FINAL REPORT

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Project Title: Plant Bioregulator Approaches to Sustaining Regular Cropping of Apple Trees in High Density Plantations

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1. Objectives

1.1 Apple Blossom Thinning

Evaluate synthetic auxins (MCPB-ethyl and NAA) and several calcium-containing products as blossom thinners for Fuji and Gala apples (1998-2001).

1.2 Growth Control of Apple with Prohexadione-Ca (Apogee®) Determine the effects of Apogee treatments on growth characteristics, stomatal conductance, and CHO and N partitioning in apple plants (Greenhouse study in 1999);
determine the effect of Apogee on shoot growth, fruit quality, and cropping of superspindle Gala/M9 apple trees in high density plantings (Field study in 2000-2001).

1.3 Determination of Absorption, Withdrawal, and Remobilisation of Foliar Urea N in Apple Trees

Quantify leaf absorption of urea-derived ^{15}N, withdrawal during leaf senescence, and spring remobilization for growth of flower clusters and spur leaves of apple trees growing under arid conditions (2000).

2. Significant Findings

2.1 Apple Blossom Thinning Studies

2.1.1 Synthetic auxins MCPB-ethyl and NAA

Sprayed at 85% full bloom on Fuji/M9 apple trees, MCPB-ethyl at up to 20 ppm or NAA at up to 21 ppm increased whole flower cluster removal linearly with rate; Sprayed on the Fuji/M26 trees, however, MCPB-ethyl failed to result in any thinning. Neither auxin treatment consistently reduced fruit set on the remaining clusters, resulting in 'clustering'. Return flowering was not improved by the auxin treatments except where there was very excessive crop reduction. Ethephon or carbaryl promoted return flowering with the carbaryl effect being more pronounced. However, this carbaryl effect was significantly countered by the bloom-time auxin whereas ethephon overcame the negative effects of the auxin treatments. The combined use of ethephon and carbaryl was effective in terms of both crop reduction and return flowering benefits in Fuji apple.

2.1.2 Calcium-containing products

Considering the overall effects on thinning, fruit size, yield, phytotoxicity, and return flowering for Fuji apple, lime sulphur at the highest rate (1.14%) was the best among the bloom-time treatments (NC99, Stopit, Cor-Clear, or lime sulphur). It proved similar to the 1.6% ATS control in most variables measured. Carbaryl further reduced fruit set and also increased fruit size, surface red color, soluble solids, and juice acidity, without interacting with any blossom thinner. Return flowering was improved by most rates of lime sulphur and lower rates of Stopit and NC99. The failure of high rate of the latter two compounds in improving bloom could be related to their phytotoxic effect on leaf damage.

2.1.3 Lime sulphur

Sprayed at 85% full bloom to Fuji/M9 and Gala/M9, lime sulphur at 4% that is much higher rate than recommended by the Grower's Guide showed thinning responses similar to those shown by 1.6% ATS, without affecting fruit quality. This rate of lime sulphur was not phytotoxic to spur leaves. Lime sulphur increased the proportion of fruiting sites with single fruit (reduced incidence of multiple fruits within clusters) compared to the untreated control. Mean fruit weight was increased by lime sulphur by 10 %.

Carbaryl further reduced crop load, produced more single fruit within clusters (fewer multiple fruit), and increased mean fruit weight. Accel®, applied once at 11-mm fruit size, showed no thinning effect for Fuji apple.

2.2 Growth Control of Apple with Apogee

2.2.1 Greenhouse study

Apogee (125-500 ppm) inhibited stem elongation, leaf formation, total leaf area and shoot dry weight, while significantly increasing specific leaf weight, root dry weight and root : shoot ratio, regardless of rate. Apogee increased N concentration in stem but not in leaves and roots. Total nonstructural carbohydrates increased in all parts of the Apogee-treated plants, due to increased levels of starch rather than soluble sugars without altering allocation pattern.

2.2.2 Field study

Apogee (250 ppm) sprayed 4 weeks after full bloom effectively suppressed shoot elongation. Fruit set was increased by Apogee but was substantially decreased by ethephon. Apogee overcame this ethephon effect. Apogee reduced mean fruit weight but increased yield. Apogee had no effects on fruit shape, firmness, and incidence of fruit stem-end russet. Apogee treatment resulted in a delay in fruit maturity and reduction in return flowering. In comparison, other growth retardants NAA and ethephon were less effective in retarding shoot elongation than Apogee; NAA and ethephon reduced fruit size and fruit set (thus yield), respectively.

2.3 Determination of Absorption, Withdrawal, and Remobilisation of Foliar Urea N in Apple Trees

In Jonagold/M9 apple trees treated with fall urea enriched with ^{15}N, leaves absorbed only 17% of the ^{15}N intercepted. This amount of N absorbed was relatively little compared to that reported for more humid regions. During leaf senescence, about 47% of the ^{15}N absorbed was withdrawn into woody tissues. In winter, 92% of the ^{15}N withdrawn was stored in the woody tissues of the treated branch; 59% in bark, 28% in wood, and 5% in dormant spur buds. In the following spring, by pink stage, 57% of the ^{15}N stored in the dormant branch had been remobilized for growth of flower bud complex including spur leaves. Fall urea spray slightly increased fruit set.

3. Methods

3.1 Blossom Thinning Studies

3.1.1 Synthetic auxins MCPB-ethyl and NAA

In 1998-1999, three experiments involving Fuji apple trees on M9 or M26 rootstocks evaluated synthetic auxins MCPB-ethyl and NAA as blossom thinners in combination with other thinners, i.e., ethephon during bloom and carbaryl post-bloom. All sprays were applied to run off to whole trees with a high pressure hand-gun sprayer. In a commercial orchard in Summerland, British Columbia or an experimental orchard at the Lewis and Brown Farm, Corvallis, Oregon State University, five to six-year-old Fuji/M9 trees or six-year-old Fuji/M26 trees, respectively, were treated with MCPB-ethyl (Agro-Kanesho Co., Ltd., Tokyo, Japan) or NAA (K-salt; Fruit Fix, AMVAC Chem. Corp., Los Angeles) at 85% full bloom, followed by carbaryl at 0 or 1000 ppm a.i. at 11-mm fruit diameter. MCPB-ethyl or NAA was applied at up to 20 ppm and 21 ppm a.i., respectively.

The following variables were determined depending on experiment; fruit set, proportion of fruiting sites that set one, two, or equal to or greater than three fruit, total and mean fruit weight, fruit L/D, percentage surface red color, firmness, total soluble solids concentration, titratable acidity, intensity of surface russet, number of seeds per fruit, and return flowering.

3.1.2 Calcium-containing products

We used Fuji/M9 and Gala/M26 apple trees in their 8th year at Gartrell Orchards and the Research Centre Orchard in Summerland, British Columbia, respectively. For Gala, two mid-stem branches were selected and blossom intensity was calculated based on cm^2 limb cross sectional area. For both cultivars, NC99 (Genesis Agri·Product Inc., 13% Ca) and Stopit (Phosyn PLC; 12% Ca) were sprayed at 2.25, 3.0 or 3.75% and for Cor-Clear $CaCl_2$ fertilizer (Sego International Inc; 34.5% Ca) at 0.75, 1.0 or 1.25%. Lime sulphur (United Agri Products, 22% sulphide sulphur) was applied at 0.68, 0.91 or 1.14%. Sprays were applied at 80% full bloom to

whole trees at 184 and 444 gallons/acre for Fuji and Gala, respectively. In addition to a non-treated control, an ATS control (1.6% product) was included as a grower standard. We used no surfactants - only Stopit is originally formulated with a surfactant. For Fuji, some trees were sprayed twice with the low rates of these $CaCl_2$ products at 35 and 80% full bloom, and post-bloom thinned with 1000 ppm carbaryl + 5 ppm NAA at 12-mm fruit diameter.

3.1.3 Lime sulphur

In 2001, nine-year-old Fuji/M9 slender spindle trees were treated with lime sulphur (United Agri Products, 22% sulphide sulphur) at 1%, 2%, or 4%. Sprays were applied at 85% full bloom to whole trees to run off. In addition to a non-treated control, an ATS control (1.6% product) was included as a grower standard. These bloom-time treatments were combined with no post-bloom control, Accel®, or carbaryl (1000 ppm) at 11-mm fruit diameter. To Gala/M9 slender spindle trees, lime sulphur at 1%, 2%, 3%, or 4% was sprayed to run off at 85% full bloom. An ATS control (1.6% product) as well as non-treated control were included. No post-bloom sprays were followed. Effects on fruit set, fruit set distribution within clusters, and some characteristics of fruit quality were determined for each cultivar.

3.2 Growth Control of Apple with Apogee

3.2.1 Greenhouse study

M26 apple rootstock liners were grown in the greenhouse for 3 months from January to April, 1999. After potting, each liner was cut back to about 20 cm and one terminal shoot was allowed to develop. Plants were watered as needed with a solution of Peter=s 20-20-20 NPK fertilizer to give N at 150 ppm. Apogee was applied on 13 April, 1999 at rates of 0, 125, 250, or 500 ppm a.i. One day later, GA_{4+7} at 200 ppm a.i. was sprayed to one-half of the plants previously treated with Apogee at 125 or 250 ppm.

Shoot growth, leaf growth, and stem internode elongation were monitored. Leaf conductance was determined 1, 8, and 17 days after Apogee treatment with a Li-1600 porometer. Since the measurements taken on the 17th day after Apogee treatment showed significant differences among treatments, we elected to measure diurnal changes in stomatal conductance throughout the following day on the 18th day. Total N and non-structural carbohydrate concentrations were determined from harvested tissues.

3.2.2 Field study

Six-year-old superspindle Gala/M9 apple trees in a commercial orchard at Summerland in British Columbia were treated with Apogee, NAA, and ethephon, alone or in combination. All trees were thinned using 1% ATS a.i. at 80% full bloom, followed by 1000 ppm carbaryl at 12-mm king fruit diameter. For the NAA paint mixture, one part of Stop Drop® (5.18% NAA K salt) was mixed with 2.5 parts of wallpaper paste just before application to make a preparation. About 2.5 weeks after full bloom this mixture was painted to the fresh cut surface of the central leader on a clear day. The mid-day air temperature was about 20°C. Apogee at 250 ppm a.i. was sprayed 4 weeks after full bloom or at 25-cm terminal shoot growth. Ten days later (35-cm terminal shoot growth), Stop Drop® NAA at 18 ppm a.i. and ethephon (Ethrel®) at 300 ppm were sprayed. The main reason of delayed application of NAA and ethephon was to prevent unnecessary fruitlet thinning. All PBR sprays were applied to run off to whole trees with 0.1% surfactant. Initial fruit set was determined after June drop. Fruits were harvested sequentially according to maturity, and the proportion of fruits harvested at each pick was recorded. Fruit quality characteristics (L/D, firmness, percent red block color, soluble solids, juice acidity, and stem-end russet) were determined using 15 fruits from the first-harvest. Mean shoot growth was determined during winter. The effect on return flowering was assessed the following spring.

3.3 Determination of Absorption, Withdrawal, and Remobilisation of Foliar Urea N in Apple Trees

In 1999, six-year-old Jonagold/M9 apple trees received 15 g per tree of $Ca(NO_3)_2$ through a drip irrigation system. After fruit harvest, two similar branches (in biomass and leaf number) were chosen from the mid-stem on each tree; one for determining absorption and withdrawal of ^{15}N, one for determining remobilization of stored ^{15}N the following spring. For each marked branch, leaf number was adjusted to about 36, with the approximate ratio of 2:3 spur and shoot leaves. Urea enriched with 9.8 atom % ^{15}N was applied at 2% once on 18 October, 1999. The rest of the tree was treated with the same concentration of unlabeled urea while the treated branches were covered with plastic to keep them from contamination. The treatment conditions were sunny and breezy and air temperature was about 13°C.

The amounts of urea-^{15}N intercepted by the canopy, ^{15}N absorbed by leaves, and ^{15}N withdrawn into woody tissues were determined by the method of Millard and Neilsen (1989). To estimate the amount of urea-^{15}N

intercepted by the branch part excluding leaves, we chose six uniform branches on other trees, and defoliated these branches. The same rate of labeled urea was sprayed with the amount just enough to cover the surface of the branch and spur buds. In winter, these branches were harvested, washed, and partitioned into bark, wood, and spur flower buds to determine the amount of ^{15}N in each tissue. The amount of ^{15}N in each tissue was used as a background level for the foliated branch.

4. Results and Discussion

4.1 Blossom Thinning Studies

4.1.1 Synthetic auxins MCPB-ethyl and NAA

The thinning effects of bloom-time MCPB-ethyl or NAA treatments appear to be confined mostly to whole flower cluster removal. Neither chemical reduced fruit set within clusters as efficiently as carbaryl, ethephon (Table 1) or ATS (Table 2). For example, in a 1999 experiment where all trees received a post-bloom carbaryl spray, 1% ATS resulted in more than 68% of fruiting sites with a single fruit compared to 35% for NAA at 14 ppm. Thus, the significantly higher fruit set on the remaining clusters required a substantial amount of hand thinning.

Furthermore, neither MCPB-ethyl nor NAA had the desired effect of stimulating return flowering. Although return flowering was improved by some treatments, this occurred at the expense of excessive crop reduction. In some other cases, return flowering was suppressed by these auxin treatments (Fig. 1), even though they substantially removed whole flower clusters and thus reduced crop load. Similar results were obtained in the first Summerland experiment where MCPB-ethyl at 20 ppm was compared with carbaryl only for their effects on thinning and return flowering.

Thus, it appears that bloom-time auxins (at least for MCPB-ethyl and NAA) are capable of suppressing flower induction. Clearly, the enhanced flowering one would expect from such whole cluster removal failed to materialize. It could be that there are some residual effects of the applied auxin on development of the terminal meristem (where flower induction occurs for the following season) and/or there is an imbalance between flower promoting and flower inhibiting hormones during the critical phase of flower induction. Further research is required to validate these possible explanations.

In the Corvallis experiment, it was evident that the beneficial effect of carbaryl on flowering was specifically countered by the bloom-time auxin treatments (e.g., Fig. 1 for NAA). Since addition of ethephon generally reversed this negative auxin effect on flowering while showing only a slight effect on reducing fruit set, one could speculate that ethylene may affect the residual activity of the auxin and/or possibly retard shoot growth sufficiently to increase flower initiation.

In conclusion, whole cluster removal with bloom-time MCPB-ethyl or NAA spray does not appear to be a viable chemical thinning strategy for Fuji apple in the Pacific Northwest. We observed over-set on the remaining clusters, over thinning and leaf epinasty at l nd suppressed return flowering. Thus, while this procedu fruit set much more drastically (Yokota et al., 1995), v Northwest. In contrast, carbaryl applied at 11-mm frui f its

Fig.1. Return flowering of Fuji/M26 trees treated with NAA and ethephon at 85% full bloom, followed by post-bloom carbaryl (1000 ppm), alone and in combination. Values are means ± SE of five replicates

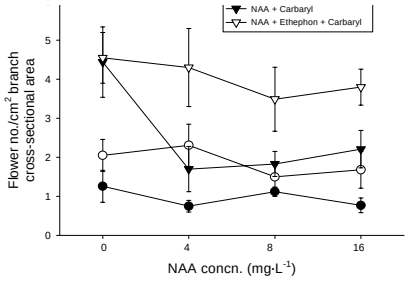

Table 1. Total fruit set (fruits/100 clusters) and fruit set distribution of Fuji/M26 apple trees treated with NAA and ethephon at 85% full bloom, alone and tank-mixed, followed by carbaryl at 1000 ppm at 11-mm fruit diameter (Corvallis, 1998)

Table 2. Total fruit set (fruits/100 clusters) and distribution of fruiting sites, intensity of hand thin, mean fruit weight, and yield of Fuji/M9 trees treated with NAA or ATS at 85% FB, followed by post-bloom carbaryl application (1000 ppm) with or without NAA at 5 ppm (Summerland, 1999)

Treatment	Total fruit set	Percentage fruiting sites with		
		single	double	3 or more
NAA 0 ppm	130	29	54	21
NAA 4 ppm	138	31	46	26
NAA 8 ppm	121	33	47	19
NAA 16 ppm	101	29	49	20
NAA 0 + Ethephon 100 ppm	-	-	-	13
NAA 4 + Ethephon 100 ppm	-	-	-	20
NAA 8 + Ethephon 100 ppm	-	-	-	22
NAA 16 + Ethephon 100 ppm	-	-	-	24
- Ethephon	135	28	51	-
+ Ethephon	110	33	47	-
- Carbaryl	142	32	40	28
+ Carbaryl	103	29	58	13

Treatment	Total fruit set	Percentage fruiting sites with		
		single	double	3 or more
NAA 0 ppm	129	57	29	15
NAA 7 ppm	113	54	31	15
NAA 14 ppm	111	38	36	27
NAA 21 ppm	28	50	36	14
ATS 1.0% a.i.	69	74	19	7
Carbaryl only (post-bloom)	97	50	32	18
Carbaryl + NAA (post-bloom)	82	59	28	13
Untreated control	183	36	31	33

4.1.2 Calcium-containing products

FUJI - NC99 at 3.75%, lime sulphur at 1.14%, and double applications of Stopit at 2.25% reduced fruit set to about 85 fruits/100 clusters. This compared to 109 fruits/100 clusters and 93 fruits/100 clusters for the untreated control and 1.6% ATS control, respectively.

Fruit size was positively related to the extent of fruit set reduction in most treatments except for the Stopit treatment where fruit size was not improved. This may have resulted from the phytotoxic effect on spur leaves by Stopit. All compounds except lime sulphur, at the middle and highest rates, showed phytotoxic effect on leaves. Stopit caused the most phytotoxicity, possibly due to the surfactant contained. Since no rate of this compound (applied only once) reduced fruit set, we doubt that Stopit will prove a successful thinner at a rate that does not cause leaf damage. None of the test compounds affected surface russet. Fruit shape (L/D), firmness, soluble solids, juice acidity, red block color, and fruit Ca were unaffected by any blossom thinner.

Considering the overall effects on thinning, fruit size, yield, and phytotoxicity, lime sulphur at the highest rate (1.14%) was the best among the bloom-time treatments. It proved similar to the 1.6% ATS control in most variables measured. Carbaryl further reduced fruit set and also increased fruit size, surface red color, soluble solids, and juice acidity, without interacting with any blossom thinner.

Return flowering was improved by most rates of lime sulphur and lower rates of Stopit and NC99, which was comparable to ATS (Table 3). This result indicates that leaf damage by bloom-time thinners possibly inhibit return bloom.

GALA - Gala proved more sensitive to the calcium sprays, especially to Stopit. The highest rate of NC99 and all rates of Stopit reduced fruit set more than the ATS control by increasing the proportion of cluster removal and fruiting sites with a single fruit. However, fruit size, though slightly larger than the untreated control, was generally smaller than on trees treated with ATS. None of treatments significantly increased the incidence of stem-end russet. As with Fuji, all treatments but lime sulphur, usually at the highest rate, were phytotoxic to leaves. Fruit shape, firmness, red block color, and fruit Ca were unaffected by treatments but soluble solids and juice acidity tended to be lower on trees treated with lower rates of NC99, Stopit, and Cor-Clear.

With Gala, we determined the effect of bloom-time thinners on fruit set of flowers on 1-year-old wood and most treatments reduced fruit set on these lateral flowers. Mean fruit set across all treatments was 65 fruits/100 clusters compared to 95 fruits/100 clusters for the untreated control. Among treatments, all rates of Stopit and the highest rate of lime sulphur substantially reduced fruit set on lateral flowers more or similar to the ATS control.

Return flowering was improved by 0.91 and 1.14% lime sulphur, 3.75% Stopit (Table 4). These were compared to the untreated control and 1.6% ATS.

Table 3. Total fruit set (fruits/100 clusters) and return flowering of Fuji/M9 trees treated with calcium-containing products or ATS during bloom, followed by post-bloom carbaryl at 1000 ppm (Summerland, 2000)

Table 4. Total fruit set (fruits/100 clusters) and return flowering of Gala/M26 trees treated with calcium-containing products or ATS during bloom (Summerland, 2000)

Treatment	Fruit set	Return bloom (Clusters/cm² branch area)
Check	93	6.7
ATS 1.6%	85	11.7
NC99 2.25%	88	10.4
NC99 3.0%	86	10.2
NC99 3.75%	79	7.1
Stopit 2.25%	85	10.1
Stopit 3.0%%	93	6.6
Stopit 3.75%	93	8.0
Cor-Clear 0.75%	88	8.4
Cor-Clear 1.0%	92	6.4
Cor-Clear 1.25%	90	6.1
Lime sulphur 0.68%	91	9.5
Lime sulphur 0.91%	90	9.0
Lime sulphur 1.14%	81	11.9
NC99 double @2.25%	86	7.4
Stopit double @2.25%	78	8.6
Cor-Clear double @0.75%	90	9.0
- Carbaryl	99	7.0
+ Carbaryl	75	10.3

Treatment	Fruit set	Return bloom (Clusters/cm² branch area)
Control	109	1.4
ATS 1.6%	83	3.4
NC99 2.25%	92	1.6
NC99 3.0%	89	1.1
NC99 3.75%	75	1.8
Stopit 2.25%	74	1.4
Stopit 3.0%	63	2.3
Stopit 3.75%	58	4.2
Cor-Clear 0.75%	98	1.5
Cor-Clear 1.0%	85	2.9
Cor-Clear 1.25%	89	2.7
Lime sulphur 0.68%	88	3.3
Lime sulphur 0.91%	77	3.4
Lime sulphur 1.14%	85	1.3

4.1.3 Lime sulphur

Lime sulphur reduced fruit set on Fuji/M9 trees, linearly with increasing rate; 4% lime sulphur reduced fruit set to 114 fruits/100 clusters, compared to 139 fruits/100 clusters of the untreated control (Table 5). Lime sulphur increased the proportion of fruiting sites with single fruit and reduced incidence of multiple fruits within clusters. Mean fruit weight was increased by lime sulphur by about 10 grams. Lime sulphur at 4% showed similar effects to 1.6% ATS on fruit set, proportion of fruiting sites with a single fruit or multiple fruits, and mean fruit weight.

Lime sulphur induced a slightly flatter fruit (Table 6). However, other characteristics of fruit quality such as percentage of red block color, incidence of russet, firmness, soluble solids, and titratable acidity were unaffected (Table 6). No phytotoxicity to spur leaves was observed with 4% lime sulphur.

Carbaryl further reduced crop load, produced more single fruit within clusters (fewer multiple fruit), and increased mean fruit weight compared to the non post-bloom control (Table 5). Accel® showed no thinning effect.

For Gala/M9 trees, lime sulphur also reduced fruit set linearly with increasing rate; 4% lime sulphur reduced fruit set from 187 fruits/100 clusters for the untreated control to 132 fruits/100 clusters. Lime sulphur treatment significantly increased the proportion of fruiting sites with single fruit (reduced the proportion of fruiting sites with multiple fruit). ATS at 1.6% was more effective than 4% lime sulphur in reducing fruit set (109 vs. 132 fruits/100 clusters). No phytotoxic damage on leaves was observed for 4% lime sulphur. Fruit quality characteristics including fruit shape, % red block color, incidence of stem-end russet, firmness, soluble solids, and titratable acidity were unaffected by lime sulphur or ATS.

The effect on return flowering will be determined in 2002.

Table 5. Effects of bloom-time lime sulphur (LS) or ATS sprays followed by post-bloom Accel® or carbaryl on fruit set, mean fruit weight, and yield of Fuji/M9 apple trees (Summerland, 2001)

Treatment	Fruit set[1]	% defruited clusters	% fruiting sites with			Mean fruit wt (g)	Yield (kg/tree)
			single	double	3-5		
Control	139	13.8	56.8	28.9	14.3	190	23.5
1% LS	130	14.9	59.9	30.2	9.9	202	25.1
2% LS	120	18.4	63.1	28.6	8.3	201	22.3
4% LS	114	18.3	69.2	24.3	6.5	212	24.6
1.6% ATS	118	20.9	63.0	28.2	8.8	214	24.7

No post-bloom thinner	135	13.7	57.5	31.0	11.5	200	22.6
Accel®	133	15.8	57.2	30.8	12.0	199	24.5
Carbaryl	104	22.2	72.4	22.3	5.3	211	25.1
Significance							
Bloom-time sprays	**	n.s.	**	n.s.	*	*	n.s.
Post-bloom sprays	****	***	****	****	***	n.s.	n.s.
bl x pb	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Contrasts							
LS linear	***	n.s.	***	*	**	*	n.s.
LS quadratic	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
LS cubic	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
LS 4% vs. 1.6% ATS	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[1]Fruit per 100 clusters, determined after June drop but before hand thinning
n.s., *, **, ***, ****Nonsignificant or significant at P = 0.05, 0.01, 0.001, and 0.0001, respectively

Table 6. Effects of bloom-time lime sulphur (LS) or ATS sprays followed by post-bloom Accel® or carbaryl on fruit quality characteristics of Fuji/M9 apple (Summerland, 2001)

Treatment	Fruit shape (L/D)	Red block color (%)	Russet[1] (0-5 index)	Firmness (N)	SS (ºBrix)	TA[2]
Control	0.91	82	0.83	80.0	14.9	7.35
1% LS	0.93	79	0.76	80.4	14.8	7.19
2% LS	0.93	80	0.80	80.7	15.1	7.42
4% LS	0.93	79	0.86	80.6	15.1	7.38
1.6% ATS	0.93	79	0.82	80.3	14.9	7.36
No post-bloom thinner	0.92	82	0.75	79.5	15.0	7.42
Accel®	0.93	78	0.76	81.9	14.6	7.02
Carbaryl	0.93	79	0.94	79.8	15.3	7.57
Significance						
Bloom-time sprays	**	n.s.	n.s.	n.s.	n.s.	n.s.
Post-bloom sprays	**	*	n.s.	n.s.	*	*
bl x pb	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Contrasts						
LS linear	*	n.s.	n.s.	n.s.	n.s.	n.s.
LS quadratic	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
LS cubic	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
LS 4% vs 1.6% ATS	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

n.s., *, **Nonsignificant or significant at P = 0.05 and 0.01, respectively
[1]Index: 0 = no russet; 5 = very severe russet
[2]The ml of 0.1 N NaOH used to titrate 15 ml of juice to pH 8.1

4.2 Growth Control of Apple with Apogee

4.2.1 Greenhouse study

Foliar application of Apogee, a gibberellin biosynthesis inhibitor, effectively inhibited stem elongation and reduced leaf number but increased specific leaf weight, root dry matter production, and root : shoot ratio. Foliar application of GA_{4+7} to the Apogee-treated plants completely reversed many of the effects induced by Apogee, indicating that growth patterns of apple can be altered by controlling the supply of gibberellins. Furthermore, the altered growth patterns are related to changes in the biochemical and physiological activities within plant parts. For example, Apogee treatment increased TNC, expressed either on a concentration or content basis, in all parts, which was largely due to the significant increase in levels of starch rather than soluble sugars. In contrast, GA_{4+7} substantially reduced TNC levels in all parts. Apogee did not alter allocation pattern of TNC

within tree parts; while GA_{4+7} application caused a slight shift from roots to stem, which was consistent with the effect on dry matter partitioning.

Early afternoon decline in stomatal conductance was observed on the Apogee-treated plants, measured 10 days after shoot growth ceased. This decline was attributed to a possible feedback inhibition of photosynthesis caused by a buildup of starch in the Apogee-treated plants where sink strength was likely substantially reduced, compared to the control or Apogee + GA_{4+7} treated plants.

Further experiments under field conditions is necessary before the potential of this GA biosynthesis inhibitor can be fully defined especially for the bearing orchard trees. Nevertheless, its potential utility for inhibiting vegetative growth to reduce pruning costs and to limit tree size in high density orchards makes feasible the use of Apogee in apple production systems.

For detailed information on this work, refer to the article of Guak et al. (2001) published in the Journal of Horticultural Science and Biotechnology 76:746-752.

4.2.2 Field study

Apogee effectively reduced shoot elongation growth. As for the upright shoots, Apogee was more effective than any single treatment of NAA paint, NAA spray, and ethephon (Table 7). The most effective treatment was the combination of NAA paint + Apogee+ ethephon. NAA paint + ethephon treatment was as effective, whereas NAA spray + ethephon was much less effective.

Fruit set was significantly increased by Apogee but decreased by ethephon (Table 7). The ethephon effect on fruit set was diminished on the trees treated with Apogee. Fruit weight was decreased by Apogee and NAA spray treatment, with the latter causing the greater reduction (Table 7). NAA paint treatment also slightly reduced fruit weight. Ethephon had no effect. Fruit yield was increased by Apogee and possibly by NAA paint treatment, but was decreased by NAA spray and ethephon treatment.

NAA spray treatment induced about 4% pygmy fruits, while Apogee, NAA paint, and ethephon had no effect. Fruit shape was unaffected by any treatment, so was fruit firmness. Soluble solids concentration was slightly decreased by Apogee or NAA paint but was significantly increased by ethephon. Titratable acidity was decreased by Apogee or NAA paint. Stem-end russet development was unaffected.

The time of harvest, as determined on the basis of red and yellow block color, was significantly enhanced by ethephon but was delayed by Apogee (Table 8). During the first pick, 28% of the total fruits were harvested on Apogee treated trees compared to 34% for control trees. In contrast, ethephon resulted in 44% of the total fruits harvested during the first pick. This ethephon effect was slightly diminished on the Apogee treated trees.

Return flowering was significantly inhibited by both Apogee and NAA treatments (Table 7). In contrast, ethephon promoted flowering. It was interesting to observe that return flowering was further suppressed when NAA paint was combined with Apogee($P < 0.05$ for NAA x Apogee).

In our previous study with 7-year-old Golden delicious/M9 slender spindle trees, Apogee, applied 28 days after full bloom, markedly suppressed shoot growth but had no effect on fruit size, yield, and return flowering (Guak et al., 2002). However, ethephon treatment, applied 35 and 71 days after full bloom, was less effective than Apogee in suppressing shoot growth while substantially reducing fruit size and yield, and promoting return flowering. With respect to fruit nutrients, Apogee increased N, K and Mg concentrations; ethephon increased N, P, K, Mg and B. Fruit Ca was unaffected.

In conclusion, Apogee proved effective in suppressing shoot elongation growth of superspindle Gala/M9 trees in high density plantings compared with other growth retardants NAA and ethephon. Other notable results with Apogee included significantly increased fruit set and yield, reduced fruit size, delayed fruit maturity, and inhibited return flowering. Some discrepancies found between experiments, despite comparison was made on the different tree types and cultivars, suggest that further research is needed before its potential is fully defined for use in apple.

Table 7. Effects of NAA, Apogee, and ethephon on shoot elongation growth, fruit set (fruit no./100 clusters), mean fruit weight, yield, and return flowering (flower clusters/cm^2 TCSA) of six-year-old superspindle Gala/M9 trees. For details in treatments, see the section of Methods

Treatment			Shoot length (cm)	Fruit set	Mean fruit wt (g)	Yield (kg/tree)	Return bloom
NAA	Apogee	Ethephon					
0	0	0	68.5	66	206	8.3	9.2
0	0	300	59.5	47	207	6.9	9.7
0	250	0	37.5	71	183	9.5	6.7
0	250	300	43.4	80	191	9.1	7.5
Paint	0	0	58.7	65	198	10.1	7.5
Paint	0	300	35.6	58	194	8.0	8.9
Paint	250	0	41.7	83	180	10.6	5.1
Paint	250	300	29.2	73	177	9.1	6.5
Spray	0	0	56.9	63	177	7.5	8.1
Spray	0	300	51.6	60	181	6.5	8.3
Spray	250	0	45.2	79	174	7.0	8.0
Spray	250	300	38.8	66	171	7.5	8.7

Table 8. Effects of NAA, Apogee, and ethephon on fruit maturity (based on both red and yellow surface color) of six-year-old superspindle Gala/M9 trees. For details in treatments, see the section of Methods.

Treatment			Proportion of harvested fruits (%)			
NAA	Apogee	Ethephon	1st pick	2nd pick	3rd pick	Leftovers
0	0	0	34	41	17	7
0	0	300	44	36	11	9
0	250	0	28	38	20	14
0	250	300	36	40	14	10
Paint	0	0	34	39	18	9
Paint	0	300	40	44	10	6
Paint	250	0	29	34	23	13
Paint	250	300	37	36	14	13
Spray	0	0	38	35	18	9
Spray	0	300	43	34	15	7
Spray	250	0	31	36	21	12
Spray	250	300	35	43	16	7

4.3 Determination of Absorption, Withdrawal, and Remobilisation of Foliar Urea N in Apple Trees

Table 9 summarizes how much urea-derived ^{15}N was absorbed by leaves, withdrawn during leaf senescence, partitioned into dormant woody tissues, and finally remobilized for the spring growth of flower clusters and spur leaves. Leaves absorbed 17% of the ^{15}N intercepted by the leaves, which was relatively little compared to that reported for more humid regions. During leaf senescence, 47% of the ^{15}N absorbed was withdrawn into perennial woody tissues; some 53% of the ^{15}N was retained in the abscised leaves.

In winter, 92% of the ^{15}N withdrawn was stored in the woody tissues of the treated branch; 59% in bark, 28% in wood, and 5% in flower buds. These results suggest that very little ^{15}N moves out of the treated branch and that substantial amounts of withdrawn N is stored in the bark tissue.

In spring, around pink stage, about 57% of ^{15}N stored in the branch had been remobilized for the growth of flower bud complex (flowers and spur leaves), which accounted for 3.5% of total N in those tissues. This proportion would probably be higher in low N trees or if we had applied urea more than once, or under conditions for improved absorption (for example, high humidity conditions following application). Post-harvest urea slightly advanced flower opening and petal fall, and slightly increased fruit set.

Table 9. Summary of absorption of foliar urea N, withdrawal during leaf senescence, and remobilization for the spring growth of flower bud complex (flowers and spur leaves) in six-year-old Jonagold/M9 apple trees treated with post-harvest urea. Values are mean of 10 trees ± SE.

Time	Type of N	Plant part	mg ^{15}N/branch
Post-harvest	Supplied-N	Leaves & woody tissues	530.2 ± 12.1
	Intercepted-N	Leaves	280.5 ± 10.3
	Absorbed-N	Leaves	47.8 ± 6.8
	Withdrawn-N	Senescing leaves	23.3 ± 1.5
Winter	Stored-N	Bark	13.7 ± 2.1
	Stored-N	Wood	6.4 ± 0.9
	Stored-N	Spur buds	1.2 ± 0.2
	Branch total		21.4 ± 4.5
Spring (pink stage)	Remobilized-N	Flower clusters including spur leaves	11.7 ± 3.3
	Retained-N	Rest tissues of the branch	8.9 ± 1.3
	Branch total		20.7 ± 3.5

5. References

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6. Publications

1. Guak, S, M. Beulah, N.E. Looney and L.H. Fuchigami. 2002. Thinning of 'Fuji' apple: Blossom thinning with synthetic auxins (MCPB-ethyl and NAA) and ethephon with or without post-bloom carbaryl. Journal of the American Society for Horticultural Science (In press).
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