FINAL PROJECT REPORT **YEAR**: 3 of 3

Project Title: Crop load and canopy management of apple

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Budget 1:
Organization Name: WTFRC **Contract Administrator:** Kathy Coffey
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Year	**2014**	**2015**	**2016**
Salaries	35,000	30,000	20,000
Benefits	10,000	9,000	6,000
Wages	50,000	35,000	26,000
Benefits	17,000	12,000	8,600
Equipment			
Supplies	1,000	500	500
Travel	3,000	2,500	2,000
Stemilt lab fees	2,000	1,500	500
WSU plot fees			6,400
Statistical consulting	1,000	0	0
Total gross costs	119,000	90,500	70,000
Reimbursements	(119,000)	(87,000)	(70,000)
Total net costs	0	3,500	0

Footnotes: Supply costs primarily covered by private industry cooperators
Travel includes fuel costs for driving to trial sites
Stemilt lab fees for use of single lane Aweta color grader
Statistical consulting for analysis of tree-to-tree variability for long-term cropping study on WSU Sunrise Granny Smiths

NOTE: Budget for informational purposes only; research is funded through WTFRC internal program

OBJECTIVES:

1) Continue screening PGRs, chemical thinners, and mechanized thinning technologies for apple
2) Refine practical PGR programs to manipulate floral initiation and promote annual bearing
3) Document horticultural effects of synthetic materials deployed as reflective ground covers or overhead shade/wind/bird protection
4) Expand collaborative efforts with other research programs working on crop load and canopy management

2014-2016 CONCLUSIONS:

K-Pax, an alternative lime sulfur formulation, performed similarly to Rex Lime Sulfur in two years of thinning studies (Table 2)

Spray oil + lime sulfur programs are the most efficacious options for chemical bloom thinning of apple (Table 3)

Metamitron can effectively reduce fruit set and boost fruit size in WA conditions when used aggressively (Tables 4, 5)

Metamitron efficacy can be promoted by tank mixing with non-ionic surfactants, lightweight summer petroleum oils, or NAA (Table 4)

Aggressive metamitron programs can induce phytotoxicity in apple trees experiencing carbon stress, but effects are largely temporary

High temperatures combined with low light conditions following applications of postbloom thinners can amplify treatment effects, potentially resulting in over-thinning (Table 4)

BA + NAA programs are as effective as any postbloom thinning program featuring carbaryl (Table 5)

Addition of calcium phosphite to postbloom thinning programs demonstrated no clear effects (see 2015 and 2016 project reports)

Multiple formulations of prohexadione calcium significantly reduced shoot growth of Fuji; efficacy increased with acidification of spray tanks with ammonium sulfate (data not shown)

2014 summer applications of new NAA formulations were as ineffective at promoting return bloom as multiple standard NAA and ethephon programs evaluated by WTFRC in the mid 2000's (data not shown)

Multiple applications of 100-200 ppm GA_3 have effectively reduced return bloom in apple over several years of study, including 2015 trials (Table 6)

Shade netting improved fruit size and packouts (reduced sunburn and hail damage) without loss of yields in Granny Smith (see 2014 project report)

Collaborative research efforts continue to help develop new information and technologies to improve crop load management of WA apples

BACKGROUND:
After years of robust efforts to evaluate various aspects of bloom and postbloom chemical thinning programs, our current focus is to screen new chemistries and provide collaborative support for external research programs working on crop load and canopy management. Most of our current trials are funded in part or wholly by third party companies that contract our services to independently evaluate their products alongside industry standard programs. We continue to evaluate the relative success of thinning programs through three measurable targets which are directly tied to a grower's economic bottom line:

1. Reduction of green fruitlet hand-thinning
2. Improved fruit size and quality
3. Increased return bloom/annual bearing

The degrees to which our chemical thinning programs achieve each of these goals are reflected in our data labeled fruitlets/100 floral clusters, harvest fruit size, and percent return bloom, respectively.

Chemical thinning programs evaluated in 2016 are listed in Table 1. Due to the potentially risky nature of many of our treatments, we conducted all but one of our trials at WSU's Sunrise Research Orchard, which also allowed us to ensure no other thinning applications were superimposed on our plots. Historically, however, additional bloom or postbloom chemical thinning applications have been left to the discretion of individual commercial grower-cooperators, provided that each experimental plot received the same programs.

Table 1. Chemical thinning programs evaluated. WTFRC 2016.

BLOOM THINNERS (applied in 100 gal water/A @ 60% & 100% bloom)
4 & 8% Rex Lime Sulfur (LS)
4 & 8% K-Pax II
2% Crocker's Fish Oil (CFO) + 1.5-3% K-Pax II
2% Crocker's Fish Oil (CFO) + 3% Rex Lime Sulfur (LS)
POSTBLOOM THINNERS (applied in 100 gal water/A at PF & 12mm, or 8mm & 15mm)
300-800 ppm Brevis (metamitron)
400-600 ppm Brevis + 1% Wilbur Ellis Supreme Oil (WES)
300-600 ppm Brevis + 16 oz Regulaid/A
600 ppm Brevis + 5 oz Fruitone L/A
600-800 ppm ADA 46342
400-600 ppm ADA 46342 + 16 oz Regulaid/A
24 oz Exilis 9.5SC + Fruitone L/A
122 oz Exilis Plus + 4 oz Fruitone L/A
48 oz Carbaryl 4L + 4-5 oz Fruitone L (NAA)/A
128 oz MaxCel + 4-5 oz Fruitone L/A

BLOOM THINNING:
2016 marked the first full scale bloom thinning trial with K-Pax, a new alternative formulation of lime sulfur being developed by Orcal Inc., the registrant of Rex Lime Sulfur. K-Pax has been engineered to produce a higher yield of H_2S, theoretically making it more efficacious against fungi including powdery mildew. Preliminary trials in 2014 and 2015 demonstrated reduced fruit set with no phytotoxicity with applications of K-Pax as a stand-alone product. In 2016, we expanded the treatment list to include tank mixes of K-Pax with a spray oil (Crocker's Fish Oil) at typical commercial rates; unfortunately, we were unable to observe thinning effects from any treatment,

including a standard program of CFO + Rex Lime Sulfur (Table 2). We had no difficulties in handling or mixing and observed no phytotoxicity to leaves or fruit from any treatment.

Table 2. Crop load and fruit quality effects of bloom chemical thinning programs. WTFRC 2016.

Treatment	Fruitlets/100 floral clusters	Blanked spurs	Singled spurs	Harvest fruit weight	Relative box size	Russet free fruit
		%	*%*	*g*		*%*
Gala / M.9 Nic.29 – Rock Island						
2 gal CFO + 1.5 gal K-Pax II	93 a	44 ns	32 ns	152 ns	119	93 ns
2 gal CFO + 3 gal K-Pax II	88 ab	49	29	152	119	97
2 gal CFO + 3 gal Rex LS	61 b	57	29	164	111	93
4 gal K-Pax II	65 ab	56	28	160	114	87
8 gal K-Pax II	72 ab	49	34	151	120	95
4 gal Rex LS	73 ab	52	31	154	118	100
8 gal Rex LS	62 b	57	29	158	115	85
Control	67 ab	55	28	153	119	98

Table 3 reflects the cumulative success rates of our most frequently tested chemical bloom thinners over time at achieving our three main criteria for effective thinning and demonstrates the overall superiority of programs featuring lime sulfur.

Table 3. Incidence and percentage of results significantly superior to untreated control. Apple chemical bloom thinning trials. WTFRC 1999-2016.

Treatment	Fruitlets/100 blossom clusters	Harvested fruit size	Return bloom[1,2]
ATS	15 / 60 (25%)	10 / 63 (16%)	4 / 55 (7%)
NC99	15 / 32 (47%)	7 / 34 (21%)	2 / 28 (7%)
Lime sulfur	26 / 58 (45%)	12 / 52 (23%)	9 / 51 (18%)
CFO + LS	62 / 115 (54%)	27 / 106 (25%)	22 / 104 (21%)
JMS + LS	14 / 24 (58%)	8 / 23 (35%)	4 / 22 (18%)
WES + LS	15 / 30 (50%)	5 / 29 (17%)	4 / 29 (14%)
ThinRite	7 / 22 (32%)	0 / 23 (0%)	0 / 12

[1]Does not include data from 2016 trials.

[2] (no. blossom clusters year 2/sample area) / (no. blossom clusters year 1/sample area)

POSTBLOOM THINNING:

Our main focus for postbloom thinning continues to be metamitron, a sugar beet herbicide that has been recently registered by Adama under the trade name “Brevis” as a postbloom thinning agent in several countries including Italy, France, Spain, and South Africa. We have worked with small quantities of metamitron since 2011, finding it to be a promising chemistry when used aggressively in our relatively low plant stress environment. While trials in Europe and the Eastern US have found single applications of 200-400 ppm metamitron to be efficacious, our results indicate that two applications of 600-800 ppm are necessary to produce similar effects in Washington conditions. With these aggressive use patterns, we continue to produce trial results which indicate metamitron can be a viable thinning chemistry for our industry, particularly if carbaryl eventually loses its registration.

This year, we evaluated Brevis, the commercial formulation of metamitron used in Europe, alongside a numbered formulation (ADA 46432) from Adama which contains a different package of inert ingredients. As in 2015, our 2016 metamitron treatments were generally equal to or better than industry standards like carbaryl and BA in terms of reducing fruit set and/or promoting fruit size across sites and cultivars (Table 4). Generally speaking, we have found that metamitron can pair well in tank mixes with a non-ionic surfactant (Regulaid), a summer oil (Wilbur Ellis Superior Oil), or NAA (Fruitone L); in most instances, a reduced concentration of metamitron in a tank mix with one of those partner chemistries has produced similar results to those of higher rates of metamitron alone. Previous WTFRC studies found that adding silicone-based surfactants or heavier-weight dormant oil to metamitron produced significant levels of phytotoxicity.

Table 4. Crop load and fruit quality effects of postbloom thinning programs. WTFRC 2016.

Treatment	**Fruitlets/100 floral clusters**	**Blanked spurs**	**Singled spurs**	**Harvest fruit weight**	**Relative box size**	**Russet free fruit**
		%	*%*	*g*		*%*
Fuji / M.9 337 – Othello						
Brevis 300ppm	116 bc	42 abc	23 ns	264 ns	69	64 b
Brevis 300ppm + Regulaid	82 c	54 a	22	259	70	48 b
Brevis 600ppm	86 c	51 ab	25	269	68	70 a
Carbaryl 4L + Fruitone L	154 a	32 c	19	269	68	78 a
Exilis 9.5 SC + Fruitone L	142 ab	38 bc	18	254	71	73 a
ExilisPlus + Fruitone L	113 bc	42 abc	24	267	68	76 a
MaxCel + Fruitone L	121 ab	41 abc	22	257	71	71 a
Control	116 bc	44 abc	22	264	69	74 a
Golden Delicious 3D / M.9 – Rock Island						
ADA 46342 600ppm	13 bc	90 bc	8 bc	261 a	70	35 ns
ADA 46342 800ppm	6 c	95 a	4 c	279 a	65	31
Brevis 600ppm	10 c	92 ab	7 bc	280 a	65	38
Brevis 600ppm + Fruitone L	10 c	92 ab	6 bc	267 a	68	26
Brevis 800ppm once	25 b	84 c	10 b	268 a	68	36
Brevis 800ppm twice	11 c	93 ab	5 c	259 a	70	30
MaxCel + Fruitone L	5 c	96 a	4 c	289 a	63	40
Control	87 a	48 d	30 a	189 b	96	55
Granny Smith 9A / M.9 337 – Rock Island						
ADA 46342 400ppm + Regulaid	35 def	67 cde	32 bcd	289 ab	63	51 ns
ADA 46342 600ppm	20 efg	81 bc	18 de	258 b	70	56
ADA 46342 600ppm + Regulaid	29 def	72 bcd	26 cde	270 ab	67	66
Brevis 400ppm	74 ab	29 f	52 a	292 ab	62	58
Brevis 400ppm + Regulaid	38 cde	64 cde	34 bcd	287 ab	63	60
Brevis 400ppm + WES	56 bc	51 ef	44 ab	273 ab	67	33
Brevis 600ppm	43 cd	59 def	40 abc	242 b	75	54
Brevis 600ppm + Regulaid	36 def	67 cde	31 bcd	252 b	72	50
Brevis 600ppm + WES	25 defg	76 bc	23 cde	295 ab	62	65
Carbaryl 4L + Fruitone L	17 fg	83 b	17 de	326 a	56	51

MaxCel + Fruitone L	6 g	95 a	5 e	293 ab	62	38
Control	79 a	44 f	38 bc	238 b	76	50

In more than 300 replicated chemical thinning trials since 1998, our research program has seen only a few cases of legitimate over-thinning, but 2016 will be remembered as a season when several of our thinning treatments were clearly too aggressive in trials on Granny Smith and Golden Delicious at the WSU Sunrise Research Orchard. Weather conditions for several days after our second sprays on May 2 featured heavy cloud cover, daytime temperatures in 70s and 80s, and nighttime temperatures in the high 50s and low 60s, creating considerable carbohydrate stress in test trees and setting them up for strong thinning responses. Dramatic reductions in fruit set and increases in harvest fruit size were observed across nearly all treatments, especially in Golden Delicious (Table 4). Treated trees were in visible shock for several days after the 15mm applications, particularly those that were sprayed with NAA, whether it was partnered with carbaryl, BA, or metamitron (Figures 1, 2). In fact, trees in several plots treated with NAA continued to feature wilted, curled leaves and poor shoot growth through most of the growing season. More typical Central Washington weather conditions bracketed the spray applications in a commercial Fuji orchard near Othello, and the thinning responses in that trial were far more subtle (Table 4).

Figure 1. Untreated control Granny Smith trees (L) and leaves (R). May 4, 2016.

Figure 2. Granny Smith trees (L) and leaves (R) 48 hours after 15mm BA + NAA application. May 4, 2016.

Several plots treated with metamitron programs also featured some phytotoxicity commonly associated with that chemistry. Mild chlorosis and marginal burn on primary leaves similar to effects observed in 2015 (Figure 3) were sprinkled throughout treated areas, but as has been the case in previous studies, those trees grew out of those conditions within a few weeks and no long-term harm to trees or fruit occurred.

Figure 3. Mild (L), moderate (C), and severe (R) leaf damage caused by metamitron applications. WTFRC 2015.

Our confidence in the potential of metamitron as a thinner in WA conditions continues to grow as we gain more experience with this chemistry. Table 5 demonstrates that after several years of testing, our success rates for producing satisfactory results from metamitron thinning treatments are comparable or superior to any standard industry programs; when metamitron is partnered with materials like a non-ionic surfactant, a summer oil, or another thinner such as NAA, our results have consistently improved. Even though metamitron is unlikely to complete registration with the EPA within the next 5 years, WA growers should be able to achieve satisfactory results with currently available products. We continue to find good results in postbloom thinning programs that feature tank mixes of carbaryl, BA, and/or NAA (Table 5).

Table 5. Incidence and percentage of results significantly superior to untreated control. Apple chemical postbloom thinning trials. WTFRC 2002-2016.

Treatment	Fruitlets/100 blossom clusters	Harvested fruit size	Return bloom[1,2]
BA	3 / 23 (13%)	0 / 24 (0%)	0 / 22 (0%)
Carb + BA	33 / 91 (36%)	10 / 89 (11%)	13 / 86 (15%)
Carb + NAA	18 / 65 (28%)	12 / 65 (18%)	6 / 61 (10%)
BA + NAA	17 / 39 (44%)	8 / 38 (21%)	5 / 32 (16%)
Metamitron	7 / 16	3 / 15	1 / 13

[1]Does not include data from 2016 trials.

[2] (no. blossom clusters year 2/sample area) / (no. blossom clusters year 1/sample area)

GIBBERELLIC ACID FOR BLOOM INHIBITION:

Despite the annual cropping tendencies of modern dwarfing rootstocks and improved chemical thinning programs, biennial bearing continues to present a major challenge to many apple growers, especially in organic production systems which have limited options for postbloom thinning and plant growth regulators (PGRs). Over the years, we have investigated a number of PGR programs to promote bloom, but had very poor results with industry standards such as summer applications of ethephon and/or NAA. Consequently, we shifted our focus to investigate cost-effective PGRs, namely gibberellic acids (GAs), which could help excessive cropping in an "on" year of an alternate bearing cycle by inhibiting flower formation after a season of light bloom (i.e. the "off" year). Our work showed that several isomers of GA can reduce return bloom in WA conditions, but our primary focus was on GA_3 due to its potential for use in organic orchards and effective rates of that isomer would potentially be less expensive to growers than effective rates of more potent isomers.

After many years of studying product rates and timings, we determined that 2-4 applications of 100-200 ppm of GA_3 in the month after petal fall yielded the most consistent reductions in return bloom across numerous sites and cultivars. Single applications of higher concentrations of product were also sometimes effective, but not as reliably as multiple applications at 7-14 day intervals. Table 6 reports results from GA trials launched in 2015 which primarily featured Falgro 2XLV, a commercial formulation of GA_3 registered for use on cherry to promote size and delay maturity.

Table 6. Effects on tree vigor, fruit size, and return bloom of GA applications. WTFRC 2015.

Treatment	**2015 shoot length**	**2015 harvest fruit weight**	**2015 relative box size**	**2016 return bloom**	**2016 return bloom per CSA**
	cm	*g*		*%*	*clusters/cm²*
Fuji / M.7 w/Red Del & Cameo interstems - Bridgeport					
Falgro 2XLV 100ppm	21.4 ns	nd	nd	339 ns	0.6 ns
Falgro 2XLV 200ppm	20.7			421	0.9
Falgro 2XLV 400ppm	20.0			263	0.7
Control	19.3			661	1.0
Fuji / Multiple leader grafts - Brewster					
Falgro 2XLV 100ppm	32.7 ns	223 ns	81	532 ns	2.7 b
Falgro 2XLV 200ppm	36.5	219	83	807	2.7 b
Falgro 2XLV 400ppm	34.6	216	84	902	4.0 b
Control	32.2	222	82	1071	6.0 a
Fuji / M.9 - East Mattawa					
Falgro 2XLV 100ppm	23.1 ns	190 ns	96	130 ns	0.8 ns
Falgro 2XLV 200ppm	20.9	206	88	139	0.5
Falgro 2XLV 400ppm	20.9	196	93	84	0.8
Control	23.2	198	92	112	0.9
Fuji – M.26 / Rock Island					
Falgro 2XLV 100ppm	40.0 ns	184 ns	99	45 ns	0.4 ns
Falgro 2XLV 200ppm	39.2	200	91	378	0.4
Falgro 2XLV 400ppm	36.3	199	91	95	0.1
Control	36.1	202	90	179	0.4
Golden Delicious / Seedling – South Mattawa					
Falgro 2XLV 100ppm	25.3 a	201 ns	90	404 ns	2.2 ns
Falgro 2XLV 200ppm	24.6 ab	205	89	337	2.0
Falgro 2XLV 400ppm	21.9 b	208	87	438	2.6
FAL 477	22.3 ab	206	88	375	2.4
Novagib 10L	25.2 a	214	85	765	2.4
Control	24.7 ab	216	84	601	2.3

As in the past, our recent trials demonstrate the inherent challenge of generating statistically significant results due to pronounced variability within return bloom data; even though a grower would consider trees with either 2 or 20 flower clusters to have insufficient bloom, results like those still reflect a 10X degree of variability, which can thoroughly confound an analysis of variance. Despite these mathematical challenges, roughly half of our GA_3 trials through the years have produced statistically significant reductions in return bloom. Further, another 20-30% of our studies have yielded results similar to those from our 2015 Bridgeport and Rock Island Fuji trials (Table 6), where numeric reductions in return bloom were observed without statistical significance.

The fundamental question remaining for these programs is not their efficacy, but whether or not registrants of GA_3 products will decide to amend their labels to accommodate this use pattern on apple. Several companies manufacture GA_3 for use in tree fruit, and we have lobbied the key PGR suppliers for the Pacific Northwest tree fruit market for years to consider relevant label expansions. Unfortunately, these companies can find little financial incentive to assume the costs and potential liabilities for doing so given the availability of several other analogous competitor products in the market.

Based on the relatively consistent performance of these GA_3 programs, it seemed of little marginal value to continue demonstrating their efficacy, so we decided in 2016 to limit any new trial work to evaluation of new GA formulations. As such, we launched two studies this spring to evaluate a new product with a unique profile of GA isomers; return bloom data will be collected this coming spring. If this formulation shows promise, the company that is developing it hopes to have it registered specifically to reduce bloom in apple.

COLLABORATIVE CROP LOAD MANAGEMENT RESEARCH:

"Effects of physiology of apple under photoselective anti-hail nets" (AP-15-104; PI: Kalcsits) – support for labor intensive data collection, harvest sampling, and postharvest fruit quality analysis; also support for project leadership team including sharing of relevant WTFRC projects and protocols, as well as editing of project manuscripts

"Pollen tube growth model validation & utilization for flower thinning" (AP-15-105; PI: Yoder) – local support for coordination with WSU-AgWeatherNet, beta testers, and flower sample collection for shipment to VTU for microscopic analysis; leadership of extension/education efforts regarding industry adoption of models

"Validation of Honeycrisp and Granny Smith pollen tube growth models" (AP-15-103; PI: Yoder) – local support for coordination of beta testers and flower sample collection for shipment to VTU for microscopic analysis

"Validation of the Red Delicious pollen tube growth model" (AP-16-108; PI: Yoder) – local support for coordination of beta testers and flower sample collection for shipment to VTU for microscopic analysis

"Development and validation of a precision pollination model" (TR-16-102; PI: Rafferty) – coordination of local data collection for bee foraging, bloom phenology, and fruit sampling activity at sites near Yakima and Chelan; active member of project leadership team (project funded through WTFRC technology committee)