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Chemical Thinning 'Fuji' Apple in the Midwest

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Abstract

'Fuji'/M.7 apple trees in a commercial orchard were treated with a range of chemical thinners over 7 years to determine their effectiveness. NAA and NAD did not adequately thin and did increase pygmy fruit. Multiple sprays of ethephon and scoring increased return bloom. Although carbaryl or BA (Accel) did not generally reduce fruit set when applied alone, the combination caused significant thinning 2 out of 5 years and 4 out of 5 years increased return bloom. In 2 of 3 years of limb treatments, Endothall applied at bloom reduced set.

Introduction

Chemical thinning is used widely in commercial apple production to increase size, enhance return bloom, improve quality, avoid limb breakage and lessen biennial bearing (3, 4, 14, 15). As new apple cultivars, such as 'Fuji,' are introduced and grown in areas removed from where they were developed, optimal thinning programs need to be developed. 'Fuji' is predicted to capture 10-11% of the world apple market by 2005 (12). 'Fuji' has been reported to have a strong tendency toward biennial bearing in Tasmania (6), Washington and British Columbia (10), Japan (9), Italy (11, 12) and from our experience in Ohio. Most of the available chemical thinning materials have been tried on 'Fuji.' Bound et al. (1) found that the most effective timing with benzyladenine (BA) was 20 d after full bloom and concentration of 200 and 400 ppm were most effective. However, these concentrations are above the rate labeled in the United States. NAA (naphthalene acetic acid) and NAD (naphthalene acetamide) have been reported to inadequately thin and result in pygmy fruit (8, 11). NAA has resulted in more thinning when applied closer to bloom than when applied later (13). Ethephon was efficient in thinning 'Fuji' in Tasmania and Italy just before full bloom, but the degree of thinning declined linearly over time becoming ineffective 5-6 days after full bloom (7, 13). Carbaryl has been tried by several investigators (10, 11), but alone it did not adequately thin or prevent biennial bearing. The combination of carbaryl with BA, ethephon or MCPB-ethyl generally resulted in increased thinning compared to the compounds alone (10, 11). Since many of these trials were conducted in warmer and drier climates than Ohio, a series of studies was initiated to determine the best method to thin 'Fuji' in a humid climate.

Materials and Methods

Beginning in 1992 a thinning trial was conducted annually on 'Fuji'/M.7 trees planted in 1988 in a commercial orchard near Pataskala, OH. Trees were freestanding and trained as a central leader with minimal pruning. Thinning sprays were applied with a high pressure handgun until drip occurred. Fruit set (%) was determined by tagging one or more limbs so that 200-300 flower clusters/tree were counted just prior to bloom with fruit counted in mid-summer well after June drop was completed. At harvest the crop was rated visually on a scale of 1 to 10 with 5 being a full crop and 10 being an excessive crop. In other studies, this rating system had a correlation with actual yield of r = 0.89-0.92. A sample of 25 fruit was taken at random from the periphery of each tree and weighed to estimate fruit size. The following spring return bloom was rated on a 1 to 10 scale with 10 being a snowball bloom. The treatments in each trial were arranged as a randomized block with single trees treated. Duncan's Multiple Range Test at P = 0.05 was used as the means separation test.

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1992 Trial. Treatments in this trial are shown in Table 1. NAD and NAA were applied at petal fall (19 May 1992) and 10-12 mm fruit diameter (28 May 1992), respectively. BA (benzyladenine) was also applied at 10-12 mm fruit diameter, while weekly ethephon sprays were begun the following week. Trees were scored at the 10-12 mm fruit diameter stage with a curved bladed knife cutting through the bark and cambium with a single cut that joined. Pygmy fruit were rated on a scale of 0 = none to 5 = many. Treatments were replicated 8 times.

1993 Trial. Treatments are listed in Table 2 and included carbaryl (Sevin XLR), NAA, BA in various concentrations and scoring. Treatments were arranged as a randomized complete block with 7 individual tree replications.

1994 Trial. Treatments were listed in Table 3 with the PF (petal fall) treatments applied May 9, 1994, and the 10-11 mm fruit diameter sprays were applied May 18, 1994. Treatments were arranged as a randomized complete block with 7 individual tree replications.

1995 Trials. Treatments are listed in Table 4 and were applied on May 14, 1995, and were arranged as a randomized complete block with 7 individual tree replications. An additional trial was established on limbs of trees in an adjoining row by applying various rates of Endothall (mono-N,N-dimethylalkylamine salt) (Table 5). Sprays were applied by a hand-held CO_2 sprayer to drip on May 7, 1995, when 80-90% of the flowers were opened. There were 8 replications of each treatment arranged as a randomized complete block. Flower clusters were counted and at harvest russet and scarf skin were rated on a 1-5 scale with 1 being none and 5 being severe. A similar scale was used to rate leaf injury which occurred as dark necrotic lesions on the leaf edges and at times in interveinal areas.

1996 Trials. Since the combination of Accel and Sevin had been promising in past trials, various rates and combinations were applied in 1996 with treatments listed in Table 6. Treatments were arranged as a randomized complete block with 8 single-tree replications. As in 1995, a second trial with 8 replications of limb treatments applied at 80-90% open flowers of various rates of Endothall (Table 7) with applications and ratings were made as previously described.

1998 Trials. The trial in 1997 was considered invalid due to very poor set, resulting from frost damage and thus, was repeated in 1998. Treatments consisted of various application times of carbaryl (Sevin XLR) and combinations of carbaryl with other materials (Table 8). Ethephon was applied at the rate of 900 ppm, carbaryl (Sevin XLR) 2.5 ml/L, NAD at 50 ppm and BA (Accel) at 50 ppm. Treatments were arranged as a randomized complete block with 8 single-tree replications. Two higher rates of Endothall were again applied to limbs when flowers were 30-50% open with 5 replications of each treatment in a randomized block design (Table 9).

Results

1992 Trial. Although there was a 25% difference among the treatment extremes of fruit set, there was no significant difference among the treatments for fruit set or crop rating (Table 1). Pygmy fruit were increased by NAA compared to the control. Fruit size was increased by NAA at 10 ppm and BA at 100 ppm. These two treatments as well as multiple ethephon sprays and scoring increased return bloom. Scoring at 10-12 mm fruit size caused the greatest increase in return bloom.

1993 Trial. BA reduced fruit set and scoring, plus BA increased fruit set and crop and the following year increased return bloom and crop rating, but only NAA at 20 ppm, Ba, and BA plus NAA at 10 ppm decreased set (Table 2). BA plus carbaryl decreased crop rating and increased fruit size and in the following year increased return bloom and crop rating.

1994 Trial. Accel at petal fall, followed by Accel at 10 mm fruit size was the only treatment that decreased set and crop rating (Table 3). Fruit size was not affected by any treatment. Return bloom was in-

Table 1. Influence of thinning treatments applied in the spring of 1992 on 5-year-old 'Fuji'/M.7 trees.

	Treatment	Time	Rate (ppm)	Fruit set (%)	Crop[w] rating	Pygmy[w] rating	Average fruit wt. (g)	Return[v] bloom
1	Control			74.9	5.0ab	.1d	357cde	3.1e
2	NAD	Petal Fall	35	68.7	4.8ab	.8cd	371abcd	4.5cd
3	NAD	Petal Fall	50	79.4	4.1ab	.5d	374abc	2.7cd
4	NAA	10-12 mm	10	70.6	4.1ab	1.7bc	380ab	5.6bcd
5	NAA	10-12 mm	20	77.0	4.7ab	3.7a	345ef	4.8cde
6	NAA	10-12 mm	10 + spreader	77.0	4.3ab	2.1b	362bcde	5.1cde
7	Ethephon[z]	6 sprays	200	73.6	3.7b	.1d	373abc	5.7bcd
8	Ethephon[z]	4 sprays	300	73.7	4.7ab	.2d	364abcde	5.7bcd
9	Score[y]	10-12 mm	----	80.2	5.5a	.3d	335f	6.7abc
10	6BA	10-12 mm	100	69.9	4.0ab	.3d	383a	5.3cd
11	Score + NAA	10-12 mm	10	92.5	4.8ab	2.6b	357cde	8.3a
12	Ethephon[z]+ Score[y]	6 sprays	200	72.7	5.5a	.2d	352def	7.5ab

[z]Weekly sprays applied beginning one week after 10-12 mm stage (28 May 1992); Petal Fall was 19 May 1992.
[y]Scoring was a connected cut through the bark encircling the trunk 30 cm above the soil.
[x]Mean comparison by Duncan's Multiple Range test p = .05.
[w]Pygmy fruit rated as 0 = none to 5 = many. Crop rating: 1 = no crop, 5 = full crop, 10 = excessive crop.
[v]Bloom rating: 0 = no flowers to 10 = snowball bloom.

creased by Accel at 50 or 100 ppm and by Accel at PF followed at 10 mm fruit size by either Accel or carbaryl.

1995 Trial. All thinning treatments reduced fruit set and crop rating and increased fruit size (Table 4). The inclusion of oil caused over thinning and resulted in too few fruit for reliable size measurements. While in previous years it required combination sprays to thin, the ease of thinning in 1995 resulted in over-thinning when Accel was combined with other products. All treatments except Accel alone at 75 ppm increased return bloom with the combination treatments causing the greatest increase. Limb treatments of various rates of Endothall had no effect on fruit set, size or shape (Table 5), which

Table 2. Influence of thinning treatments on fruit set, average fruit size, fruit Ca and crop load of 'Fuji'/M.7 apple in 1993.

						1994	
Treatment	Rate	Fruit set %	Fruit[z] wt. g	Crop[y] rating	Fruit Ca nmol.kg$_{-1}$	return[w] bloom rating	crop[y] rating
Check		62.8ab	145b	7.7ab	2.20ab	1.0cd	0.7d
NAA	10 ppm	77.9abc	148bc	7.4ab	2.04b	0.8d	0.8cd
NAA	20 ppm	57.0c	154bc	7.4ab	2.27ab	1.0cd	1.4bcd
Carbaryl	2.5 ml/L	70.3bc	155abc	6.4bc	2.56a	2.1bcd	2.4ab
BA	50 ppm	58.1c	161ab	6.2bc	2.08ab	1.5bcd	1.4bcd
BA + Carbaryl	50 ppm + 2.5 ml/L	62.8bc	170a	5.2c	2.18ab	3.6a	2.8a
BA + NAA	50 ppm + 2.5 ml/L	59.0c	145bcd	6.5bc	2.21ab	2.2bc	1.7bcd
Score	----	81.4abc	120e	8.7a	2.09ab	2.2bc	1.7bcd
Score + NAA	---- + 10 ppm	89.5ab	122e	7.7ab	1.81gb	1.7bcd	1.1cd
Score + BA	---- + 50 ppm	100.9a	125de	9.08a	2.10ab	2.4b	1.8abc

[z]Random sample of 25 fruit/tree.
[y]Crop Rating: 1 = no crop; 5 = full crop; 10 = excessive crop.
[x]Mean comparison by Duncan's Multiple Range Test p = .05.
[w]Bloom Rating: 0 = no flowers to 10 = snowball bloom.

Table 3. Performance of ACCEL and Carbaryl as thinners on 7-yr.-old 'Fuji'/M.7 trees in Pataskala, Ohio in 1994.

Treatment	Rate	Timing	Fruit set %	Crop rating[z]	Fruit weight g	Return[y] bloom 1995
Control			88.7a[x]	7.87a	133	1.1c
Accel	50 ppm	PF	70.4ab	6.57ab	135	2.0abc
Accel	50 ppm	10-11 mm	84.8a	7.28ab	145	3.5a
Accel	100 ppm	10-11 mm	65.9ab	7.28ab	132	3.1ab
Accel + Carbaryl	50 ppm + 2.5 ml/L	10-11 mm	54.9ab	7.42ab	137	1.4bc
Carbaryl	2.5 ml/L	10-11 mm	69.9ab	7.00ab	139	1.8abc
Accel + Accel	50 ppm + 50 ppm	PF + 10-11 mm	45.9b	5.6b	140	3.3a
Accel + Carbaryl	50 ppm + 2.5 ml/L	PF + 10-11 mm	79.6a	6.42ab	146	3.2a

[z]Crop rating: 1 = no crop, 5-6 = full crop and 10 = excessive crop.
[y]Return bloom rating: 1 = no bloom to 10 = snowball bloom.
[x]Mean comparison by Duncan's Multiple Range Test p = .05.

could have been related to the light crop on these trees. Fruit russet and scarf skin were not influenced, but leaf injury was increased with the higher rates.

1996 Trial. None of the thinning treatments influenced fruit set, size or crop (Table 6). In the following year a frost in April killed many flowers so return bloom was light and unaffected 1996 by treatments. Applications of Endothall to limbs when 80-90% of the flowers were open, decreased fruit set with no significant influence of rate, although a trend existed for the highest rates to cause the greatest reduction (Table 7). Scarf skin tended to be increased by higher rates of Endothall, while russet and stem cracking were unaffected by treatments.

1998 Trial. Although carbaryl alone did not decrease fruit set, when another thinner was applied in combination with carbaryl, set and crop were reduced (Table 8). Generally treatments that decreased set also increased fruit size and return bloom. Two or three applications of ethephon were particularly effective in increasing return bloom. Crop ratings greatly above 5 (full crop) resulted in trees with no bloom the following year. Limb treatments of Endothall applied when 30-50% of the flowers were open significantly reduced set linearly as rate increased, but with no change in fruit size (Table 9).

Discussion

In the 1992 and 1993 trials NAA or NAD did little thinning, but NAA at 10 ppm did increase fruit size in 1992, but not in 1993. Combining NAA with BA did not cause thinning relative to the control. The lack of effectiveness of NAA to thin 'Fuji' was also found by others (8, 11). Howev-

Table 4. Influence of chemical thinning treatments on 'Fuji' apples in 1995 (Pataskala, OH).

Treatment at 10 mm (rate/100 gal)	Rate	Fruit set (%)	Crop rating[z]	Fruit wt. (g)	Return[y] bloom 1996
Check		50.7a[x]	7.2a	135c	2.2c
Accel	75 ppm	18.6bc	5.1b	162ab	3.0bc
Carbaryl	2.5 ml/L	31.6b	5.6b	155b	3.5b
Accel + Carbaryl	75 ppm + 2.5 ml/L	10.6c	3.2cd	166a	5.1a
Accel + Oil	75 ppm + 5 ml/L	7.5c	3.0cd	----	5.1a
Accel + Oil + Carbaryl	75 ppm + 5 ml/L + 2.5 ml/L	9.1c	2.6d	----	5.3a
Accel + Ethrel	75 ppm + 400ppm	8.4c	3.9c	170a	4.8a

[z]Crop load estimate: 1 = no crop, 5 = full crop; 10 = excessive crop.
[y]Return bloom rating: 1 = no bloom to 10 = snowball bloom.
[x]Mean comparison by Duncan's Multiple Range Test p = .05.

Table 5. Influence of bloom applications of Endothall to limbs of 'Fuji' on fruit set, fruit size and quality in 1995.

Treatment	Rate ml/L	Fruit set (%)	Fruit weight (g)	Fruit shape (L/D ratio)	Russet[z]	Scarf[y]	Leaf injury[w]
Check	----	26.5	180	.82	1.7	4.6	1.0b[x]
Endothall	.63	28.5	166	.81	1.9	4.4	1.0b
Endothall	.93	23.9	138	.82	1.8	4.2	2.0a
Endothall	1.25	24.2	154	.83	1.9	4.0	2.5a
Endothall	1.88	23.5	183	.81	1.8	4.6	2.3a

[z]Rate for Russet: 1 = no russet to 5 = complete russet.
[y]Rating for Scarf Skin: 1 = no scarf skin to 5 = complete scarfing.
[x]Mean comparison by Duncan's Multiple Range Test p = .05.
[w]Rating for Leaf Injury: 1 = no injury to 5 = leaf killed.

er, NAA applications around bloom as opposed to 10-14 days after bloom caused thinning (7, 10). Our work confirms that of others that NAA and NAD does cause pygmy fruit with 'Fuji' (6, 8, 11, 13). NAD also has been reported to have a negative effect on fruit bud development the following year (13).

Carbaryl alone was used in 5 studies, and only in 1995 when all thinners worked, did it adequately thin 'Fuji.' The combination of carbaryl and BA (Accel) caused significant thinning in 2 out of 5 years, and in 2 other years return bloom was increased even though a significant reduction in set did not occur. This combination was also successful in British Columbia (10). The combination of mineral oil to enhance the effect of carbaryl was effective in Italy (11). In the present study, spray oil was used with BA or BA and carbaryl in the easy to thin year (1995) and over-thinning occurred. Thus, the combination of carbaryl and BA (Accel) was one of the most successful treatments in these trials in breaking the biennial tendency of 'Fuji.'

Ethephon has been used successfully to thin 'Fuji' in several studies when applied around bloom (7, 11, 13). However, Jones et al. (8) found that ethephon when sprayed at full bloom caused excessive russet. However, they concluded that "ethephon at FB is currently the only satisfactory thinning spray for Fuji." In 1992, multiple sprays of low rates of ethephon did not cause thinning, but did increase return bloom. In 1998, combining ethephon with carbaryl at petal fall caused optimal thinning and enhanced return bloom. Following this treatment with a second ethephon spray at 10-12 mm fruit size, resulted in over-thinning and a corresponding dramatic increase in return bloom. The combination of carbaryl, NAD and ethephon at petal fall also caused nearly optimal thin-

Table 6. Influence of various rates of Accel and Carbaryl on fruit set and size of 'Fuji' in 1996 at Pataskala, OH.

Treatment	Rate (ppm)	Carbaryl rate ml/L	Fruit set %	Crop[z] rating	Fruit weight/ (g)	Return[w] bloom 1997
Control			47.9	5.3	138	3.37
Accel + Promalin[y]	50	2.5	37.4	5.3	137	3.62
Accel	75	1.25	36.4	5.8	150	3.62
Accel	75	2.5	38.1	4.8	154	4.87
Accel	50	1.25	35.9	5.0	148	3.62
Accel	50	2.5	34.6	5.7	152	4.25
Carbaryl	---	2.5	36.6	5.2	148	4.50

[z]Crop rating: 1 = no crop; 5 = full crop; 10 = excessive crop.
[y]Promalin rate: 1.85 ml/L Kings open (May 9); PF (May 14); May 22 applied Carbaryl (Sevin XLR).
[x]Mean comparison by Duncan's Multiple Range Test p = .05.
[w]Return bloom rating: 1 = no bloom to 10 = snowball, rated after severe frost in April that greatly reduced bloom.

Table 7. Influence of various rates of Endothall on fruit set, size, and quality of 'Fuji' in 1996, Pataskala, OH.

Treatment	Rate ml/L	Fruit set (%)	Fruit wt. (g)	Russet[z]	Scarf[y] skin	Stem[w] cracking
Control		29.8a[x]	133.6	2.3	4.1c	.05
Endothall	.93	14.4b	135.6	2.4	4.4bc	.00
Endothall	1.25	14.0b	130.3	2.1	4.8a	.01
Endothall	1.88	13.6b	127.9	2.4	4.5ab	.05
Endothall	2.50	7.9b	137.1	2.3	4.5ab	.01

[z]Rating for russet: 1 = no russet to 5 = excessive russet.
[y]Rating for scarf skin: 1 = no scarf skin to 5 = excessive scarf skin.
[x]Mean comparison by Duncan's Multiple Range Test p = .05.
[w]Rating for stem cracking: 0 = no cracks, 1 = cracks.

ning. These treatments are promising and need to be tested further under humid Midwest conditions. Recent recommendations from Tasmania suggest ethephon at bloom followed by BA at 140-160 ppm, 20 days after full bloom as a thinning program (6). Research in Tasmania indicates that 'Fuji' trees could be cropped at higher levels than 'Golden Delicious' or 'Delicious' due to large fruit size and later picking date (6). This is not the experience in Ohio where 'Fuji' must have lower crop loads than these cultivars if it is to have bloom the following year. The difference is likely the amount of growing season after harvest in Tasmania. In Ohio due to 'Fuji's' late harvest date, leaves are often exposed to frost prior to picking.

Mantinger (11) states that "thinning of 'Fuji' is more difficult than other varieties, and moreover even sufficient thinning does not always bring about a satisfactory flower bud differentiation for the following year." Since it is generally accepted that the earlier that thinning occurs, the greater is the effect on return bloom, thinning at bloom should be evaluated with this cultivar. Byers (2) reported that Endothall, pelargonic acid, V1-1066, Wilthin and ammonium thiosulfate inhibited fruit set of apples, but he did not report trials on 'Fuji.' Of bloom thinning materials tried in Ohio, Endothall has been the most consistent causing significant thinning of spur-type 'Delicious' in each of the last 4 years (5). Limb treatments of Endothall caused a reduction in fruit set of 'Fuji' in 2 of the 3 years, particularly at the higher rates. Scarf skin was increased slightly in one year, but there was no effect on russeting.

Table 8. Influence of chemical thinning treatments on fruit set and yield of 'Fuji' apples at Pataskala, OH in 1998.

Treatment[w]	Fruit set %	Crop rating[z]	Fruit weight (g)	Return[y] bloom
Control	46.7a[x]	7.7a	115c	0.1d
Carbaryl PF	46.6a	7.0a	131bc	0.1d
Carbaryl + Ethephon PF	33.6bc	4.5c	171a	5.5b
Carbaryl + Ethephon PF + Ethephon 10-12 mm	19.5de	2.8d	184a	8.0a
Carbaryl + NAD + Ethephon PF	24.1cde	4.3c	177a	5.1b
Carbaryl + Ethephon PF + Ethephon 10-12 mm + Ethephon 20-25 mm	17.4e	3.0d	184a	8.0a
Carbaryl + Accel 10-12 mm	28.6cd	5.1bc	175a	3.8c
Carbaryl 10-12 mm	38.9ab	5.8b	142b	1.1d

[z]Crop rating: 1 = no crop, 5 = full crop, 10 = excessive crop.
[y]Return bloom rating: 1 = no bloom to 10 = snowball bloom, correlation of crop rating and return bloom is -.89**.
[x]Mean comparison by Duncan's Multiple Range test p = .05.
[w]Treatment: Ethephon applied at 900 ppm, Carbaryl (Sevin XLR) applied at 2.5 ml/L, NAD applied at 50 ppm, and Accel applied at 50 ppm.

Table 9. Influence of Endothall applied at bloom on fruit set and fruit size of 'Fuji,' Pataskala, OH 1998.

Treatment	Rate ml/L	Fruit set %	Crop rating[z]	Fruit weight (g)
Check	---	52.0a[y]	6.5	121
Endothall	1.56	30.2b	5.3	120
Endothall	3.12	24.1b	4.6	116
Linear		**	NS	NS
Quadratic		NS	NS	NS

[z]Crop rating: 1 = no crop, 5 = full crop, 10 = excessive crop.
[y]Mean comparison by Duncan's Multiple Range Test p = .05.

Looney et al. (10) reported that the synthetic auxins NAA and MCPB-ethyl applied at bloom were effective whole-cluster thinners of 'Fuji,' but many of the remaining fruit were in clusters with multiple fruit. A carbaryl spray applied postbloom further reduced crop and increased the incidence of singles. In Japan where 'Fuji' originated, blossoms are often removed by hand to insure large fruit size and good return bloom (9). Studies by Waldner and Knoll (13) confirm the earlier that hand thinning of 'Fuji' is accomplished, the greater the effect on return bloom. They found that thinning 45 days after full bloom improves flowering the following year, whereas at 75 days after bloom it is no longer effective.

In summary, results from this group of experiments indicate that NAA and NAD should not be used because of inadequate thinning and pygmy fruit. Carbaryl or BA (Accel) alone will not generally thin adequately, but the combination of these materials at 10-12 mm fruit size gave the most consistent thinning program. We need more experience with ethephon in combination with carbaryl. Bloom thinners, such as Endothall, also show promise when they become approved for use. 'Fuji' under our conditions is very biennial and it remains a significant challenge to correctly thin it with bioregulators.

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