CONTINUING PROJECT REPORT **YEAR**: 2 of 3

Project Title: Modeling Washington apple bloom phenology and fruit growth

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Total project funding request: **Year 1:** $4,180 **Year 2:** $7,938 **Year 3:** $5,690

Other funding ~~s~~Sources: ~~NONE~~None

WTFRC Collaborative expenses:

Item	2009	2010	2011
Stemilt RCA room rental			
Crew labor[1]	5,000	5,000	7,000
Shipping			
Supplies			
Travel[2]	1,800	1,800	2,400
Miscellaneous			
Total	$6,800	$6,800	**$9,400**

[1] Labor calculated as 2 persons at $16.00/hr working 12 hrs per week for 13 weeks during the growth season.

[2] In-state travel to research plots.

NOTE: 2011 budget increased from $6800 to reflect additional sites handled by WTFRC staff

Budget 1

Organization Name: WSU Extension **Contract Administrator:** M.L. Bricker

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Item	2009	2010	2011
Salaries[1]		2,941	3,059
Benefits		847	881
Wages[2]	1,000	1,000	1,000
Benefits	180	150	150
Equipment			
Supplies			
Travel[3]	3,000	3,000	600
Total	$4,180	$7,938	**$5,690**

[1] Salary (benefits at 28.8%) for Nairanjana Dasgupta

[2] Wages (benefits at 15%) for part-time help in Wenatchee for bloom observations.

[3]Cooperator in-state travel for bloom observations (5 persons at $600 each)

NOTE: 2011 budget decreased from $8090 to reflect reduced participation from Extension staff (Olmstead, Suverly, Lewis, Hoheisel)

Objectives:

1. Develop functional models for apple bloom development from bud break to petal fall for three cultivars: 'Red Delicious' (standard with historic data), 'Cripps Pink' (early bloomer), and 'Gala' (mid-late bloomer).
2. Develop fruit growth models for the same three cultivars from petal fall until harvest.
3. Incorporate models into WSU DAS system.

Significant Developments:

- Bloom phenology observations successfully recorded at 11 location nodes throughout Central Washington, including 11 Red Delicious, 11 Gala, and 9 Cripps Pink blocks (Table 1)

- Time course photographs taken of same bud/flower/fruitlet from green tip to 20mm fruitlet size at most sites

- Fruit growth measured throughout growing season at 11 Red Delicious, 10 Gala, and 9 Cripps Pink blocks; fruit diameter recorded at all sites, as well as fruit length for Red Delicious blocks (Table 1)

- Streamlined data forms facilitated data entry and analysis; sampling protocols were universally standardized to improve data consistency and statistical robustness

- Field testing of autonomous digital cameras yielded mixed results; cameras successfully captured good quality images at preset intervals, but limited field of view and inability to focus on buds in camera foreground impaired ability to discern precise morphology (Figures 2, 3)

- WTFRC crew will assume all data collection for Prosser and Royal Slope sites in 2011; Omak site will be dropped due to loss of local cooperator (Suverly)

- Preliminary statistical models have been built for bloom phenology (Table 2) and fruit growth (Figure 1) by statisticians with 2009 data; incorporation of 2010 data is ongoing

- Initial discussions held with Dasgupta and Ute Chambers to begin preparations for incorporation of models into WSU Decision Aids System (DAS)

Methods:

Bloom phenology: Team members from WSU Extension and WTFRC internal program observed and evaluated flagged apple blocks around the state (Table 1) at regular intervals from bud break until mean fruitlet size reached 20mm. Representative buds/clusters at chest level on the northwest side of trees of each cultivar were categorized by phenologic stage and digital pictures were taken of representative buds/flower/fruitlets. Based on input from WSU statisticians, observation intervals were shortened to 2-3 days (2-5 days in 2009) and sample size was increased to 30 buds for the 2010 season (20 buds in 2009). Data were recorded on a tally sheet by each individual and eventually submitted to the WTFRC internal program for collation. Hobo data loggers were deployed at each site to record ambient temperatures throughout the season.

Fruit growth: After June drop and hand-thinning, 50 surviving fruit were tagged in the same blocks used for the bloom phenology observations. All fruit were measured by WTFRC staff for diameter and Red Delicious was additionally measured for length as an indicator of fruit type at weekly intervals until the blocks were harvested in the fall. As with bloom phenology, fruit growth protocols (sample size and intervals) were modified for 2010 based on recommendations from statisticians.

Table 1. Roster of sites utilized for apple bloom phenology observations and fruit growth measurements. 2010. (RD = Red Delicious, CP = Cripps Pink, G = Gala)

LOCATION	GROWER	CVs	ELEV (ft)	STAFF	FRUIT GROWTH
Omak	Root	RD, G	1250	Suverly/Crew	RD only
S Shore Chelan	Easley	CP	1120	Auvil/Crew	Y
	Sunshine	RD, G	1450	Auvil/Crew	Y
Brays Landing	Podlich	RD, CP, G	900	Auvil/Crew	Y
S Orondo	C & O Nursery	RD, CP, G	755	Crew	Y
E Wenatchee	Gausman	RD, CP	910	Esteban	Y
	Witte	G	1025	Esteban	Y
Rock Island	WSU-TFREC	RD	910	Crew	Y
	WSU-TFREC	G	880	Crew	Y
	Zirkle CRO	CP	775	Crew	Y
Royal Slope	Delay	CP	1095	Lewis/Crew	Y
	Delay	RD, G	1055	Lewis/Crew	Y
Naches	Rowe	RD, G	1580	Crew	Y
Parker	Brandt	RD, CP, G	879	Crew	Y
Sawyer	WTFRC Rootstock	G	870	Crew	Y
	Badgely	RD	870	Crew	Y
	Weippert	CP	870	Crew	Y
Prosser	Ballard	RD, CP, G	681	Hoheisel/Crew	Y

Results & Discussion:

The contributions of our cooperating statisticians brought immediate and meaningful impact to the project which has improved both our resource efficiency and robustness of results. Based on their recommendations, the following changes were adopted in our second season of data collection:

- Shorter and more regular sampling intervals
- Increased sample size for bloom observations
- Decreased sample size for fruit measurements
- Standardized data collection protocols

These changes not only improved the statistical strength of our 2010 data sets, but helped reduce confusion and error in field data collection. Sampling protocols for 2011 may be further revised to optimize accuracy and efficiency.

Hobo data loggers were again deployed at all nearly all sites to record ambient temperatures in the immediate microclimate of the sampled trees; most sites were selected due to their proximity to AWN stations (usually within a mile), and models using temperatures from both systems will be evaluated for the best statistical fit. Potential discrepancies between temperatures recorded by AWN and individual data loggers could have many explanations, but may be instructive regarding broader extrapolation of weather readings from either system.

In an effort to explore options for reducing time commitments for our field personnel, we tested autonomous digital cameras designed for monitoring big game trails to assess their utility for making routine observation of bloom development. A camera deployed at the WSU Sunrise orchard near Rock Island performed flawlessly, capturing and storing hundreds of good quality images Figures 2, 3). Unfortunately, the camera's effective focal range is 5+ feet; images of branches inside that range were too blurry to prove useful and images of branches that were in focus were too small to discern individual buds or flowers. We have been unable to locate alternative cameras that accommodate better near-range focus within a reasonable price range.

Statistical analysis was done separately for bloom phenology and growth data. For the growth data we used a Non-linear regression model to model the growth pattern for the different locations for the 2009 data. We used the Richards's curve formulation (model given below):

$$Y_{ji} = \frac{\beta_i}{(1 + e^{\delta_i(X_{ji} - \tau_i)}}$$

Where: Y_{ji} represents the growth for apple *j* at location *i*, X_{ji} denotes the time in Julian Days, the parameter β represents the maximal growth reached by the fruit, δ represents the growth rate and τ represents time when maximum growth occurred. As these parameters all have physical meaning in the context of apples we decided to use this model. From the model it is evident that we used location-specific parameters indicating that the model allowed the parameters to be different across locations. Table 2 represents some of our findings showing significant differences across sites. To compare across sites we used a technique that we developed (Many-to-one comparisons for Apple Growth, Dasgupta and Shaffer, submitted to *Journal of Agricultural, Biological, and Environmental Statistics*). At this point we did not use weather information across sites to explain the difference; our hope is to incorporate weather information in the models with 2010 data that will make the model more relevant for DAS users. To delineate our results we attach Figure 1 which shows the growth data for the Red Delicious across all the locations and our overall fit from the non-linear model. We also overlay the LOESS non-parametric (data driven) fit on the graph to see how closely our non-linear models fit what the data represents.

We are still in the process of analyzing bloom data as we investigate how to best convey relevant information to growers. One issue with the bloom data is that our response is categorical (stage of bloom) and the data for a particular bloom is auto-correlated over time. To investigate how to deal with binary auto-correlated data we pursued some research and have submitted the paper "Many-to-one comparisons in the longitudinal Binary Data set up" co-authored by Dasgupta, Sutradhar, and Yang to *Sankhya* to address the statistical methodology for this issue. However we also did some simple analysis and Table 2 shows the most likely bloom stage over the time of data collection in Julian Days for the three cultivars.

Figure 1: Plot of Apple growth over Time with our non-linear fit and loess fit

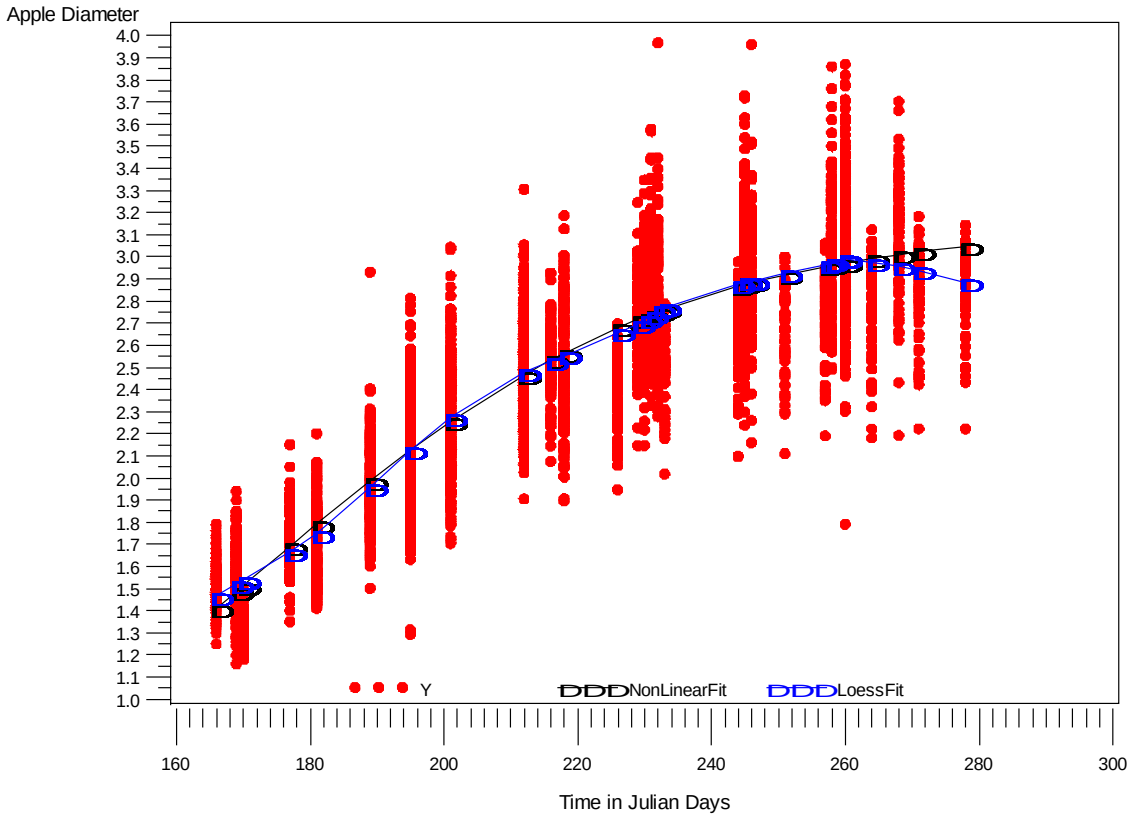

Table 2: Probable Julian dates for phenologic stages of three apple cultivars based on initial analysis of 2009 and 2010 data.

Cultivar STAGE	Red Delicious	Gala	Cripps Pink
GreenTip	72-79	72-79	72-74
½ Inch Green	81-88	81-96*	75-85*
Tight Cluster	89-96	97-104*	86-90*
First Pink	97-105*	105-106*	92-97*
Full Pink	106-107*	107-110	98-104
First Bloom	108-109	111-113	105-107
Full Bloom	109-113	111-113	108-110
Petal Fall	>113	>113	>110

The "*" indicates that some of the range is not continuous, but we report the most likely range. Results are confounded by location to location variability.

Statistical followup and future plans for analysis:

1. Fit growth models to 2010 data
2. Model bloom data with multinomial models
3. Incorporate weather information into both models

Figure 2. Sample photo taken by autonomous trail camera at WSU Sunrise research orchard. Note images of buds in foreground are too blurry to discern between tight cluster and first pink.

Figure 3. Sample photo taken by autonomous trail camera at WSU Sunrise research orchard. Note king bloom is open in two clusters on branch in foreground, but it is difficult to assess phenology of other clusters facing away from the camera.