5, when 95 to 100% of blooms were open, and temperature during thinning applications was about 4°C, reaching a maximum of 20°C that day. No post-bloom thinner was applied.

Experiments in 2000. Experiments were conducted with 'BC-2 Fuji' and 'Jonathan'. The 7-year-old 'BC-2 Fuji'/ M.9 EMLA orchard with 1.5 x 4.6 m tree spacing was near Wilder, Idaho. Treatments on 'Fuji' trees are described in Table 4. Trees with either a single or double applications of ATS treatment received one application on April 17, when 87% of blooms were open, and temperature during thinning applications was about 21°C, reaching a maximum of 22°C that day. Trees with double ATS treatments, received an additional ATS application on April 19, when 92% of blooms were open and temperature during thinning applications was about 16 °C, reaching a maximum of 21°C that day. The mixture of post-bloom thinner for 'Fuji' was sprayed at petal fall on April 25, when temperature was about 18°C, reaching a maximum of 21°C that day.

The 7-year-old 'Jonathan'/M.7 EMLA orchard with 3.0 x 5.2 m tree spacing was located near Fruitland, Idaho. Treatments are described in Table 5. Trees with Wilthin® and either a single or double applications of ATS treatments received one application on April 20 when 87% of blooms were open, and temperature during thinning applications was about 21°C, reaching a maximum of 22°C. Trees with double ATS treatments received an additional ATS application on April 21, when 95 to 100% of blooms were open and temperature during thinning applications was about 16°C, reaching a maximum of 21°C. The post-bloom thinner was applied to all treatments at petal fall on April 27, when temperature was about 18°C, reaching to maximum of 21°C that day.

Results and Discussion

1998 Experiments. Dormex at 1.56 or 2.34 $mL.L^{-1}$ and ATS at 16 or 24 $mL.L^{-1}$ equally reduced fruit set and increased fruit weight of 'Top Red Delicious' (Table 1). Fruits from trees receiving ATS at 24 $mL.L^{-1}$ had better color than those from control trees. Dormex™ at 1.56 $mL.L^{-1}$ significantly increased yield as compared to control, perhaps because the fruit set in this treatment was lower than control but slightly (although not significantly) higher than other treatments, while fruit weight was greater than control.

Fruit set of 'Law Rome Beauty' was significantly reduced by Dormex™ at 3.12 $mL.L^{-1}$ or ATS at 16 or 24 $mL.L^{-1}$ in 1998 (Table 2). Application of ATS at 24 $mL.L^{-1}$ increased fruit russeting in 'Law Rome Beauty'. Although some differences in 'Law Rome Beauty' fruit set existed among ATS and Dormex™ treatments, fruit weight in these treatments were similar, because all treatments were hand-thinned after counting fruits and calculating fruit set, and thus, fruit size differences were eliminated by harvest time. Yields of 'Law

Table 1. Effect of Dormex™ and ATS blossom thinners on fruit set, fruit quality, and yield of 'Top Red Delicious' apple, Parma, Idaho in 1998[z].

Treatment and rate (v/v)[y]	Fruit set[y] (fruit/cm^{-2})	Fruit wt (g)	Fruit color (1-5)	Yield (kg/tree)
Control	8.83 a	99.9 b	2.7 b	146.4 b
Dormex™ 1.56 mL.L^{-1}	6.54 b	128.1 a	3.0 ab	194.5 a
Dormex™ 2.34 mL.L^{-1}	5.92 b	140.5 a	3.0 ab	163.0 ab
ATS 16 mL.L^{-1}	5.67 b	128.5 a	3.1 ab	163.0 ab
ATS 24 mL.L^{-1}	5.78 b	136.3 a	3.3 a	174.5 ab

[z]Mean separation within columns of each year by LSD at $\alpha \leq 0.05$.
[y] Latron B-1956 as a surfactant, at a rate of 1.25 mL.L^{-1} was applied with Dormex™ treatments. ATS treatments did not receive a surfactant.
[x]Fruit set= Number of fruit / branch cross-sectional area .

Table 2. Effect of Dormex™ and ATS blossom thinners and hand thinning on fruit set, fruit quality, and yield of 'Law Rome Beauty' apple, Parma, Idaho in 1998 [z].

Treatment and rate (v/v)[y]	Fruit set (fruit per 100 mixed buds)	Fruit wt (g)	Russeting (%)	Yield (kg/tree)
Control (Hand thinning only)	105.5 a	173.8 a	0 b	108.7 a
Dormex™ 2.50 mL.L^{-1}+Hand	85.3 ab	173.7 a	0 b	109.6 a
Dormex™ 3.12 mL.L^{-1}+Hand	82.1 bc	172.9 a	10 ab	103.9 a
ATS 16 mL.L^{-1}+Hand	75.8 c	165.7 a	0 b	109.6 a
ATS 24 mL.L^{-1}+Hand	82.1 bc	177.9 a	21 a	103.9 a

[z]Mean separation within columns by LSD at $\alpha \leq 0.05$.
[y]Latron B-1956 as a surfactant, at a rate of 1.25 mL.L^{-1} was applied with Dormex™ treatments. ATS treatments did not receive a surfactant. Hand = Hand thinning was done in the whole tree after June drop and fruit counting.

Rome Beauty' were not affected by any thinning treatments, because reduction in fruit number was compensated by an increase in fruit size.

1999 Experiments. ATS, Dormex™, and Endothal at all rates significantly reduced fruit set of 'Law Rome Beauty' (Table 3). Fruit weight and fruit color were not affected by any blossom thinner treatments, because yield was reduced by frost injury and all trees were thinned by hand, eliminating fruit-to-fruit competition. Double application of Endothal tended to cause higher fruit russeting and lower yield than other treatments, although differences were not always significant (Table 3). This was due to the excessive observed phytotoxicity (no data presented), leading presumably to lower leaf surface and leaf/fruit ratio, and perhaps lower net photosynthesis by damaged leaves and the tree canopy.

2000 Experiments. All treatments, except ATS applied once at 15 mL.L^{-1} and postbloom treatment, reduced 'BC-2 Fuji' fruit set as compared to control (Table 4). Compared with control, fruit weight was not affected by ATS treatments, because fruits of all treatments were hand thinned in June, providing sufficient leaf/fruit ratio in most treatments. One application of ATS at 15 mL.L^{-1} slightly

Table 3. Effect of ATS, Dormex™, and Endothal blossom thinners and hand thinning on fruit set, fruit quality, and yield of 'Law Rome Beauty' apple, Fruitland, Idaho in 1999[z].

Treatment and rate (v/v)[y]	Fruit set (fruit per 100 mixed buds)	Fruit wt (g)	Russeting (%)	Fruit color (1-5)	Yield (kg/tree)
Control (No chemical thinning)+Hand	106.3 a	248.8 a	29 abc	3.8 a	23.8 a
ATS 16 $mL.L^{-1}$+Hand	62.6 b	236.2 a	35 ab	3.8 a	21.3 abc
ATS 24 $mL.L^{-1}$+ Hand	40.6 b	237.6 a	22 c	3.6 a	16.5 abc
Dormex™ 3.12 $mL.L^{-1}$+ Hand	56.7 b	240.5 a	34 ab	3.8 a	17.2 abc
Dormex™ 3.75 $mL.L^{-1}$+ Hand	30.0 b	233.4 a	27 bc	3.6 a	11.9 bc
Endothal 1.25 $mL.L^{-1}$ twice+ Hand	48.3 b	232.1 a	41 a	3.6 a	10.0 c
Endothal 1.88 $mL.L^{-1}$ once+ Hand	57.1 b	233.4 a	33 abc	3.8 a	22.9 ab

[z]Mean separation within columns by LSD at $\alpha \leq 0.05$.
[y]Latron B-1956 as a surfactant, at a rate of 1.25 $mL.L^{-1}$ was applied with Dormex™ treatments. ATS and Endothal treatments did not receive a surfactant. Hand = Hand thinning was done in the whole tree after June drop and fruit counting.

Table 4. Effect of fruit thinning treatments on 'Fuji' apple fruit, Wilder, Idaho in 2000 [z].

Treatment and rate (v/v)[y]	Fruit set (fruit per 100 mixed buds)	Fruit wt (g)	Fruit color (1-5)
Control + Hand	133.2 a	206.0 ab	3.4 a
ATS 15 $mL.L^{-1}$ once+PB+Hand	114.4 ab	229.0 a	2.9 ab
ATS 15 $mL.L^{-1}$ twice+PB+Hand	95.3 bc	198.4 ab	2.4 b
ATS 25 $mL.L^{-1}$ once+PB+Hand	77.0 cd	215.2 ab	3.1 ab
ATS 25 $mL.L^{-1}$ twice+PB+Hand	56.3 d	191.1 b	2.6 b
ATS 30 $mL.L^{-1}$ once+PB+Hand	97.0 bc	220.6 ab	2.6 b
PB+Hand	122.2 ab	204.0 ab	2.8 ab

[z] Mean separation within columns by LSD at $\alpha \leq 0.05$.
[y] PB= Post bloom thinner mixture consisted of carbaryl (Sevin 4-F) at 1.25 $mL.L^{-1}$, ethephon [(2-chloroethyl) phosphonic acid (Ethrel) at 1.25 $mL.L^{-1}$, [1-naphthaleneacetamide (NAD) Amid-Thin, a.i.=8.4%] at 375 $mg.L^{-1}$, plus Regulaid as a surfactant at a rate of 1.25 $mL.L^{-1}$. ATS treatments did receive a surfactant. Hand= Hand thinning was done in the whole tree after June drop and fruit counting.

(but not significantly) reduced fruit set as compared to control. A double application of ATS at 25 $mL.L^{-1}$ significantly reduced fruit set but caused major phytotoxicity, which resulted in smaller fruit size as compared to a single application of ATS at 15 $mL.L^{-1}$. Also, trees receiving ATS as a single application of 30 $mL.L^{-1}$ or a double application at 15 or 25 $mL.L^{-1}$ had lower fruit color than control. Fruit russeting was not affected by any of the treatments (data not shown).

In general, fruit set in 'Jonathan' was low in 2000 due to severe frost damage. Single or double applications of ATS at rate of 25 $mL.L^{-1}$ significantly reduced fruit set (Table 5). 'Jonathan' trees that received a single or

Table 5. Effect of fruit thinning treatments on 'Jonathan' apple fruit, Fruitland, Idaho in 2000 [z].

Treatment and rate (v/v) [y]	Fruit set[x] (fruit/cm^{-2})	Fruit wt (g)	Russeting (%)	Fruit color (1-5)
PB + Hand	2.29 a	207.3 b	67 a	4.0 a
ATS 15 mL.L^{-1} once +PB+Hand	1.62 abc	232.0 a	49 b	4.1 a
ATS 15 mL.L^{-1} twice+PB+Hand	1.86 abc	236.9 a	48 b	4.3 a
ATS 25 mL.L^{-1} once+PB+Hand	1.32 bc	221.1 a	51 b	4.0 a
ATS 25 mL.L^{-1} twice+PB+Hand	1.26 c	228.4 a	43 b	4.1 a
Wilthin® 2.5 mL.L^{-1} once+PB+Hand	1.97 ab	206.1 b	53 ab	4.0 a

[z] Mean separation within columns by LSD at $\alpha \leq 0.05$.
[y] PB= post bloom treatment consisting of carbaryl (Sevin XLR) at 0.63 mL·L^{-1} plus 1.02 mL·L^{-1} Regulaid as a surfactant, was used at petal fall. ATS treatments did receive a surfactant. Wilthin® was combined with Regulaid at 1.02 mL·L^{-1}. Hand=Hand thinning was done in the whole tree after June drop and fruit counting.
[x] Fruit set= Number of fruit / branch cross-sectional area.

double application of ATS at 15 or 25 mL.L^{-1} had higher fruit weight and lower russeting than those receiving only post-bloom fruit thinners. Lower russeting in the fruits that received ATS could be due to suppression of powdery mildew. However, Wilthin® had no significant effects on fruit set, fruit weight, or russeting. Fruit color was not affected by any ATS or Wilthin® treatments because fruits were hand thinned and fruits of all treatments likely received sufficient light to develop similar color rating.

General comments. This study demonstrated that ATS, Dormex™, and Endothal blossom thinners effectively reduced the fruit set of several cultivars including 'Delicious', 'Law Rome Beauty', 'Fuji', and 'Jonathan' in multiple years. These results were in general agreement with previous studies under different experimental conditions (7, 8, 18). Blossom thinners in this experiment resulted in a fruit set reduction of between 15% and 72% (Tables 1-5). This reduction in hand thinning following blossom thinners can be a significant saving in cost of labor, which is a major issue at the present time. Endothal and ATS also resulted in 50% to 80% reduction in hand thinning in peaches (13).

A double application may pose a number of problems and risks. The first potential problem is over-thinning as sufficient number of flowers may not have been fertilized at the times of application. The second problem is that because the effective time for most blossom thinners is very limited, it may not always be feasible to apply them twice, particularly in orchards of large acreage.

Most of the blossom thinners are believed to be caustic and their mode of action is similar to Elgetol (9) that works by damaging pistils and thereby preventing ovule fertilization. (14). One should be cautious about fruit marking and leaf burning with the application of blossom thinners. Leaf burning may have an impact on the photosynthetic capacity of young leaves, and thus on the cell division process, particularly during and following bloom period. Although most of these blossom thinners, particularly Endothal and Dormex™ induced varying degrees of leaf and foliage burning in our project (data not shown), even the most severe symptoms disappeared after a few weeks and did not cause any adverse effect on the health of the trees. Therefore, it is doubtful that over-all photosynthetic capacity of the whole tree is significantly diminished over a long period of time with low rates of Dormex™, ATS, or Endothal. Effects of blossom thinners on leaf photosynthesis need further study.

Temperature, bee activity, bloom developing stages, cultivar differences (9), tree vigor (16, 19, and Fallahi, unpublished data), and spray volume (1, 15) are also factors influencing the effectiveness of blossom thinning in apples. The impact of spray volume on stone fruit thinning has recently been documented (10). Temperature affects bee activity and thus, subsequently the number of fertilized flowers. It is essential that blossom thinners be applied when some, but not all ovule fertilization has taken place. In this project, we sprayed trees when more than 85% of blooms were open. The effectiveness of these blossom thinners, either in a single or double application, could have been different if we had sprayed at an earlier stage of bloom opening. Additional research is also needed to determine a method for quick determination of the proper stage based on physiological development of pollen tube and/or fertilization of the ovules.

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