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 Schmidt
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Item	2008	2009	**2010**
Salaries	23,230	26,220	25,000
Benefits	6,770	7,650	7,200
Wages	27,150	25,700	24,000
Benefits	12,750	12,100	11,500
Equipment	2,500	3,000	3,000
Supplies	2,500	3,000	3,000
Travel	2,000	2,000	2,000
RCA rental	1,200	4,200	4,200
USDA facilities fee	750	750	750
Total gross costs	76,850	84,620	80,650*
Reimbursements	(27,600)	(25,000)	(36,450)*
Total net costs	$49,250	$59,620	$44,200*

Footnotes: RCA rental based on fiscal year billing cycle
Travel includes fuel costs for driving to trial sites
USDA facilities fee covers storage space and use of research packing line
* Figures do not include $72,000 for contracted chemical thinning trials (confidential)

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

OBJECTIVES:

1) Evaluate pre-bloom, bloom, and post-bloom chemical thinning agents and mechanical thinning technologies with particular focus on complete programs to achieve three goals:
   a) Minimize costs of green fruitlet thinning
   b) Maximize fruit quality
   c) Encourage annual bearing
2) Investigate influence of important variables (drying conditions, spray technology, carrier volume) on chemical thinner efficacy and fruit finish
3) Develop practical PGR programs to manipulate floral initiation and promote annual bearing
4) Evaluate horticultural effects of reflective materials (Extenday, mylar products)
5) Profile natural tree-to-tree variation in long-term cropping patterns in a newly planted apple block
6) Expand collaborative efforts with other research programs

SIGNIFICANT FINDINGS:

Effective chemical thinning programs reduce hand-thinning, improve fruit size and quality, and increase return bloom; bloom thinners generally achieve these goals more consistently than postbloom programs (Tables 3,5)

Oil (dormant, summer, vegetable, fish) + lime sulfur programs are the most efficacious options for bloom thinning; results with Crocker's Fish Oil are most consistent (Table 3)

Endothall (ThinRite) has been as effective as Crocker's Fish Oil + lime sulfur in recent trials and may provide a viable alternative for chemical bloom thinning of apple (Table 2)

Thinning efficacy and fruit finish were not clearly affected by variations in spray technology (AccuTech vs. Proptec vs. airblast), carrier volume (100 vs. 200 gal/acre), or drying conditions (dawn vs. noon vs. evening sprays) of chemical thinning programs (data not shown)

BA + carbaryl thinning programs give results equal or superior to NAA + carbaryl or ethephon + carbaryl programs; BA often shows a positive effect on fruit size (Tables 4, 5)

Crops may be effectively thinned chemically without use of carbaryl; BA + NAA programs demonstrate positive results (Tables 4, 5) with no deleterious effect on fruit quality

Apogee shows no clear, consistent effect on the efficacy of chemical bloom or postbloom thinners in the first year of testing (Tables 2, 4)

Summer applications of NAA have not increased return bloom in WTFRC trials; GA trials to inhibit return bloom show promise for mitigation of biennial bearing (Figure 1, Table 6)

Extenday products improve yields of target fruit in apple by:

1) Increasing fruit set without sacrificing fruit size (Tables 7, 8)
2) Increasing fruit size without reducing fruit set (Tables 7, 8)
3) Increasing fruit color (Tables 7-9)

Trees treated with Extenday products over multiple seasons demonstrate increasing capacity to carry high quality fruit (Tables 7, 8)

Mylar products increase apple fruit color, but not as dramatically as Extenday in WTFRC trials (Table 9)

Long term study of tree-to-tree variability in cropping and growth is underway at WSU Sunrise research orchard (data not shown)

Ongoing collaborative efforts across disciplines, institutions, and regions leverage funding and increase relevance and impact of research (Table 10)

BACKGROUND:
We have scaled back internal research efforts in chemical thinning to accommodate more collaborative work in other areas, but also in part because of the success of earlier work. Many programs and principles put forward by our research, especially aggressive bloom thinning with lime sulfur, are now firmly established across the Washington industry. We will continue screening new materials and programs for crop load management (see new McArtney metamitron proposal), but our focus is now increasingly on collaborative projects exploring mechanical thinning techniques (see Lewis/Schupp technology committee project report) and increasing the precision and predictability of crop load management programs through web-accessible developmental models and decision systems (see Yoder project report on pollen tube growth model and Schmidt project report on bloom phenology and fruit growth models).

We continue to evaluate the relative success of chemical and mechanical 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.

Our protocols generally assume two applications of each bloom thinning program, at 20% and 80% full bloom. Likewise, most postbloom thinning programs are applied twice, typically at 5mm and 10mm fruitlet size. Programs in 2010 are reflected in Table 1; in those which show a range of possible rates, higher concentrations are typically reserved for cultivars known to be difficult to thin, such as Fuji and Golden Delicious. In most cases, additional chemical thinning treatments were left to the discretion of individual grower-cooperators, provided that each experimental plot receives the same programs.

Table 1. Chemical thinning programs evaluated. WTFRC 2010.

BLOOM THINNERS
2% Crocker's Fish Oil (CFO) + 2-3% LS
2% Crocker's Fish Oil (CFO) + 2% LS preceded by 12 oz/A Apogee
24-32 oz ThinRite/A 1x
16-24 oz ThinRite /A 2x
0.5% GSL 90 + 1-2% Sulforix
6% NC99
POSTBLOOM THINNERS
48 oz Sevin (carbaryl) + 3 oz NAA/A
48 oz Sevin (carbaryl) + 128 oz BA/A
48 oz Sevin (carbaryl) + 3 oz NAA/A preceded by 12 oz/A Apogee 2x
48 oz Sevin (carbaryl) + 128 oz BA/A preceded by 12 oz/A Apogee 2x
128 oz BA + 3 oz NAA/A preceded by 12 oz/A Apogee 2x

BLOOM THINNING:
Even though we conducted several contract thinning trials subsidized by private chemical companies, we carried out only one independent chemical bloom thinning trial in 2010. Our second year of evaluation of Sulforix plus a non-ionic surfactant confirmed some potential for reduced fruit set, but fruit marking (Table 2) continues to be a concern and may preclude this material from providing a viable sulfur alternative to standard lime sulfur programs.

Ongoing trials with endothall (ThinRite) have yielded some modestly encouraging results in that some programs (Table 2), especially those utilizing two applications, have been as effective as standard lime sulfur treatments. The material's registrant, United Phosphorus, believes ThinRite will be fully registered and available for commercial use in 2012 and we anticipate further trial work in 2011 to fine tune effective programs.

Several researchers in Europe and the Eastern United States have reported reduced chemical thinner efficacy in the context of standard prohexadione-Ca (Apogee) programs. Despite pre-treating trial plots with Apogee, we were unable to detect any effect on the efficacy of a standard fish oil + lime sulfur program in Gala (Table 2).

Table 2. Crop load effects of bloom thinning programs. Gala/M.9, Manson, WA. WTFRC 2010.

Treatment	Fruitlets/100 floral clusters	Blanked spurs	Singled spurs	Harvest fruit weight	Relative box size	Russeted fruit
		%	%	g		%
Apogee; 2% CFO + 2% LS	69 b	44 a	43 ns	164 ns	116	72 a
2% CFO + 2% LS	84 ab	34 ab	50	162	118	71 ab
0.5% GSL 90 + 2% Sulforix	66 b	47 a	40	168	114	77 a
0.5% GSL 90 + 1% Sulforix	76 ab	40 ab	47	163	117	65 abc
5% NC99	96 a	27 b	50	158	121	52 bc
24 oz ThinRite 1x	76 ab	40 ab	45	162	118	59 abc
16 oz ThinRite 2x	69 b	42 ab	48	164	116	65 abc
Control	84 ab	34 ab	49	160	119	50 c

Intrigued by results from European thinning trials, we attempted to utilize a food grade black food dye as a chemical bloom thinner. After consulting with Carolyn Ross (Food Science Dept, WSU), we procured some powdered food dye which the manufacturer felt had the most potential for such an application. Unfortunately, we were unable to discover a spray solution that would adequately adhere to plant material. Laboratory assays of several surfactants, bases, and acids mixed with the dyewere unsuccessful at allowing the initial black hue to persist once the spray solutions had dried.

Even though we have reduced our work in bloom thinning, we continue to corroborate prior results of ATS and oil + lime sulfur programs in the context of other experiments. No thinning program we have evaluated to date outperforms oil + lime sulfur combinations. Table 3 summarizes results from all apple bloom thinning trials conducted by the WTFRC since 1999, reflecting a very conservative standard by which to assess our most frequently studied programs.

Table 3. Incidence and percentage of results significantly superior to untreated control. Apple chemical bloom thinning trials. WTFRC 1999-2010.

Treatment	Fruitlets/100 blossom clusters	Harvested fruit size	Return bloom[1,2]
ATS	15 / 57 (26%)	10 / 60 (17%)	4 / 52 (8%)

NC99	15 / 32 (47%)	7 / 34 (21%)	2 / 28 (7%)
Lime sulfur	25 / 54 (46%)	12 / 48 (25%)	9 / 47 (19%)
CFO + LS	61 / 106 (58%)	26 / 97 (27%)	21 / 93 (23%)
JMS + LS	14 / 24 (58%)	8 / 23 (35%)	4 / 22 (18%)
WES + LS	14 / 27 (52%)	4 / 26 (15%)	4 / 26 (15%)
VOE	13 / 29 (45%)	4 / 28 (14%)	2 / 30 (7%)

[1]Does not include data from 2010 trials.

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

POSTBLOOM THINNING:
As with bloom thinning trials, we also designed a 2010 trial to assess the effects of Apogee on the efficacy of standard postbloom thinning programs. Results were mixed and non-significant when comparing results with and without pretreatments of Apogee, but all programs demonstrated effective thinning as compared to the untreated control (Table 4).

Results from 2010 trials are consistent with prior outcomes which demonstrate that 1) tank mixes of carbaryl and BAare at least as effective as tank mixes of carbaryl and NAA (Tables 4, 5) and 2) BA + NAA programs are equal or superior to any standard postbloom thinning programs utilizing carbaryl (Tables 4, 5). Perhaps most striking about Table 5 is the overall dearth of significant effects from any postbloom chemical thinning program; when compared to the general success rates of bloom chemical thinners (Table 3), it becomes all the more clear that early, aggressive thinning is critical to effective crop load management.

Table 4. Crop load effects of postbloom thinning programs with and without Apogee. Fuji/M.26, Quincy, WA. WTFRC 2010.

Thinners	Apogee	Fruitlets/100 floral clusters	Blanked spurs	Singled spurs	Harvest fruit weight	Relative box size	Russeted fruit
			%	%	g		%
BA + NAA		70 ab	60 ns	21 ns	186 ns	103	51 ab
BA + NAA	Y	60 b	59	26	181	105	56 ab
Carbaryl + BA		66 ab	58	23	190	100	60 ab
Carbaryl + BA	Y	75 ab	52	28	185	103	51 ab
Carbaryl + NAA		60 b	57	29	189	101	44 b
Carbaryl + NAA	Y	76 ab	52	26	206	93	45 b
Control		95 a	48	24	201	95	69 a

Table 5. Incidence and percentage of results significantly superior to untreated control. Apple chemical postbloom thinning trials. WTFRC 2002-2010.

Treatment	Fruitlets/100 blossom clusters	Harvested fruit size	Return bloom[1,2]
BA	2 / 18 (11%)	0 / 19 (0%)	0 / 19 (0%)
Carb + BA	29 / 78 (37%)	9 / 77 (12%)	9 / 73 (12%)
Carb + NAA	12 / 52 (23%)	7 / 52 (13%)	5 / 50 (10%)
BA + NAA	5 / 15 (33%)	3 / 15 (20%)	1 / 11 (9%)
Carb + NAA + Ethephon	0 / 5	0 / 5	2 / 5
Carb + NAA + BA	0 / 8	0 / 8	3 / 8

[1]Does not include data from 2010 trials.

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

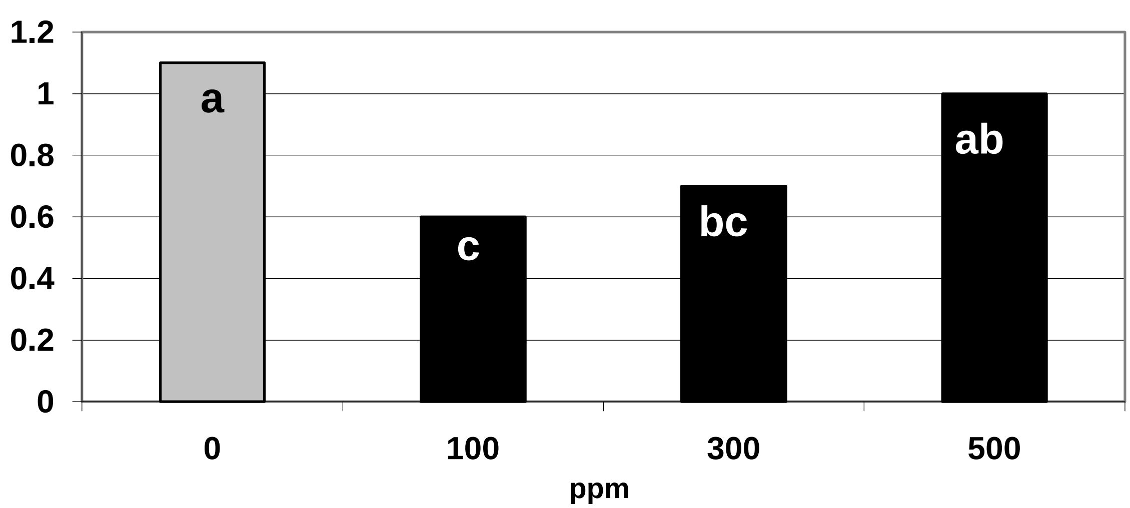
At this stage, we are confident that BA + NAA programs can provide satisfactory, if not superior, alternatives to postbloom thinning programs which rely on carbaryl. We have not observed any pygmy fruit in any of our 11 trials evaluating that combination, nor any other harmful effects to fruit quality; language on product labels warning against tank mixing of BA and NAA products is likely an artifact of historic concerns of NAA causing pygmy fruit in isolated cases and has little relevance to combining the two chemistries.

Reports from Europe suggest that low doses of the herbicide metamitron provide effective postbloom chemical thinning; we were unable to procure any material for Washington trials in 2010, but will seek out new sources for material samples in 2011. Further, we have also begun evaluation of another novel postbloom thinner which has shown promise in European studies and could potentially be approved for use in organic orchards. Results of these trials are protected by a confidentiality agreement and cannot be shared at this juncture.

RETURN BLOOM PROGRAMS:

After several years of unimpressive trial results, we discontinued our efforts to develop programs to improve return bloom with ethephon and NAA. Our focus recently has been to use gibberellic acid (GA) products to suppress flowering of the on year of biennial bearing cycles in pursuit of consistent annual cropping. In several recent trials, we observed the interesting trend that higher concentrations of GA do not amplify treatment effects (Figure 1).

Figure 1. 2009 return bloom effects (flower clusters/cm^2 TCSA) of 10mm applications of GA_3. Fuji/M.26, Orondo, WA.WTFRC 2008.



After observing these effects, we assayed a broader range of GA concentrations, as well as multiple applications of lower rates. Table 6 reflects successful reduction of return bloom from four weekly applications of 200 ppm GA_3 starting at 10 mm fruitlet size in two trials without deleterious side effects on shoot growth or fruit size. Trials launched in 2010 focus more heavily on programs based on multiple applications; if results from these trials are as compelling as those initiated in 2009, we are hopeful that key GA_3 product registrants will pursue label changes for their materials to accommodate these new use patterns.

Table 6. Key effects of WTFRC 2009 GA_3 return bloom trials.

GA_3 concentration	2009 shoot length	2009 fruit weight	2010 return bloom
ppm	cm	g	flower clusters/cm^2 LCSA
Braeburn/M.7 - George			
200	36.5 ns	251 a	4.1 bc
400	35.0	229 b	6.0 a
800	34.9	246 a	4.5 bc
4 x 200 (weekly apps)	34.1	233 b	3.5 c
Control	34.2	234 ab	5.1 ab
Gala/M.26 - George			
200	31.2 ns	171 ns	4.3 ab
400	30.4	170	4.4 ab
800	30.1	180	4.0 ab
4 x 200 (weekly apps)	30.9	180	3.2 b
Control	31.9	170	4.7 a

REFLECTIVE MATERIAL TRIALS:

Since 2005, we have conducted approximately30 trials evaluating reflective materials in commercial Washington apple orchards. Products tested have included the woven plastic fabrics Extenday, Daybright, and Daywhite, all distributed by Extenday USA, as well as Brite N'Up, a Mylar-based material. The Extenday products are designed for use throughout the growing season and may be reused for 6-8 years with good maintenance, while Mylar products cannot be reused and are generally only deployed 2-3 weeks before harvest.

Each material we tested is designed to reflect sunlight striking the orchard floor back up into plant canopies. Increased light saturation as harvest approaches can increase red color development, while increased light saturation throughout the growing season is associated with enhanced carbon fixation (photosynthesis), cell division, and cell expansion. While all products tested improved apple fruit color when deployed shortly before harvest (Table 9), Extenday products have also consistently increased fruit set and/or fruit size in WTFRC apple (Tables 7, 8), pear, cherry, peach, and nectarine trials. Because these materials specifically promote the production of high yields of large, well-colored, high quality fruit, they have tremendous potential to significantly improve grower returns.

Table 7 reflects four years of results from a Honeycrisp block treated with Extenday from bloom until harvest. Due to concerns about poor fruit color in this high value block, the grower-cooperator deployed reflective Mylar film 3-4 weeks before harvest in control plots during each year of the study. Fruit color was similar in Extenday and Mylar plots in all years of the study, except the first season when Extenday plots improved yields of the premium color grade by 30%.Overall yields were significantly higher in Extenday plots in all 4 years, whether due to increased fruit set and/or improved individual fruit size.

Table 7. Fruit yield and color effects of full-season Extenday vs. late-season Mylar control. Honeycrisp/Sup.4, Selah, WA. WTFRC 2007-2010.

	YIELD			COLOR GRADE	
	Fruit set	**Fruit wt.**	**Yield**	**WAXF**	**WAF**
	(#/tree)	(g)	(kg/tree)	(%)	(%)
2007					
Extenday	496 ns	206 a	98 a	39	49
Mylar control	469	182 b	86 b	30	46

2008					
Extenday	202 ns	219 a	39 a	28	69
Mylar control	198	187 b	35 b	27	70
2009					
Extenday	510 a	193 a	99 a	42	25
Mylar control	442 b	174 b	71 b	44	28
2010					
Extenday	472 a	228 a	97 a	52	47
Mylar control	361 b	209 b	70 b	53	46

Increased yield differentiations in later years of a trial are not unique; we have frequently observed cumulative increases in yields over the course of multiple year studies. Table 8 summarizes the average effects of Extenday in each season of every full-season apple trial we have conducted since 2005. While modest yield gains are typical in the first year of trials, the effects are more dramatic in subsequent seasons, likely due to increased carbohydrate reserves and renewed fruiting wood, especially in lower, shaded portions of tree canopies.

Table 8. Mean cumulative yield effects relative to untreated controls of full-season multiyear use of Extenday in all WTFRC apple trials. 2005-2010.

Trial age	*n*	Fruit set (harvested fruit/tree)	Individual fruit size (g)	Total yield (kg/tree)
1st year	12	+ 9%	+ 6%	+ 15%
2nd year	7	+ 24%	+ 2%	+ 26%
3rd year	4	+ 17%	+ 8%	+ 23%

Reflective materials deployed late in the growing season have little effect on apple fruit set or size, but can improve fruit color in red or partially red cultivars. Table 9 shows effects of Extenday and Brite N'Up on Gala fruit color; both materials were deployed at the same timings using equal material widths. While the Mylar product improved color, Extenday was more effective in all three seasons.

Table 9. Effects of reflective materials deployed 4 weeks prior to harvest on harvest sequence and fruit color. Gala/M.9, Othello, WA. WTFRC 2007-2009.

	TOTAL YIELD HARVESTED				COMMERCIAL COLOR GRADE		
	1st pick	**2nd pick**	**3rd pick**	**4th pick**	**WAXF**	**WAF**	**US#1**
	(%)	(%)	(%)	(%)	(%)	(%)	(%)
2007							
Extenday	39 a	40 ns	19 b	2 b	92	7	1
Brite N' Up	21 b	42	30 a	7 a	82	17	1
Control	16 b	40	35 a	8 a	78	21	1
2008							
Extenday	32 a	59 ns	9 b	na	99	1	0
Brite N' Up	19 b	63	19 b		96	4	0
Control	14 b	56	30 a		95	5	0
2009							
Extenday	68 a	26 b	6 b	na	87	12	1
Brite N' Up	38 b	40 a	22 a		65	30	6
Control	24 c	47 a	29 a		49	46	5

COLLABORATIVE RESEARCH:
In the last three years, we have continued to build productive and dynamic research and outreach partnerships with a number of cooperators (Table 10). These working relationships bring in outside funding for our work (e.g. SCRI projects), attract elite scientists to focus on WA issues, elevate our profile nationally and internationally, and lay the foundation for synergistic collaborations which will be crucial to the future success of our program.

Table 10. Significant WTFRC collaborations on external crop load and canopy management projects 2008-2010.

COLLABORATOR(S)	PROJECT	COMMENTS
Yoder, Combs	Pollen tube growth model	WA field testing, flower style sampling
Olmstead, Lewis	Bloom phenology& fruit growth models	See project report AP-09-908 for details
Lewis, Schupp	Mechanized thinning	Field support for WA portion of SCRI project
Lewis, Singh	CASC	Field support for WA portion of SCRI project
McArtney	Novel chemical thinners	WA testing of alternative sulfur products
McArtney, Greene	Return bloom programs	Bud sampling, WA testing of NAA programs
Elfving	Return bloom programs	Field support for GA trials
Rom, McAfee	Novel chemical thinners	WA testing of organic thinning agents
Elfving	PGRs for shoot growth	Field support for Apogee, ABA trials