FINAL REPORT

Project Title: Identifying causes of variability in fruit quality

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Agency Name: Emerging Research Issues, WSU-ARC
Amt. awarded: $64,756 awarded

Budget 1
Organization Name: WSU **Contract Administrator: Mary Lou Bricker**
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Item	**2009**	**2010**	
Salaries	26,952	28,030	
Benefits	1,955	2,033	
Wages	7,500	7,500	
Benefits	728	728	
Equipment			
Supplies	2,000	2,000	
Travel	10,000	10,000	
Miscellaneous			
Total	49,135	50,291	

OBJECTIVES

1. Document role of fruit developmental history at key stages (i.e., flowering, thinning, fruit maturation) and management interventions in fruit quality
2. Map fruit quality and position within high resolution 3D digital canopies
3. Develop practical strategies for reducing variability and maximizing genetic potential.

SIGNIFICANT FINDINGS

- Quality can vary considerably among fruit in high density fruiting wall architectures
- Variability in quality is not related to fruit position in high density fruiting wall architectures
- In general, the later opening blooms yielded lesser quality fruit
- Timing of flowering did not account for a great amount of the variability in fruit quality
- Fruit quality was negatively related with fruit number per tree underscoring the importance of crop load management
- Tree architecture and fruit quality 'maps' can be recreated in 3D using data points captured by laser-scanning
- In Gala there was no difference in fruit quality potential between king and side blooms

RESULTS AND DISCUSSION

Experiments were conducted in 2009 and 2010 at C & M Orchards, Prosser, WA on 11^{th} and 12^{th} leaf 'Buckeye Gala', and 3^{rd} and 4^{th} leaf 'Aztec Fuji'. Both were trained to super spindle architecture. Initially, before bud break, we gathered a geospatial electronic spectrum and limb diameters of three trees per variety. At harvest, we removed the leaves, collected geospatial data on fruit position and woody structure, measured limb diameters, and picked every fruit. During bloom, each flower was tagged using 3M ScotchCode™ numbered wire marker tape on the day it opened (i.e., was accessible to pollinators).

To evaluate the role of fruit position on quality, we used a Topcon total station to identify the position of every fruit and the woody structure of the tree at 2-inch increments. The canopy and fruits' positions were then recreated digitally using Matlab software. We assessed positional relationships with quality by analyzing quality parameters in three 'directions' – east to west, north to south, and vertically in the tree. There were no clear effects of a fruit's position on its quality irrespective of the attribute assessed (Fig. 1). Virtual 3D maps of fruit quality further illustrate a lack of relationship between fruit position and quality (Fig. 2). This suggests that thinning was effective and that light distribution was good – not surprising for 3^{rd} leaf trees that had not yet filled the space.

In 2009, the first bloom for Gala (Fig. 3) and Fuji (Fig. 3) was on 22^{nd} and 23^{rd} of April, respectively. The final blooms for Gala and Fuji were tagged on 12^{th} and 8^{th} of May, respectively. Gala had a total of 2094 tagged flowers with trees 1, 2, and 3 having 669, 643, and 782 flowers, respectively. Progression of bloom is being modeled with growing degree hours currently (data not shown). By 10 days from the first bloom, 60% of the floral buds were open and these flowers accounted for 92% of the fruit retained for harvest. At harvest on 26 August, there were 189 Gala fruit with tree 1, 2, and 3 yielding 64, 61, and 64 fruit, respectively. The fruit to bloom ratio was 9% for Gala in 2009. In Fuji for 2009, we counted a total of 524 tagged blooms with tree 1, 2, and 3 having 124, 128, and 271 flowers, respectively. The fewer flowers compared to Gala were due to incomplete canopies of the 3^{rd} leaf trees. At harvest on 7 October, there were 99 Fuji fruit with tree 1, 2, and 3 yielding 49, 21, and 29 fruit, respectively. The fruit to bloom ratio overall for Fuji was 6% in 2009 – slightly lower than expected due to frost damage.

The bloom count/tagging for Gala in 2010 started 13 April and finished 3 May with 2022 total blooms tagged with tree 1, 2, and 3 having 572, 732, and 718 flowers, respectively. We followed the same three trees in both years and can draw no cause-effect relationship between fruit number per tree in 2009 and return bloom in 2010. Interestingly, tree 1 had about 28% fewer flowers than tree 2 despite the trees having similar fruit numbers in the previous year, and being pruned similarly. At harvest on 30 August, there were a total of 221 fruit with tree 1, 2, and 3 yielding 78, 71, and 72 fruit, respectively. Fruit set (meaning here the number of fruit harvested per number of flowers) was therefore about 14%, 10%, and 10%, respectively. For Fuji, bloom tagging started on 15 April and finished on 3 May totaling 1329 with tree 1, 2, and 3 having 531, 314, and 494 flowers, respectively. At harvest on 5 October, there were a total of 174 Fuji fruit with tree 1, 2, and 3 yielding 73, 35, and 66 fruit, respectively, or, a final fruit set of about 14%, 11%, and 13%. The similar final 'fruit set' percentage between Fuji and Gala (despite significantly different flower numbers per tree) reflect the effectiveness of the thinning crew and the managers' knowledge of optimizing fruit load per tree.

Crop load management was accomplished in both years and for both Gala and Fuji with 'standard' chemical bloom and post-bloom programs (lime sulphur and carbaryl) followed by hand thinning. Lime sulfur was applied in both years on both cultivars at 50% bloom with following applications at 70% bloom. Further, Fuji trees received applications of carbaryl and ethephon to reduce crop load attempting to reduce the effects of biennial bearing. Prior to hand thinning, whether the result of chemical thinning or natural drop, the Gala trees had a reduction in flower/fruitlets of 74% and 71% in 2009 and 2010, respectively. Hand thinning fruit accounted for reductions of crop load of only 8% and 2% for 2009 and 2010, respectively. The Fuji trees had a reduction in flower/fruitlets of 67% and 81% in 2009 and 2010, respectively. Hand thinning accounted for 20% and 4% of thinning in 2009 and 2010, respectively. We continue to analyze cluster composition in relation to thinning applications to judge efficacy. The efficacy of the two thinning treatments (bloom and post-bloom) is questionable since we did not record notable fruit drop in the weeks following application (data not shown).

The orchard managers' goal in 2010 was to increase the crop load and this meant there was less hand-thinned fruit (trees in 2010 bore an additional 7 to 14 fruit compared to 2009). The increased crop load in 2010 did not have a significant effect on Gala, whereas Fuji by contrast, had reduced fruit quality in 2010 compared to 2009. In Gala, the average mass difference was only 4% with average fruit weighing only 9 g more in 2009. The other quality parameters assessed were similarly variable, suggesting that the increase in fruit number in 2010 was nearer the target crop load. Indeed, the increase of about 20 fruit per tree did not reduce the average harvested fruit size below size 88. However, Fuji fruit quality varied considerably between 2009 and 2010 seasons. In 2009, weight was 21% greater, diameter was 16% greater, and color was 28% greater. In addition, starch was higher in 2009 by 48% and conversely firmness was lower by 18%. Though variability appears large between the years, the average fruit quality for packout did not fall below 88's.

The variability within the individual trees in 2010 cannot be attributed to a single aspect of crop load per limb, position in canopy, or multiple fruits per spur. We found, for example, that a 53 g fruit was at the top of the canopy and that a 272 g fruit was harvested from the same limb (i.e., ostensibly a similar environment). Further, at approximately a height of 2 m (6 feet), in the same tree, four fruit were harvested, weighing 248 g, 181 g, 261 g, and 278 g, a difference of greater than 50%, again from fruit in a similar environment. As another example in the same year in Fuji, at 1.5 m (about 5 feet), a single limb carried 5 fruit that weighed 284 g, 244 g, 229 g, 289 g, and 293g. These preceding examples may demonstrate variable capacity for some limbs to partition photoassimilates, or a pre-determined limit to fruit size. When work is finished on the geo-spectral mapping, we will be able to gather a clearer understanding of limb structure and position of the limb's capacity for crop load. Multiple fruit per spur, left to mature, have varying quality. Generally, in our study multiple fruit per spur was uncommon. In 2010, there were only 6 spurs with more than singles after hand thinning in Gala. One spur held 3 fruit and the others had 2. On the spur with the 3 fruit, the largest apple weighed 204 g followed by 198 g and 145 g. Of the 13 fruit observed, only 5 fruit weighed greater than 215 g or graded larger than 88. We continue to evaluate dynamic cluster composition data to determine the role of fruit-fruit competition on final fruit quality. Our current analyses are evaluating cluster composition of 1) the poor quality fruit (10^{th} percentile) vs. high quality (90^{th} percentile) and, 2) fruit from flowers that opened on the same day yet varied in quality significantly at harvest.

Comparing bloom time and fruit quality reveals a subtle relationship that does not account for the significant variability among fruit in their quality. Overall, the fruit from earlier bloom tended to be heavier and larger than fruit from the late-opening flowers (Figs. 5 & 6). Conversely, the earlier blooms yield fruit that have slightly lower starch and are less firm. Over the 20 days of Gala flowering in 2009, mean fruit weight dropped by 42%, diameter decreased by 17% (Fig. 5), starched decreased by 37% and firmness increased by 11%. In 2010, bloom was complete in 20 days with weight decreasing by 46%, diameter reduced by 18% (Fig. 3), starch rating was 83% lower, and firmness was 9% greater. For Fuji over an 11-day bloom period, mean fruit weight decreased by 50%, diameter was reduced by 19% (Fig. 4), starch decreased by 17%, and a reduction of 22% was recorded in firmness. In 2010, over a 13-day bloom period, Fuji fruit lost 45% weight, 16% diameter (Fig. 4), 15% starch, and firmness increased by 18%. While the variability among fruit from flowers opening on a given day remains substantial (Figs. 4 & 5), crop load management strategies should focus on removing late-opening flowers/fruit.

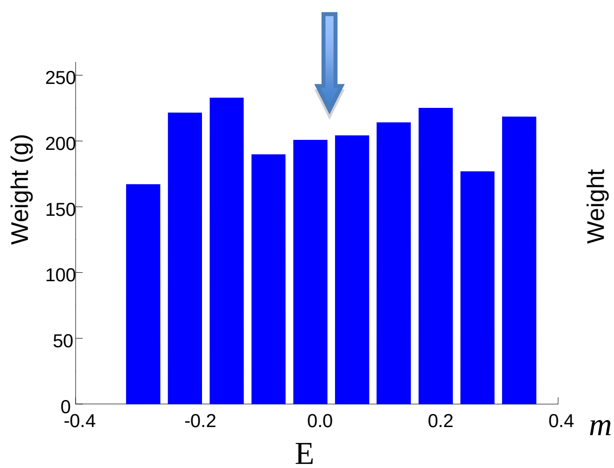
King and Side Bloom Comparison. Gala floral buds/blooms/fruitlets were pinched back to either one king bloom or side bloom to assess fruit quality at different stages in floral development. Statistical comparisons of king, side, and control (fruit from the timing of flowering experiment above) show that quality of fruit from king blooms is not any better than fruit from side blooms considering fruit quality characteristics such as weight, diameter, and height (Table 1). Trees in this study that had similar crop loads (kg/cm^2) to the floral timing trees, fruit quality was not significantly different. However, trees with crop loads above 6 $fruit/cm^2$ began to show greater variability within the treatment (Table 2). Our trees in this study were not hand-thinned to adjust crop load. To truly identify fruit superiority the whole crop load adjustment regime should have been applied through the treatments. However, our data underscore the importance of crop load management for growing superior quality fruit. It is not sufficient in many orchard systems to limit crop load to a single fruit per cluster – cluster thinning to a target fruit number per tree is necessary to achieve high quality.

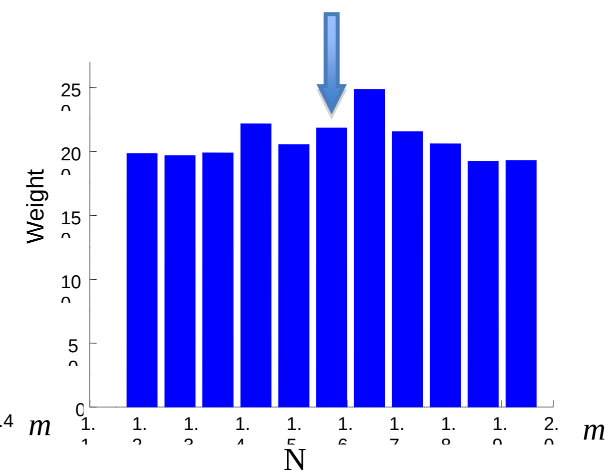
Table 1. Comparisons of fruit quality of 'Buckeye' Gala trees thinned to one flower per cluster (king, side) with control (hand thinned) by least significant difference ($P \leq 0.05$)

Treatment	% Red (Closest 10%)		Weight g		Diameter mm		Height mm		Firmness lb		Water Core Rating 1-5		Starch Rating 1-6		Brix	
Control	86.057	a	229.86	a	78.13	a	78.37	a	17.47	a	1	a	3.77	a	11.96	a
King	54.701	c	203.42	b	74.13	b	74.96	c	17.28	a	1	a	2.92	c	10.68	b
Side	62.704	b	229.39	a	77.92	a	76.44	b	17.47	a	1	a	3.23	b	10.62	b
lsd	3.105		7.67		1.16		1.23		0.39		0.02		0.22		0.17	
r x r	0.35		0.08		0.08		0.04		0.002		0.002		0.07		0.28	

Table 2. Comparisons of mean fruit yield and quality from trees thinned to only king or side bloom at various timings. All comparisons are calculated as least significant difference ($P \leq 0.05$).

Treatment	# of Fruit		Yield (kg)		Fruit Weight (g)		TCSA (cm*cm)		Fruit/cm2
4/17/ King	107	ab	23.3	a	216	a-c	16.4	a-d	6.5
4/17/ Side	87	bc	18.5	b-c	211.2	bc	13.5	cd	6.4
4/21/ King	93	a-c	18.6	a-d	200.8	bc	15.5	b-d	6.0
4/21/ Side	87	bc	18.6	a-d	214.1	a-c	11.9	d	7.3
4/27/ King	97	a-c	19.7	a-c	204.13	bc	16.3	a-d	6.0
4/27/ Side	60	d	14.8	de	246.6	a	22.9	ab	2.6
5/5/ King	91	a-c	20.1	a-c	226.5	ab	21.5	a-c	4.2
5/5/ Side	52	d	12.5	e	244.6	a	18.3	a-d	2.8
5/13/ King	109	ab	21.4	a-c	196.7	bc	17.6	a-d	6.2
5/13/ Side	97	a-c	21.7	ab	223.3	ab	23.9	a	4.1
5/26/ King	110	a	20.2	a-c	183.5	c	12.3	d	8.9
5/26/ Side	84	c	16.8	c-e	199.1	bc	20.9	a-c	4.0
lsd	21.7		4.6		33.3		8.13		
r x r	0.73		0.62		0.56		0.49		





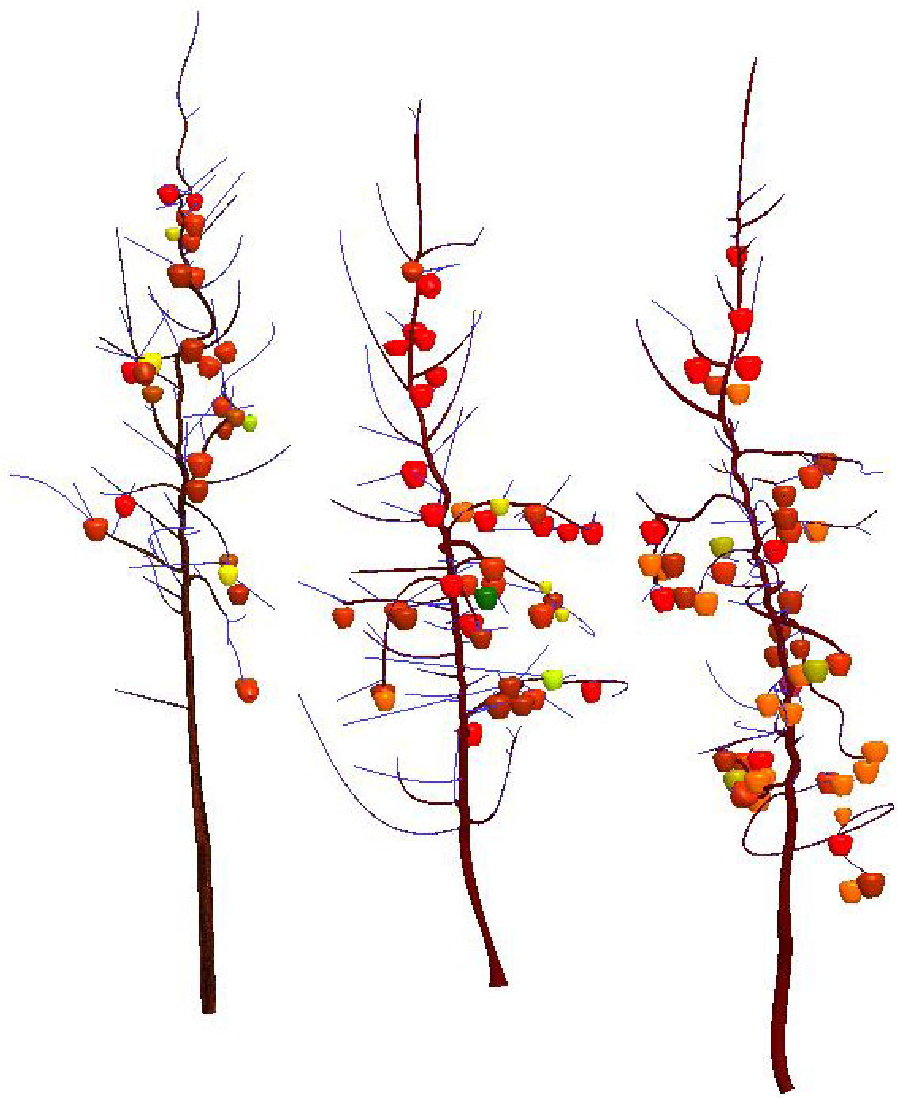


Figure 2. Model of 3 consecutive 3rd leaf 'Fuji' trees illustrating fruit position, size and color. Size of model fruit is proportional to actual size and color is indicative of actual fruit color. Data points were collected with Topcon laser total station; 3D virtual trees and fruit were constructed using Matlab software.

Figure 1. Distribution of mean apple weight (g) in E-W (left) and N-S (right) directions within 3rd leaf 'Aztec Fuji' canopies. The canopy central axis is at the middle along the x-axis (indicated by arrow). Row orientation is N-S.

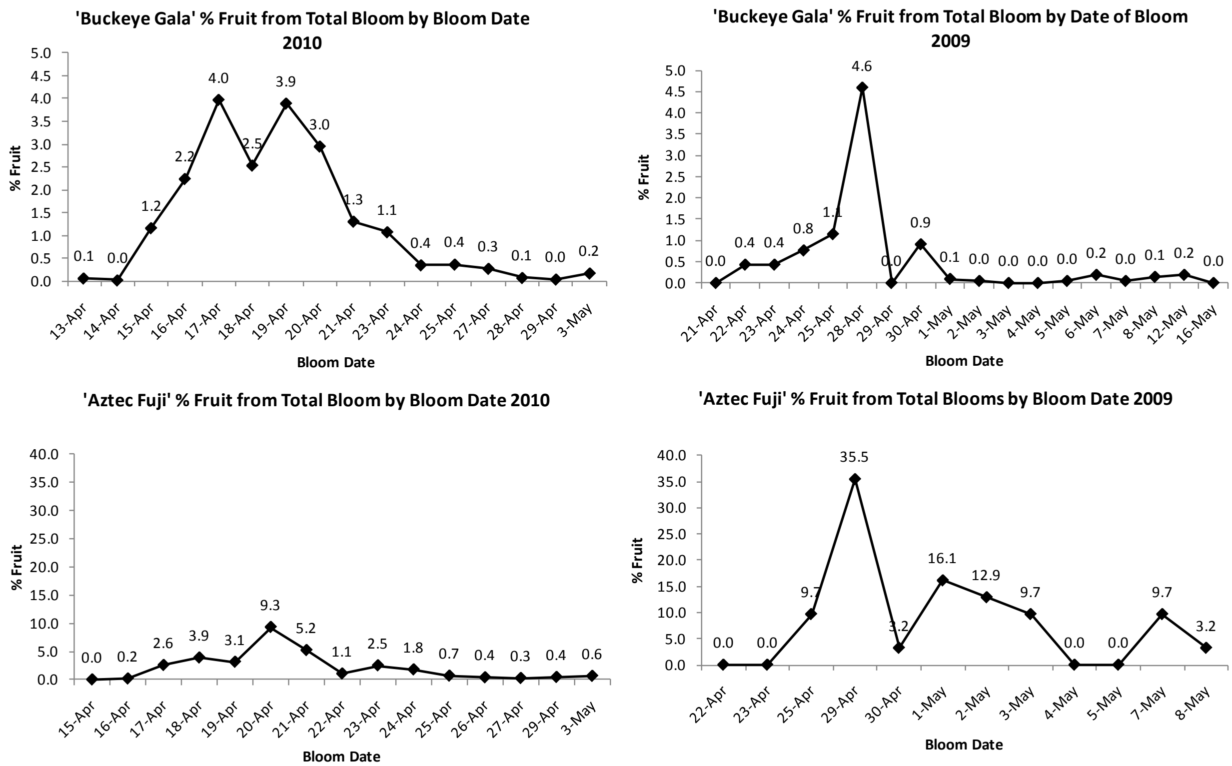


Figure 3. The fruit harvested as a percentage of total blooms open throughout the bloom period for 3 consecutive trees of 'Buckeye Gala' or 'Aztec Fuji'. 'Buckeye Gala' had 2094 blooms with 189 fruit harvested in 2009 and 2022 blooms with 221 fruit harvested in 2010. 'Aztec Fuji' had 524 blooms with 99 fruit harvested in 2009 and 1329 blooms with 174 fruit harvested in 2010.

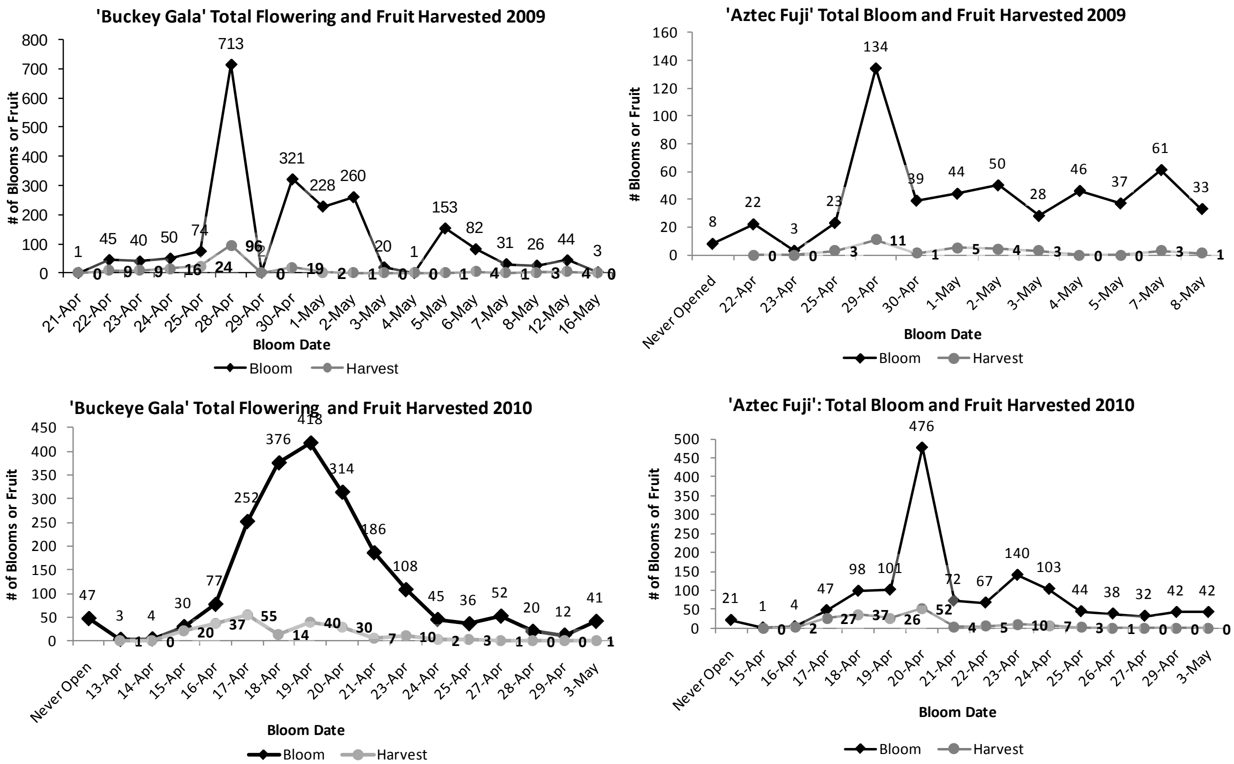


Figure 4. Total flowers opening by date (black line), and total fruit harvested from flowers open on that date (grey line) for 'Buckeye Gala' and 'Aztec Fuji' in 2009 and 2010.

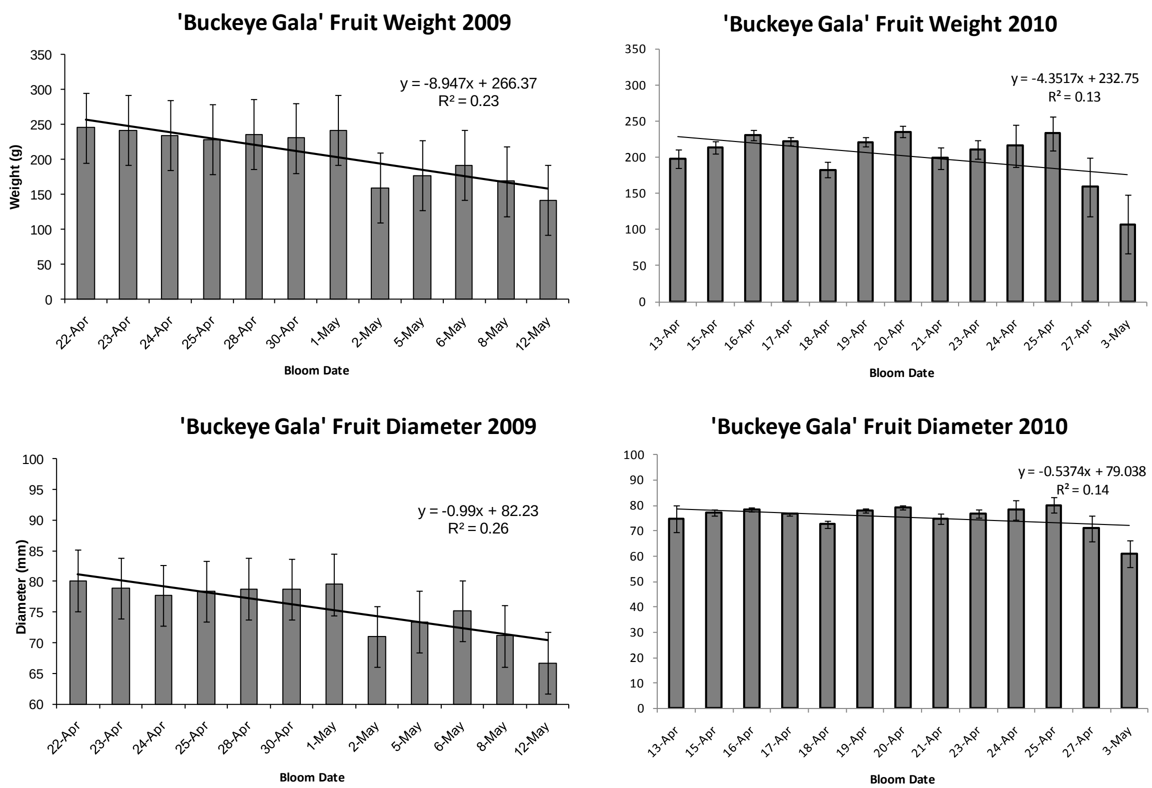


Figure 5. Fruit weight (g) and diameter (mm) of 'Buckeye Gala' by the date of the flower opening in 2009 and 2010, $P < 0.05$.

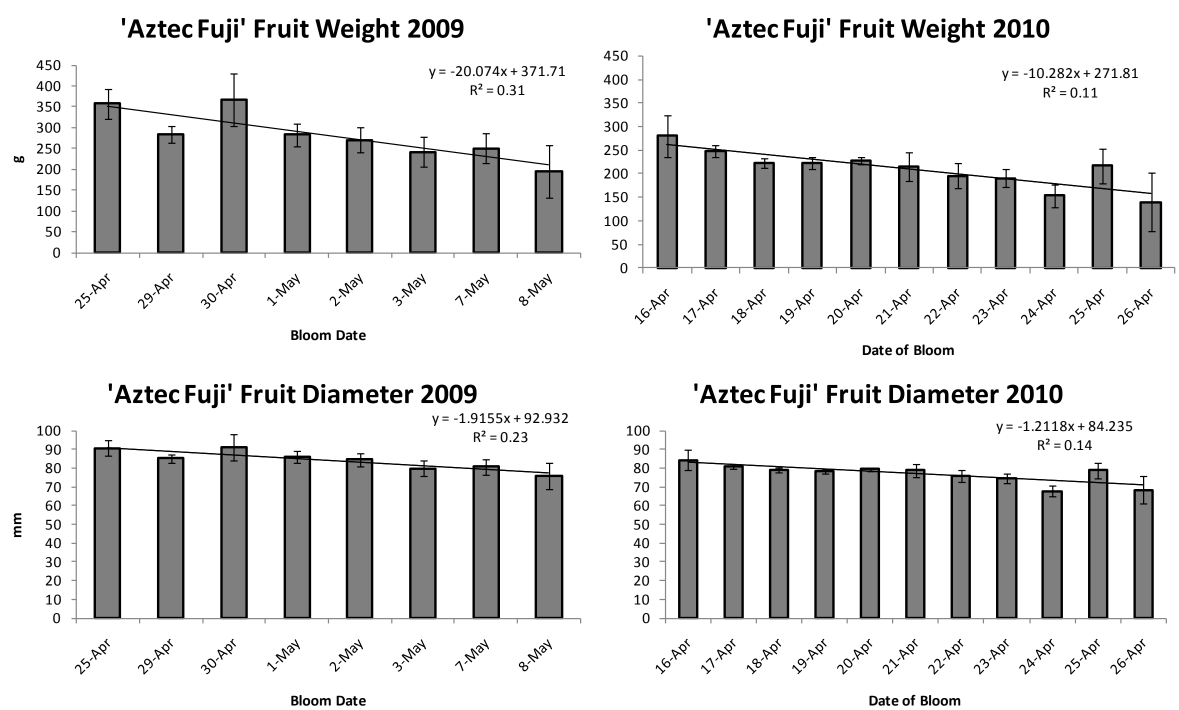


Figure 6. Fruit weight (g) and diameter (mm) of 'Aztec Fuji' by the date of the flower opening in 2009 and 2010, $P < 0.05$.

EXECUTIVE SUMMARY

Our research team set out better understand the role of fruit position, timing of flowering, floral hierarchy (i.e., king vs. side bloom), and fruit developmental context (i.e., a single vs. triple-fruited spur prior to thinning, etc.) on fruit quality in apple. Our previous data had identified tremendous variability in fruit quality at harvest despite being grown with high management inputs and in compact fruiting wall architectures. We hypothesized that much of this variability is due to differences in floral timing, fruit position, and/or fruit developmental context. We evaluated these elements for 'Buckeye Gala' and 'Aztec Fuji' over two years in commercial orchards north of Prosser, Washington. To test the hypotheses, we labeled each flower when it had opened sufficiently for a pollinator to access. Starting May 19 2009 and 2010, we counted and recorded position of the number of fruit/fruitlets remaining and measured them for diameter weekly until harvest. At harvest, the fruit quality was analyzed by measuring weight, diameter, height, color (as % red), firmness, water core, starch, soluble solids and recorded any blemish affecting quality (e.g. sunburn, mechanical, insect and/or animal damage). In addition, at harvest we made three-dimensional structural maps of the harvested trees and each fruit's position using data acquired by a Topcon total station laser scanner and Matlab software.

In the high-density fruiting wall orchards studied, we found no role of fruit position on fruit quality – there were high and poor quality fruit in every canopy position, though, overall, fruit quality was very high. We created high resolution 3D virtual canopies that demonstrate this point dramatically. In trees of the 'standard' system – central leader, moderate density (e.g., 7 x 13), we documented a significant role of position on quality with the highest quality (size and color) fruit positioned around the periphery of the canopy and the poor quality fruit situated in the lower canopy tiers and to the interior (data not shown). Our studies now focus on the poor quality fruit and understanding what made them so. It appears that timing of flowering is not entirely responsible for variability in fruit quality, though we did document a slight relationship between final fruit quality and timing of flowering, with fruit from the later-opening flowers being poorer quality than those from the early- and mid-opening flowers. The significant variability that exists among fruit that were from flowers opened on the same day becomes the next concern. This can be as much as 100 g – the difference between several box sizes. Our current efforts are to reconcile these differences with fruit developmental context, reviewing what cluster composition was and when thinning occurred within the individual cluster. Future studies should also investigate the possibility of there being differences in fruit quality potential among flowers (i.e., already established by the time of flowering) that would have been established in the previous season, post initiation.