Project/Proposal Title: Measuring the impact of leaf removal on spur and tree health

Report Type: Final Project Report

Primary PI: **Lee Kalcsits**
Organization: Washington State University
Telephone: 509-293-8764
Email: lee.kalcsits@wsu.edu
Address: 1100 N Western Ave.
City/State/Zip: Wenatchee, WA 98801

Co-PI 2: Karen Lewis
Organization: Washington State University
Telephone: 509-754-2011
Email: kmlewis@wsu.edu
Address: 1525 E Wheeler Road
City/State/Zip: Moses Lake, WA 98837

Cooperators: Orlando Howe, Thiago Campbell, Lissett Gonzalez, McDougall and Sons, Gebbers Farms, Zirkle Fruit

Project Duration: 3 Year

Total Project Request for Year 1 Funding: $ 60,344
Total Project Request for Year 2 Funding: $ 66,377
Total Project Request for Year 3 Funding: $ 52,580
Other related/associated funding sources: None

Budget 1
Primary PI: Lee Kalcsits
Organization Name: Washington State University
Contract Administrator: Anastasia Mondy
Telephone: 916-897-1960
Contract administrator email address: Anastasia.Mondy@wsu.edu

Item	2022	2023	2024
Salaries[1]	$40,777	$43,826	$31,460
Benefits[2]	$6,637	$7,393	$10,895
Wages[3]	$5,187	$5,394	$0
Benefits[4]	$518	$539	$0
Equipment	$0	$0	$0
Supplies[5]	$3,000	$5,000	$5,500
Travel[6]	$4,225	$4,225	$4,225
Miscellaneous[7]	$0	$0	$500
Plot Fees	$0	$0	$0
Total	$60,344	$66,377	$52,580

Footnotes:

[1] Salary is requested for a 25% post-doc in years 1 and 2 and then 50% in year 3 as well as a graduate assistant in year 1 and 2 to complete the applied physiology experiments.

[2] Benefits are calculated at 34.6% for the post-doc and 12.6% for the graduate assistant.

[3] Wages are for covering summer salary for the graduate assistant

[4] Benefits are calculated at 10% for summer graduate students

[5] Supplies are for field and lab consumables to conduct applied experiments for objective 1 and 2 and then Extension material for objective 3.

[6] Travel funds are requested for frequent travel to the Sunrise research orchard for PIs and personnel and to commercial orchards to conduct deleafing trials.

[7] Funding is requested for a small personal service contract for a videographer to capture some of the applied experiments being conducted for this project.

Objectives*

*1,2, and 4 are original objectives. #3 is an additional objective

1. Quantify improvements in leaf color and changes to sunburn incidence from leaf removal for an early and late-season bicolor apple cultivar.

2. Determine whether differences in leaf removal severity and timing before harvest impacts energy and nutrient storage and subsequent spur health the following season or an early and late-season bicolor apple cultivar.

3. **(ADDITIONAL OBJECTIVE) Determine whether there are differences in red color or sunburn risk from full tree deleafing compared to lower canopy deleafing (commercial practice) and determine additive effects of reflective fabric with deleafing.**

4. Develop practical operating guidelines and economic cost-benefit thresholds for leaf removal based on commercial trials in WA.

Significant Findings

- In 2022, color development was poor for earlier cultivars but was much improved in 2023 for both cultivars. Leaf removal did not affect red color for WA 38 in a good coloring year like 2023 but was effective in a poor coloring year like 2022.
- Leaf removal greater than 50% reduced return bloom, yields but did not affect vegetative vigor.
- Leaf removal significantly enhanced color development but also increased sunburn damage for Honeycrisp but not for WA 38. Benefits were observed as low as 25% leaf removal. Unsurprisingly, above 75% leaf removal increased sunburn damage in unprotected fruit.
- Leaf removal had limited benefit for a high coloring cultivar like WA 38, but also had limited sunburn risk. In a poor coloring year like 2022, leaf removal would likely have benefits for bicolored cultivars with high color requirements.
- Carbohydrate content in storage tissues were relatively unaffected by deleafing treatments.
- The timing of leaf removal had little impact on red color development. Deleafing can be done in as little as 7 days before harvest with improved color still observed.
- The speed of operation varied by commercial orchard depending on the brand of equipment, age of orchard, vigor, etc.
- An 8’ window from the ground was the targeted location for leaf removal for commercial deleafing
- Growers can be less conservative with the use of deleafing machines and risks for sunburn are only high if forecasted temperatures are high and reflective material is used.

Results and Discussion

Severity Experiment:

Goal: To assess how differing leaf removal severities affects sunburn, red color development, return bloom, and following season vegetative vigor for Honeycrisp (hard to color) and WA 38 (easy to color) apples.

Treatments: 0%, 25%, 50%, 75%, and 100% leaf removal.

Conclusion: When leaf removal % is lower than 50%, there is limited risk of sunburn and strong benefits for red color development for Honeycrisp. There were no carryover effects on return yield nor vegetative vigor unless leaf removal % exceeded 75%. Growers should be mindful of possible cumulative effects on tree health and adjust deleafing severity each year based on block vigor and light exposure.

Results and Discussion:

Sunburn incidence and severity

Differences in sunburn development were observed between 'Honeycrisp' and 'WA 38' apples. 'Honeycrisp' is particularly susceptible to sunburn due to its low surface temperature threshold (46-49°C) for sunburn browning, compounded by earlier maturation during periods of high solar radiation (Schrader et al., 2008). In contrast, 'WA 38' apples exhibit extensive red skin coverage, which may mask visible browning and reduce apparent sunburn incidence (Gomez & Kalcsits, 2020). In this study, these findings highlight the relationship between leaf removal severity and sunburn incidence, suggesting that increased defoliation intensifies sunburn severity, particularly for both 'Honeycrisp' and 'WA 38' apples.

Sunburn was affected by defoliation treatments in both years (Tables 1 and 2). The proportion of fruit with no sunburn (SB 0) decreased as the amount of removed leaves increased for both cultivars. When no leaves were removed, an average of 78.2% of fruit had no sunburn but only 16.3% of fruit had no sunburn when 100% of leaves were removed prior to harvest in 2022. Similar patterns were observed in 2023, but a lower proportion of fruit had no sunburn for the control (54.2%) and 100% leaf removal (12.3%). The proportion of mild sunburn (SB 1) was the lowest when there were no leaves removed and highest when greater than 25% of leaves were removed in 2022 ($P = 0.027$). However, there were no significant differences among treatments in the proportion of fruit with SB1 classifications of sunburn ($P = 0.31$). SB2, which signifies a medium severity of sunburn, increased with leaf removal for both years. However, SB2 was greater than the control starting when more than 75% of leaves were removed in 2022 ($P = 0.0012$) and only when 100% of leaves were removed in 2023 ($P = 0.0096$). Only 6.1% of the fruit was classified as SB2 in 2022 when no leaves were removed, and 26.9% of the fruit was classified as SB2 when all the leaves were removed. Similarly, SB3 was also highest when all leaves were removed compared to the control ($P = 0.0011$). The proportion of fruit with SB3 sunburn classification was 5.9% and 3.3% for the control in 2022 and 2023, respectively. The proportion of fruit with SB3 was only higher than the control when all the leaves were removed and was 25.7% and 31.5% in 2022 and 2023, respectively. Even the most severe sunburn classification (SB4) increased in both 2022 and 2023. The proportion of fruit with SB4 was 0.5% and 0% for 2022 and 2023, respectively. Similar to SB3, only full leaf removal had greater proportions of fruit with SB4 where 5.8% and 7.2% of fruit were classified as SB4 in 2022 and 2023, respectively.

‘WA 38’ had less severe sunburn symptoms compared to ‘Honeycrisp’. The proportion of fruit with no sunburn symptoms was 98.3% and 90.3% for the control in 2022 and 2023, respectively. When all leaves were removed, the proportion of fruit with no sunburn was significantly lower (88.7%) compared to the control ($P<0.05$) in 2022. However, there were no significant differences in the proportion of fruit with no sunburn among treatments in 2023 ($P = 0.347$). There were significant differences among treatments for the proportion of fruit classified as SB1 in 2022 ($P = 0.0075$) but not 2023 ($P = 0.141$). The proportions of fruit classified as SB1 were 1.6% and 7.1% for trees with no leaves removed in 2022 and 2023, respectively. When all leaves were removed, 8.4% of fruit was classified as SB1 and was significantly greater than the control. The proportions of fruit affected by SB2 remained very low across all treatments for both years, never exceeding 4.8% and were not significantly different among treatments ($P = 0.614$ and 0.629 in 2022 and 2023, respectively). There were no SB3 or SB4 classifications observations across both years for ‘WA 38’.

Red color

Red color coverage was much higher in 2023 than in 2022. Control trees had an average of 11% red color coverage in 2022, whereas in 2023, the mean red color coverage for the control was 52.4% (Tables 3 and 4). As leaf removal increased, there was a significant decrease in the proportion of ‘Honeycrisp’ fruit with 0-20% red color coverage in both 2022 ($P=0.013$) and 2023 ($P=0.039$) (Table 3). This pattern was accompanied by a corresponding increase in the proportion of fruit with high red color coverage (80-100%) as defoliation severity increased ($P = 0.012$ in 2022, $P= 0.016$ in 2023). For 2022 and 2023, the proportion of fruit meeting premium color standards with >33% red color coverage increased as leaf removal increased, as shown in Figure 1.

For ‘WA 38’, there were significant increases in mean color coverage when deleafing was greater than 50% in 2022 (Table 4). The mean red color coverage was just over 70% for the control (71.5%) and just under 90% when 100% of the leaves were removed (88.6%) (4). There were no differences between the partially defoliated and the control in 2022 ($P>0.05$ for all comparisons) (Table 4). In 2023, mean color coverage was nearly 100% for every treatment, including the control, with mean red color coverage ranging from 97.4% to 98.1%, and there were no significant differences among the treatments ($P>0.05$ for all comparisons) (Table 4). The proportion of fruit with >50% red color coverage increased in 2022 as leaf removal increased, going from approximately 80% of fruit meeting that standard to more than 95% of fruit meet that standard when 100% of the leaves were removed (Figure 2). In contrast, there were no significant changes in the proportion of fruit with >50% red color coverage in 2023.

Vegetative vigor and return yields

Leaf removal treatment affected yield in the following year for both ‘Honeycrisp’ and ‘WA 38’. When 100% of leaves were removed, there was a significantly lower yield in 2023 and 2024 compared to the control and 25% leaf removal treatments (Figure 3 and Table 5). For 'Honeycrisp,' yield decreased by 91% under the 100% leaf removal treatment, while for 'WA 38,' the reduction was 71%. 'WA 38' yields were only significantly different between the control and 100% leaf removal treatments, indicating lower sensitivity to intermediate defoliation levels compared to 'Honeycrisp.' In 2023, vegetative shoot growth in ‘Honeycrisp’ varied significantly across defoliation treatments from 8.77 to 16.6 cm, with the lowest growth recorded when 100% of the leaves were removed ($P = 0.005$), while 2022 had no significance ($P = 0.104$) and growth ranged from 9.8 to 15.5 cm (Table 6). There were no significant differences found in vegetative shoot growth for ‘WA 38’ under the same treatments in both 2022 and 2023 ($P = 0.56$ and $P = 0.649$). The growth for ‘WA 38’ remained consistent across treatments (Table 6).

The impact of leaf removal on vegetative growth was minimal, suggesting that moderate leaf removal might not adversely affect tree vigor over the duration of the experiment. While the short-term effects of leaf removal were not observed in these experiments, it is important to consider that prolonged or extreme defoliation could lead to further depletion of carbon reserves, potentially reducing vegetative growth in subsequent seasons. The current study focused on a limited time frame, and future research would be valuable to explore the long-term consequences of extreme defoliation on tree health and productivity, particularly regarding carbon storage and allocation over time. However, high rates of leaf removal reduced yields in the following season for both cultivars, indicating that extreme defoliation may deplete storage reserves in the tree. Di Lorenzo et al. (2013) reported the photosynthetic response to leaf removal is particularly notable when the source-sink ratio is constrained, leading plants to promote the growth of apical meristems to offset reduced leaf area. Zhou and Wang (2021) highlight that defoliation intensity can impede tree growth by restricting the availability of carbon sources and sinks, which affects carbon storage within the tree. This dynamic was evident in our study, where extreme defoliation (100%) in 'Honeycrisp' apples led to a significant decrease in vegetative shoot extension, indicating a carbon allocation disruption.

Defoliation rates can have differential responses in different plant species. Quentin et al. (2011) reported that moderate defoliation, typically between 50% and 66%, can have varied impacts on the total above-ground biomass of different tree species, ranging from significant reductions to negligible changes. In line with this, our findings show no significant changes in vegetative growth across varying severities of defoliation. Bledsoe et al. (1988) reported that in *Vitis vinifera* (Sauvignon blanc) grape vineyards, neither the timing nor the extent of leaf removal significantly affected yield or its components, prompting further research into its long-term effects on yield stability and fruit quality. However, this finding likely does not universally apply across all fruit types, as evidenced by our study where significant yield reductions were observed in 'Honeycrisp' apples subjected to high levels of defoliation. This contrast highlights the necessity of species- and cultivar-specific research into horticultural practices, as techniques beneficial in one type of fruit or cultivar may be less effective or could even be detrimental in another.

The results of this study suggest that moderate leaf removal (25-50%) can effectively increase red color development in 'Honeycrisp' and ‘WA 38’ apples without severely impacting sunburn incidence or future yields. For 'Honeycrisp,' which is more prone to sunburn, a more conservative approach may be necessary to avoid significant quality losses due to sunburn, particularly during years or in locations where the risk of sunburn is high. On the other hand, ‘WA 38’ can tolerate higher leaf removal rates with less risk of sunburn, making it a suitable candidate for more aggressive defoliation strategies to improve red color. Alternatively, in some years, defoliation may not be necessary since red color development will be sufficient for all levels of light exposure in the canopy depending on the training of the tree and fruit exposure levels. Strategies that increase the amount of light penetrating the canopy, such as reflective ground covers, manual pruning techniques, and training systems tailored to optimize canopy architecture, are frequently used by growers to enhance the red coloration of bicolor cultivars. This study provides valuable insights for apple growers aiming to optimize fruit quality through the addition of leaf removal practices.

Future research should focus on the long-term effects of repeated leaf removal on tree health and productivity to develop sustainable management practices that balance immediate quality improvements with long-term orchard health. While leaf removal enhances apple coloration, its application must be carefully managed to minimize risks such as sunburn and ensure the long-term health of the tree. Additionally, cost-benefit analyses are needed to assess the economic impact of leaf removal on farm profitability. This study emphasizes the need for balanced defoliation practices to prevent financial losses and provides valuable insights for developing horticultural strategies that enhance color while managing sunburn risks and protecting future yields.

Table 1. Mean proportions of fruit affected by sunburn (SB0-SB4) for 'Honeycrisp' apples with 0, 25, 50, 75, or 100% of leaves removed in 2022 and 2023. Lettering indicates mean separation within each year among treatments determined using a Tukey's HSD test (α = 0.05).

Year	Leaf Removal %	Proportion of Fruit under Sunburn Classification (% Fruit)				
		SB 0	SB 1	SB 2	SB 3	SB 4
2022	0%	78.2 ± 4.4 a	9.3 ± 2.0 a	6.1 ± 1.3 a	5.9 ± 2.1 a	0.5 ± 0.5 a
	25%	72.0 ± 9.6 ab	11.3 ± 3.7 ab	10.7 ± 2.9 ab	5.5 ± 3.2 a	0.5 ± 0.5 a
	50%	63.7 ± 4.3 ab	19.6 ± 4.6 b	12.1 ± 1.8 ab	4.2 ± 0.1 a	0.4 ± 0.4 a
	75%	41.5 ± 4.8 bc	22.7 ± 4.9 b	23.6 ± 3.5 bc	11.1 ± 2.1 a	1.0 ± 0.7 a
	100%	16.3 ± 13.2 c	25.3 ± 2.9 b	26.9 ± 5.6 c	25.7 ± 6.1 b	5.8 ± 1.6 b
	p-value	**<0.0001**	**0.0269**	**0.0012**	**0.0011**	**0.0005**
2023	0%	54.2 ± 2.4 a	28.3 ± 1.5 a	14.2 ± 2.6 a	3.3 ± 0.1 a	0 ± 0 a
	25%	60.8 ± 3.3 a	25.8 ± 4.9 a	12.5 ± 1.9 a	0.1 ± 0.1 a	0 ± 0 a
	50%	55.2 ± 6.4 a	27.3 ± 5.2 a	14.6 ± 4.0 a	2.5 ± 1.2 a	0.4 ± 0.4 a
	75%	32.5 ± 4.2 b	31.8 ± 5.3 a	24.0 ± 3.1 ab	11.3 ± 4.9 ab	0.4 ± 0.4 a
	100%	12.3 ± 5.1 c	18.2 ± 4.0 a	30.3 ± 5.5 b	31.5 ± 11.8 b	7.2 ± 4.1 a
	p-value	**<0.0001**	**0.306**	**0.0096**	**0.0067**	**0.0465**

Table 2. Mean proportions of fruit affected by sunburn (SB0-SB4) for 'WA 38' apples with 0, 25, 50, 75, or 100% of leaves removed in 2022 and 2023. Lettering indicates mean separation within each year among treatments determined using a Tukey's HSD test (α = 0.05).

Year	Leaf Removal %	Proportion of Fruit under Sunburn Classification (% Fruit)				
		SB 0	SB 1	SB 2	SB 3	SB 4
2022	0%	98.3 ± 0.4 a	1.6 ± 0.4 a	0 ± 0 a	0 ± 0 a	0 ± 0 a
	25%	97.1 ± 1.4 a	2.9 ± 1.4 a	0 ± 0 a	0 ± 0 a	0 ± 0 a
	50%	95.4 ± 1.7 a	4.2 ± 1.5 ab	0.4 ± 0.4 a	0 ± 0 a	0 ± 0 a
	75%	93.7 ± 1.1 ab	5.8 ± 1.2 ab	0.4 ± 0.4 a	0 ± 0 a	0 ± 0 a
	100%	88.7 ± 0.5 b	8.4 ± 1.2 b	1.2 ± 1.2 a	0 ± 0 a	0 ± 0 a
	p-value	**0.0004**	**0.0075**	**0.614**	**-**	**-**
2023	0%	90.3 ± 2.5 a	7.1 ± 1.9 a	2.1 ± 0.9 a	0.4 ± 0.4 a	0 ± 0 a
	25%	89.6 ± 2.7 a	7.4 ± 0.9 a	2.5 ± 1.5 a	0.4 ± 0.4 a	0 ± 0 a
	50%	87.9 ± 4.1 a	7.1 ± 2.1 a	3.5 ± 1.7 a	0.8 ± 0.8 a	0 ± 0 a
	75%	84.4 ± 2.3 a	12.2 ± 1.6 a	2.6 ± 0.8 a	0.8 ± 0.8 a	0 ± 0 a
	100%	83.1 ± 2.7 a	11.7 ± 2.2 a	4.8 ± 1.3 a	0.4 ± 0.4 a	0 ± 0 a
	p-value	**0.347**	**0.141**	**0.629**	**0.972**	**-**

Table 3. Mean proportions of fruit in red color coverage classes (0-20, 20-40, 40-60, 60-80, and 80-100% coverage) for 'Honeycrisp' apples with 0, 25, 50, 75, or 100% of leaves removed in 2022 and

2023. Lettering indicates mean separation within each year among treatments determined using a Tukey's HSD test (α = 0.05).

Year	Leaf Removal %	Percentage of fruit belonging to each red color class (%)				
		0-20%	20-40%	40-60%	60-80%	80-100%
2022	0%	80.3 ± 4.3 a	11.4 ± 3.1 a	4.0 ± 2.0 a	2.5 ± 1.2 a	1.8 ± 0.1 a
	25%	62.9 ± 9.8 ab	16.4 ± 3.5 a	11.4 ± 4.2 ab	6.1 ± 2.7 ab	3.2 ± 1.1 ab
	50%	64.2 ± 12.4 ab	15.1 ± 5.3 a	9.6 ± 3.8 ab	8.0 ± 3.6 ab	3.2 ± 1.2 b
	75%	39.9 ± 1.0 ab	22.1 ± 3.6 a	18.7 ± 3.5 ab	13.4 ± 2.7 ab	5.9 ± 0.1 b
	100%	26.3 ± 13.8 b	15.9 ± 2.7 a	16.0 ± 2.5 b	22.5 ± 1.8 b	21.7 ± 8.5 b
	p-value	**0.013**	**0.389**	**0.042**	**.0368**	**0.012**
2023	0 %	22.4 ± 8.5 a	15.8 ± 3.0 a	13.8 ± 3.0 a	20.7 ± 1.5 a	27.2 ± 1.1 a
	25%	24.5 ± 7.7 a	17.0 ± 2.1 a	18.2 ± 3.0 a	22.4 ± 1.8 a	17.9 ± 7.0 ab
	50%	7.1 ± 2.5 a	13.0 ± 5.0 a	16.8 ± 4.1 a	27.6 ± 4.2 a	35.5 ± 1.0 ab
	75%	8.8 ± 3.8 a	11.9 ± 2.1 a	13.9 ± 3.6 a	25.6 ± 2.2 a	39.8 ± 7.7 b
	100%	2.5 ± 1.7 a	5.8 ± 2.5 a	8.3 ± 3.0 a	17.7 ± 3.1 a	65.7 ± 9.4 b
	p-value	**0.039**	**0.137**	**0.321**	**0.120**	**0.016**

Table 4. Mean proportions of fruit in red color coverage classes (0-20, 20-40, 40-60, 60-80, and 80-100% coverage) for ‘WA 38’ apples with 0, 25, 50, 75, or 100% of leaves removed in 2022 and 2023. Lettering indicates mean separation within each year among treatments determined using a Tukey's HSD test (α = 0.05).

Year	Leaf Removal %	Percentage of fruit belonging to each red color class (%)				
		0-20%	20-40	0-20%	60-80	0-20%
2022	0%	2.3 ± 0.1 a	8.3 ± 3.8 a	17.5 ± 6.2 a	23.3 ± 2.41 a	47.9 ± 11.6 a
	25%	4.7 ± 2.2 a	8.0 ± 2.0 a	19.7 ± 4.4 a	27.3 ± 3.4 a	40.3 ± 10.5 a
	50%	3.8 ± 2.4 a	5.9 ± 3.6 a	8.8 ± 3.6 a	17.6 ± 6.1 a	63.4 ± 13.4 a
	75%	0 ± 0 a	2.6 ± 0.9 a	12.5 ± 6.4 a	17.6 ± 3.8 a	67.3 ± 7.17 a
	100%	0 ± 0 a	0 ± 0 a	3.2 ± 1.4 a	11 ± 0.6 a	85.8 ± 1.87 a
	p-value	**0.195**	**0.220**	**0.159**	**0.077**	**0.059**
2023	0 %	0.8 ± 0.5 a	0 ± 0 a	0 ± 0 a	0.4 ± 0.4 a	98.8 ± 1.14 a
	25%	0.4 ± 0.4 a	0 ± 0 a	0 ± 0 a	1.75 ± 1.8 a	97.8 ± 2.6 a
	50%	1.4 ± 0.6 a	0 ± 0 a	0.4 ± 0.4 a	0 ± 0 a	98.2 ± 1.1 a
	75%	0.4 ± 0.4 a	0 ± 0 a	0 ± 0 a	1.25 ± 1.25 a	98.3 ± 1.8 a
	100%	0.9 ± 0.6 a	0 ± 0 a	0 ± 0 a	0.5 ± 0.5 a	98.6 ± 2.2 a
	p-value	**0.639**	**-**	**0.431**	**0.265**	**0.941**

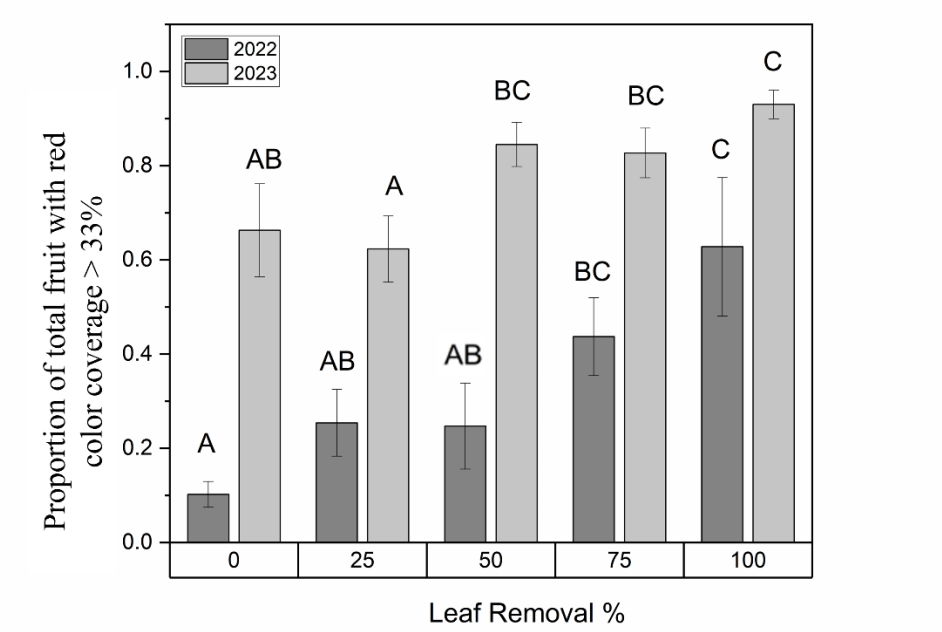

Figure 1. The proportion of 'Honeycrisp' apples with more than 33% red color coverage for five defoliation severities (0, 25, 50, 75, and 100% leaf removal). Error bars denote the standard error of the mean (N=5), and lettering indicates mean separation within each year among treatments determined using a Tukey's HSD test (α = 0.05).

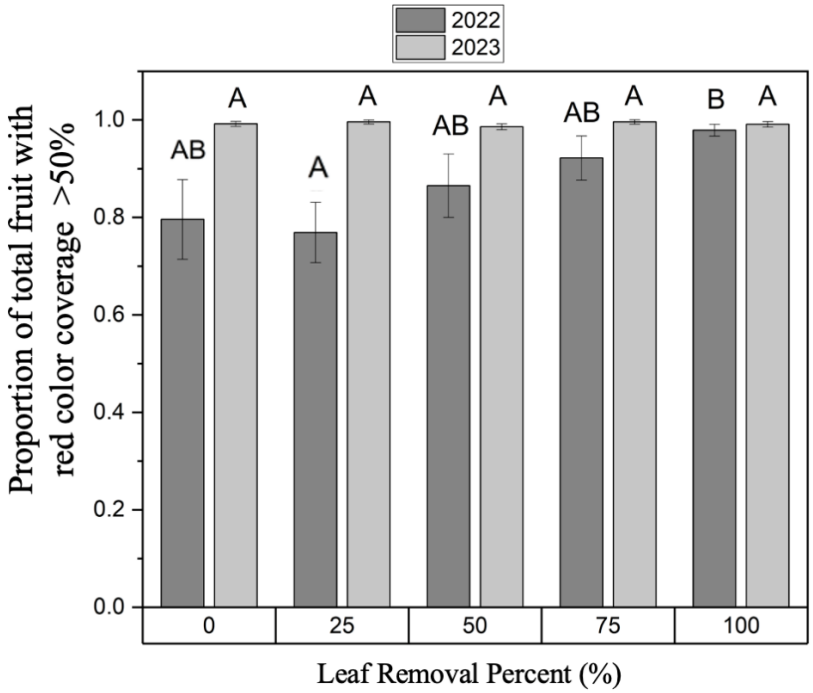

Figure 2. The proportion of 'WA 38' fruit with more than 50% red color coverage for five defoliation severities (0, 25, 50, 75, and 100% leaf removal). Error bars denote the standard error of the mean (N=5), and lettering indicates mean separation within each year among treatments determined using a Tukey's HSD test (α = 0.05).

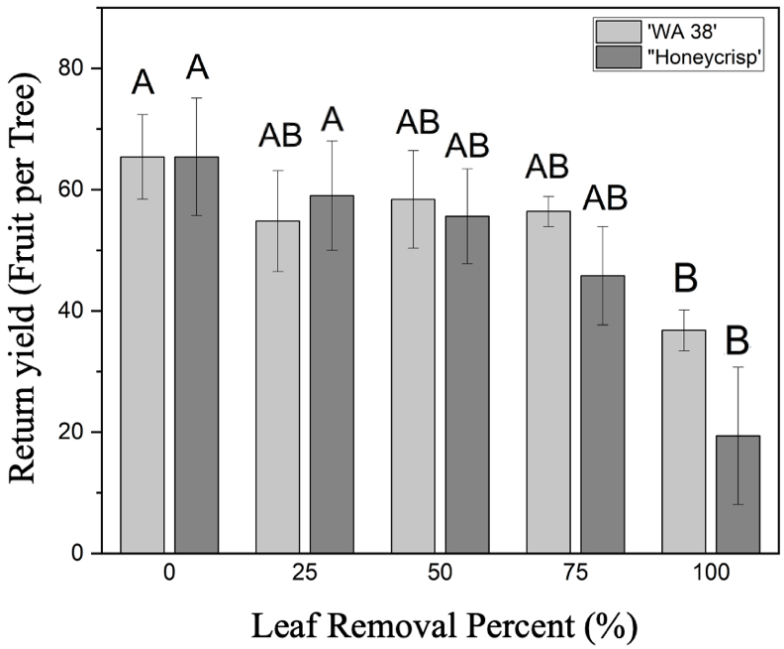

Figure 3 Return yield (fruit per tree) in 2023 following leaf removal in 2022 for 'Honeycrisp' (light grey) and ‘WA 38’ (dark grey). Crop loads were equal among treatments in 2022. Error bars indicate the standard error of the mean (N=5) for each leaf removal treatment group.

Table 5. Return yield in 2024 for ‘Honeycrisp’ and ‘WA 38’ apples under different defoliation treatments (0%, 25%, 50%, 75%, and 100% leaf removal). Crop loads were equal among treatments in 2023.

	Treatment	Honeycrisp	WA 38
‘Honeycrisp'	**0**	32.8	26.4
	25	29.6	33.8
	50	23.8	20.4
	75	11.8	20.2
	100	4.6	13

Table 6. Vegetative growth in 2023 for ‘Honeycrisp’ and ‘WA 38’ apples under different defoliation treatments (0%, 25%, 50%, 75%, and 100% leaf removal). Lettering indicates mean separation within each year among treatments determined using a Tukey's HSD test (α = 0.05).

Cultivar	Treatment	Length (cm)	Groups	Length (cm)	Groups
‘Honeycrisp'	**0**	14.2 ± 3.0	ab	13.9 ± 1.0	abc
	25	15.3 ± 1.3	a	16.6 ± 1.1	a
	50	11.1 ± 1.5	ab	16.1 ± 2.8	ab
	75	13.9 ± 0.5	ab	9.4 ± 1.2	bc
	100	9.8 ± 0.9	b	8.8 ± 1.4	c
	p-value	0.034		0.005	
‘WA 38'	**0**	18.6 ± 4.4	a	27.7 ± 3.7	a
	25	27.8 ± 6.4	a	24.0 ± 4.1	a
	50	18.6 ± 3.2	a	25.0 ± 1.2	a
	75	22.5 ± 4.0	a	22.0 ± 2.1	a
	100	19.8 ± 3.4	a	22.4 ± 2.4	a
	p-value	0.56		0.649	

Table 7. Estimated revenue gains for six case study commercial trials of Envy, Cripps Pink, Fuji, WA 38, Gala, and Honeycrisp apples in Washington State using different deleafing machines.

Cultivar	% gain of premium colored fruit (> 40% red color coverage) compared to check	Estimated % lost to sunburn	Extra packed boxes per bin (@ 22 boxes per bin)	Estimated revenue at 60 bins/acre ($)**
Envy	8.5	0.0	1.87	5055
Cripps Pink	1.0	0.0	0.23	385
Fuji	2.1	0.0	0.47	730
WA 38*	0.00	0.0	0.00	0
Gala***	13.1	2.0	2.45	2937
Honeycrisp***	15.6	3.0	2.78	7499

*Red color threshold for WA 38 was 50% red color coverage.

**Price per box was $45 for Envy, $28 for Cripps Pink, $26 for Fuji, $28 for WA 38, $20 for Gala, and $45 for Honeycrisp based on FOB pricing in December 2024 and may vary depending on year and time in storage.

***Gala and Honeycrisp trials were done in 2022 when color development was exceptionally poor. These gains may not be realized in a better coloring year.

Timing Experiment

Goal: To assess how differing leaf removal timings near harvest affects sunburn and red color development for Honeycrisp (hard to color) and WA 38 (easy to color) apples.

Treatments: Control, 50% leaf removal 7 days before harvest, and 50% leaf removal 14 days before harvest.

Conclusion: Leaf removal increased red color compared to the control, even 7 days before harvest. In years where temperatures are high, leaf removal a week prior to harvest can still have a positive effect on red color development for hard to color cultivars like Honeycrisp.

Table 8. Average red color coverage distribution on 'Honeycrisp' apples analyzed by a AWETA Commercial Fruit Sorting Line (AWETA, Nootdorp, Netherlands) in 2022 and 2023. Fruits were collected from trees with 50% leaf removal at 7 or 14 days before harvest plus an untreated control. Percentages of red color coverage were categorized into five ranges: 0-20%, 20-40%, 40-60%, 60-80%, and 80-100%. Lettering indicates mean separation within each year among treatments determined using a Tukey's HSD test ($\alpha = 0.05$).

Year	Treatment (DBH)	Proportion of Red Color Coverage (%)				
		0-20	20-40	40-60	60-80	80-100
2022	0	70.2 ± 6.3 a	15.8 ± 3.8 a	7.4 ± 1.4 a	3.7 ± 1.5 a	2.8 ± 1.5 a
	7	62.5 ± 13.8 a	8.14 ± 3.3 a	8.9 ± 4.9 a	15.5 ± 7.4 a	4.5 ± 3.4 a
	14	46.1 ± 9.4 a	24.3 ± 6.9 a	13.7 ± 4.4 a	12.7 ± 3.7 a	3.1 ± 2.6 a
	p-value	0.279	0.118	0.511	0.238	0.885
2022	0	26.6 ± 4.3 a	25.0 ± 3.5 a	16.3 ± 4.3 a	18.3 ± 3.5 a	13.8 ± 2.8 a
	7	10.4 ± 3.9 b	19.6 ± 1.7 a	18.8 ± 2.2 a	28.3 ± 2.8 ab	22.9 ± 3.8 ab
	14	13.3 ± 4.1 ab	14.3 ± 3.2 a	18.0 ± 2.8 a	21.4 ± 3.7 a	32.9 ± 6.3 b
	p-value	0.033	0.068	0.854	0.139	0.035

Table 9. The average red color coverage distribution on 'WA 38' apples was analyzed by the AWETA Commercial Fruit Sorting Line (AWETA, Nootdorp, Netherlands) in 2022 and 2023. The table displays the percentages of red color coverage categorized into five ranges: 0-20%, 20-40%, 40-60%, 60-80%, and 80-100%.

Year	Treatment (DBH)	Proportion of Red Color Coverage (%)				
		0-20	20-40	40-60	60-80	80-100
2022	Control	87.5 ± 3.9	12.5 ± 3.9	0 ± 0	0 ± 0	0 ± 0
	7	93.3 ± 4.1	6.3 ± 3.7	0 ± 0	0 ± 0	0 ± 0
	14	90.1 ± 5.2	8.3 ± 4.9	0 ± 0	0 ± 0	0 ± 0
	p-value	0.684	0.609	-	-	-
2023	Control	0 ± 0	0 ± 0	0.4 ± 0.4	1.6 ± 1.2	97.9 ± 1.6
	7	0.4 ± 0.4	0 ± 0	0 ± 0	0.4 ± 0.4	99.1 ± 0.1
	14	0.4 ± 0.4	0 ± 0	0 ± 0	0.4 ± 0.4	99.2 ± .005
	p-value	0.618	-	0.397	0.465	0.679

The results of this study suggest that the timing of 50% leaf removal before harvest has minimal impact red color development or sunburn incidence in 'Honeycrisp' and 'WA 38' apples. Both cultivars benefited from increased light exposure through defoliation, with a higher proportion of fruit displaying enhanced red color coverage. However, whether leaf removal was performed 7 or 14 days before harvest, no significant differences in fruit quality, including red color intensity and sunburn incidence, were observed. This indicates that growers have flexibility in scheduling leaf removal operations within this timeframe.

For 'Honeycrisp,' which is more prone to sunburn, it is important to balance improving red color with minimizing sunburn risks, as this cultivar exhibited a trend toward higher sunburn incidence with leaf removal, particularly at 50% removal 14 days before harvest. 'WA 38,' on the other hand, displayed greater tolerance to sunburn and can potentially benefit from more aggressive defoliation strategies to enhance red color without compromising fruit quality.

These findings provide useful insights for growers aiming to optimize fruit color while minimizing the risk of sunburn. While 50% leaf removal at different intervals before harvest showed no significant impact on sunburn or color for 'WA 38,' careful management is still needed for 'Honeycrisp.' Complementary practices such as reflective ground covers, strategic pruning, and canopy management may further enhance light penetration and improve fruit quality. Future research should investigate the long-term effects of repeated 50% leaf removal on tree health, productivity, and overall cost-benefits to develop sustainable orchard management strategies that ensure both high fruit quality, tree vitality, and on-farm profitability.

Deleafing location and combining reflective material experiment

Goal: To assess whether whole tree deleafing increased sunburn risk compared to lower canopy deleafing like a commercial machine would as well as assess the use of reflective material in deleafed orchards and its effects on red color and sunburn incidence.

Treatments: Either Extenday or grass and then combined with a control, whole tree leaf removal, or just lower canopy leaf removal.

Conclusion: Extenday continues to have strong positive effects on red color and combining reflective material and deleafing can strongly improve red color development leading to better packout and revenue for the grower. Growers should be mindful of the type of reflective material and environmental conditions during deployment to reduce the risk for photooxidative sunburn that can sometimes develop.

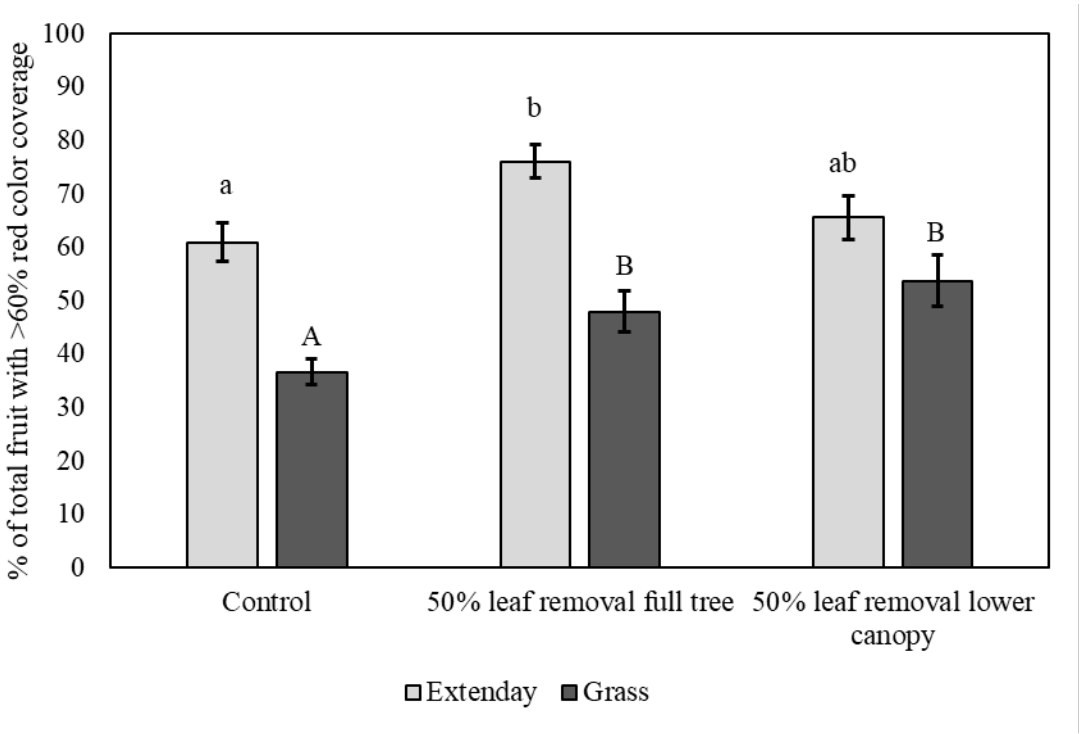

Figure 4. The percentage of fruit with greater than 60% red color coverage for Honeycrisp apple with either Extenday placed four weeks prior to harvest or just grass and then either 50% leaf removal on the full tree, 50% leaf removal on just the lower canopy, or an untreated control. Error bars denote standard error and letters denote significant differences between deleafing treatments.

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EXECUTIVE SUMMARY

Project title: Measuring the impact of leaf removal on spur and tree health

Key words: Deleafing, return yield, red color, sunburn, Honeycrisp, WA 38

Abstract: Leaf removal before harvest can be useful for enhancing red color for bicolor apple cultivars. Red color increases the appeal to consumers. Despite the potential benefits of leaf removal for enhancing red color, there may also be risks to fruit quality. Removing leaves increases sun exposure, which can lead to sunburn damage, reducing the percentage of marketable, non-sunburned fruit and affecting overall fruit quality. It is important to maximize fruit coloration but minimize risks to both the current and subsequent seasons' crops. In the industry, leaf removal has been used to enhance red color but has not thoroughly addressed the impact on tree health and productivity in subsequent years. Here, two experiments were conducted to research the impact of leaf removal on fruit quality. In one experiment, five different leaf removal levels were applied (0%, 25%, 50%, 75%, and 100% of the leaf canopy) 14 days before harvest (N=5) to assess their effects on fruit coloration, sunburn, return yields, and shoot vigor in ‘Honeycrisp’ and ‘WA 38’ apples. In the second experiment, red color development and sunburn was evaluated for leaf removal treatments either 7 or 14 days before harvest compared to an untreated control. As the percentage of leaf removal increased, the percentage of marketable, non-sunburned fruit decreased, indicating that sunburn increased as leaf removal increased for both cultivars but to a lower extent for ‘WA 38’. Red color coverage increased with an increase in leaf removal, with 100% removal resulting in the highest percentage of red color coverage in both ‘Honeycrisp’ and ‘WA 38’. When leaf removal severity was greater than 50%, the yields the following year were lower but shoot vigor was unaffected. Leaf removal at either 7 or 14 days before harvest improved red color compared to the control, but there were no differences between these two treatments, indicating that the window for leaf removal can be as little as 7 days before harvest. ‘WA 38’ was easier to color than ‘Honeycrisp,’ and deleafing in a poor color year was good for both cultivars but in a good color year like 2023, deleafing was only useful for hard to color cultivars like ‘Honeycrisp’