FINAL PROJECT REPORT

Project Title: Effects on physiology of apple under photoselective anti-hail nets

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Cooperators: McDougall & Sons, Inc., Sara Serra (WSU TFREC), Giverson Mupambi (WSU TFREC).

Total Project Request: **Year 1**: $84,102 **Year 2**: $85,713

Other funding sources

Agency Name: Washington State Department of Agriculture Specialty Crop Block Grant K1771
Amount requested/awarded: $248,000
Notes: This project started in October, 2015 and will extend the project through 2017 and provide another year of data to the tree fruit industry that won't require support from the WTFRC.

Agency Name: Wilson Irrigation
Amt. requested/awarded: Approximately $15,000
Notes: In-kind contribution of 6,500 sq. ft. of shadehouse structures for netting experiments

WTFRC Collaborative expenses:

Item	2015	2016
Wages and benefits[1]	8,000	8,000
Salaries and benefits[2]	5,000	5,000
Supplies	500	500
Travel	500	500
Total	14,000	14,000

Footnotes:
[1]Time slip wages for building shadehouses and harvesting fruit for quality analysis.
[2]Salaries for Tory Schmidt and Felipe Castillo.

Budget 1
Organization Name: WSU **Contract Administrator:** Carrie Johnston/Joni Cartwright
Telephone: 509-335-4564/509-663-8181 **Email:** carriej@wsu.edu/joni.cartwright@wsu.edu

Item	2015	2016
Salaries[1]	16,000	16,640
Benefits[2]	4,882	5,077
Wages[1]	16,320	16,972
Benefits[2]	3,100	3,224
Travel[3]	4,000	4000
Goods and Services[4]	25,800	25,800
Total	70,102	71,713

Footnotes:
[1]Salaries for 33% research intern (Kalcsits) and time slip wages (Layne and Musacchi).
[2] Benefits at 30.5% and 19% for research intern and time slip wages, respectively.
3Frequent travel to orchard site (Quincy) where trials are being conducted.
[4]Goods and services include in-orchard temperature/humidity dataloggers, soil moisture and temperature monitors, isotope analysis, WSU TFREC fees for soil, leaf and fruit mineral nutrient analyses.

RECAP ORIGINAL OBJECTIVES

1. Determine characteristics of three net colors on light spectrum and their effects on the light quality and quantity of incoming radiation throughout the day.
2. Quantify the impact of nets on orchard microclimate, photosynthesis, vegetative growth and tree stress.
3. Evaluate fruit and leaf nutritional balance and fruit quality under different light conditions.

Working in a Honeycrisp orchard on Bud-9 that was planted in 2013, environmental sensors were installed, the physiological and growth status of the trees were measured, and fruit quality of the trees were assessed under red, blue and pearl netting compared to an uncovered control. A parallel experiment was set up at the WSU tree fruit research and extension center in Wenatchee using the same treatments to monitor the physiological changes in greater detail than would be possible when working in a commercial orchard.

SIGNIFICANT FINDINGS

- Photoselective netting reduced light intensity differently depending on color. All 20% netting reduced photosynthetic active radiation (PAR) by between 25% (red) and 21% (pearl). When using a new netting product, it is recommended that light intensity is verified using sample material before purchasing.
- Netting strongly reduced wind (by more than 50%) but did not affect air temperature in the tree canopy.
- Netting altered the spectra of incoming light and created a better light environment for plant and fruit growth. This was particularly true for the pearl netting that provides more scattered light than the other colors.
- Absorptive surfaces (fruit, leaves, soil) were more impacted by netting than the air under the canopy. Soil, leaf and fruit temperatures were all lower by using 20% netting (Figure 1, 2; Kalcsits et al. 2017).
- Netting reduced light and heat stress on the tree and improved leaf-level photosynthesis and light-use efficiency (Table 4).
- Netting increased flower induction and fruit set after a ‘heavy crop’ year in pearl and red netting.
- Canopy growth was greater under netting than for the uncovered control.
- Netting increased fruit size and had no major negative effects on fruit quality. There were small reductions in color development with the blue and red netting in 2015 (Table 5).
- Netting strongly reduced sunburn compared to an uncovered control and provided a similar level of sunburn control to evaporative cooling in 2016 (Figure 3)

RESULTS & DISCUSSION

Objective 1. Determine how photoselective anti-hail nets modify the microenvironment to mitigate stress-inducing conditions in WA State's growing environment

Environmental Monitoring

In June, 2015, at three separate locations each in the four experimental treatments, mini weather stations were positioned that included an EM50G datalogger (Decagon Devices, Inc., Pullman, WA) that recorded data every 10 minutes and transmitted data by cellular signal to a cloud-based server. Sensors at each station included a VP-4 humidity and temperature sensor (Decagon Devices, Inc., Pullman, WA), a Davis cup anemometer, a photosynthetically active radiation (PAR) sensor (Decagon Devices, Inc., Pullman, WA). These were used to measure, air temperature, relative humidity, wind speed and PAR in each treatment. For measurements that contain more variability, such as in-canopy air temperature and humidity and soil moisture and temperature, four replicate VP-4 sensors for measuring in-canopy air temperature and humidity were placed near the trunk at 1.6 m from the ground in each color of netting. Four 5TM soil moisture and temperature capacitance sensors (Decagon Devices, Inc., Pullman, WA) were installed at dispersed distances within each treatment. The capacitance sensors were installed at depths of 20 and 40 cm to measure volumetric water content (cm^3 cm^{-3}). Sensor locations were chosen to limit interferences from tree and post shadowing of irrigation microsprinklers and were equidistant from trees within the row. Data was downloaded monthly using DataTrac software (Decagon Devices Inc., Pullman, WA) from the online database to ensure that sensors were functioning correctly.

Results

Netting did not affect air temperature or relative humidity within the orchard canopy, but reduced wind speed by 40% compared to the uncovered control. Netting reduced soil temperature and increased soil moisture at 20 and 40 cm depths throughout the study period compared to the uncovered control. Amongst different colors of netting tested in this study, pearl and blue netting significantly reduced soil temperature compared to red netting. Netting also reduced photosynthetically active radiation (PAR) by approximately 20% and strongly reduced fruit surface temperature during hot periods. During full sunlight, differences in maximum fruit surface temperature between the uncovered control and the protective netting were 2.6 to 4.3°C under full sun conditions and reduced the incidence and severity of sunburn measured at harvest.

Table 1. Light intensity and wind speed in 2015 and 2016 in a commercial 'Honeycrisp' apple orchard under blue, pearl, and red netting compared to an uncovered control

	2015		2016	
	Light Intensity (umol m^{-2} s^{-1})	**Wind Speed (miles h^{-1})**	**Light Intensity (umol m^{-2} s^{-1})**	**Wind Speed (miles h^{-1})**
Control	1804 a	8.0 a	1782 a	10.3 a
Blue	1404 b	3.76 b	1407 b	4.7 b
Pearl	1459 b	3.96 b	1420 b	5.0 b
Red	1355 b	3.64 b	1354 b	4.7 b

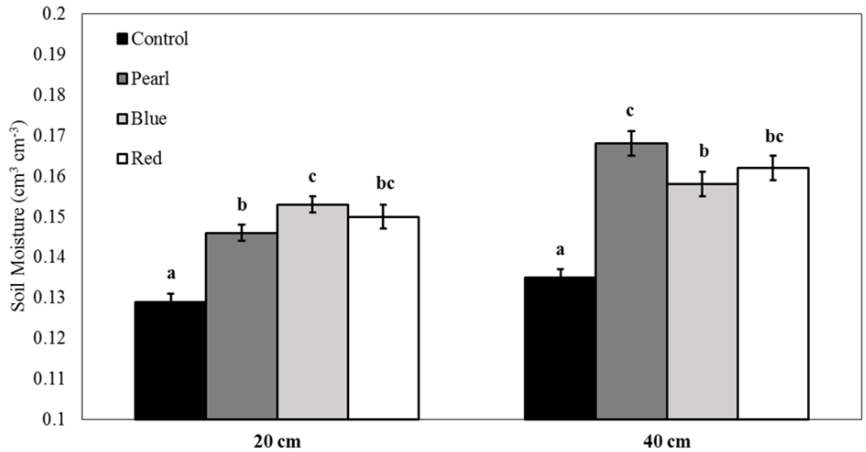


Figure 1. Mean volumetric soil moisture content (cm^3 cm^{-3}) at 20 and 40 cm depth under pearl, blue and red anti-hail netting compared to an uncovered control in a three year-old 'Honeycrisp' apple orchard in Quincy, WA (47.23° N, 119.85° W). Different letters denote significant differences between means determined using a one-way ANOVA ($P<0.05$).

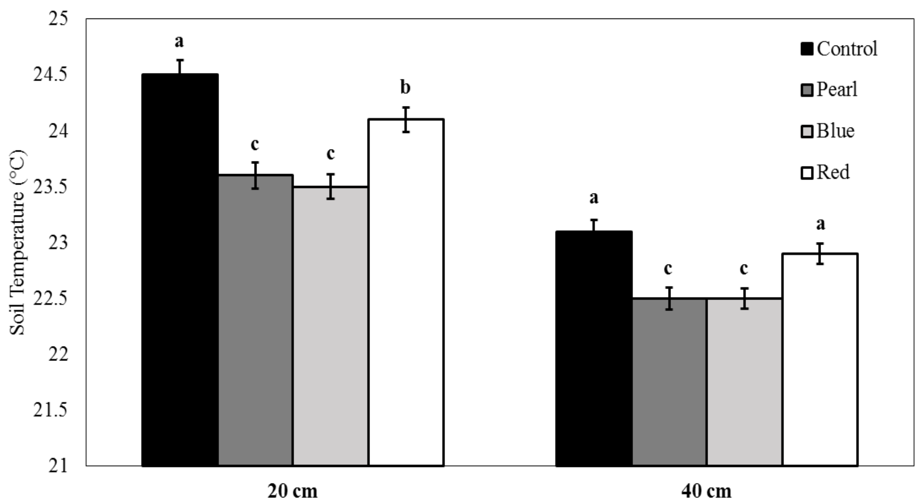


Figure 2. Mean soil temperature (°C) (±SE, N=4) at 20 and 40 cm depth under pearl, blue and red protective netting compared to an uncovered control in a three year-old 'Honeycrisp' apple orchard in Quincy, WA (47.23° N, 119.85° W). Different letters denote significant differences between means determined using a one-way ANOVA ($P<0.05$).

Canopy light interception (%)

The light interception of the canopies under three different netting treatments was significantly greater compared to the uncovered control in 2015 and 2016. Trees under colored nets developed more robust canopies than the uncovered control. This is supported by approximately 15% higher light interception for trees covered by nets than the uncovered control. Light interception was not significantly different among netting colors indicating similar canopy development between netting colors.

In 2015, the third year of growth, light interception was measured in trees with a crop (fruiting) and with all flowers removed (non-fruiting). In 2015, fruiting trees had a less developed canopy compared to the non-fruiting trees. However, in 2016, a targeted crop load was applied to all trees, fruiting or non-fruiting. In 2016, growth in the fruiting trees was greater because of low or no flowering and as such, there was no significant difference in light interception between fruiting and non-fruiting trees. The interaction between net color and fruiting treatment was significant ($p < 0.01$). The pearl net reported a higher light interception in the trees that bore fruit in 2015. This may be related to fruit set under the targeted crop load and higher vigor in 2016 when fruit load was low. Light interception increased from May to July, as the first-year tree growth increased, but were not statistically different.

Light transmittance (%) can be different for each colored net and is expressed as total light under each net / total light outside the net (open field) x 100. Transmittance describes the percentage of light coming through the nets relative to full sun and the shading percentage of each type of net is confirmed to range from 20-23% (as from manufacturer). Each colored net has a distinct transmittance curve calculated from the light spectra from 300 to 1000 nm. Variability during the season can be caused by how the sun hits the material or dust on the net. Blue net has a lower shading effect in the range from 400 to 550 nm (PAR range) than the red net. There was an increased in transmittance in in the infrared range (>780 nm) that is different from the other two net colors. The pearl net filtered the lowest wavelengths (UV-VIS) and shows a more uniform transmittance than the other colors. Red net has an increase in transmittance (%) immediately before 600 nm. In conclusion, transmittance measured in 2016 showed a similar trend with 2015 data and literature (Shahak and Gussakovsky, 2004). Spectra of scattered light under colored nets showed similar trends as reported in Shahak and Gussakovsky (2004) for scattered light on the total light under the different nets for all the wavelength.

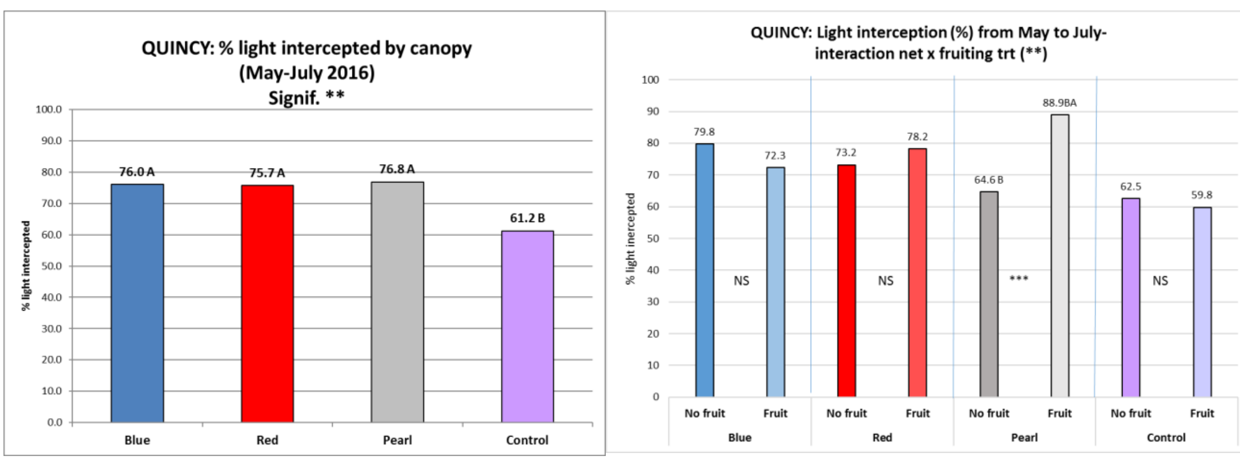
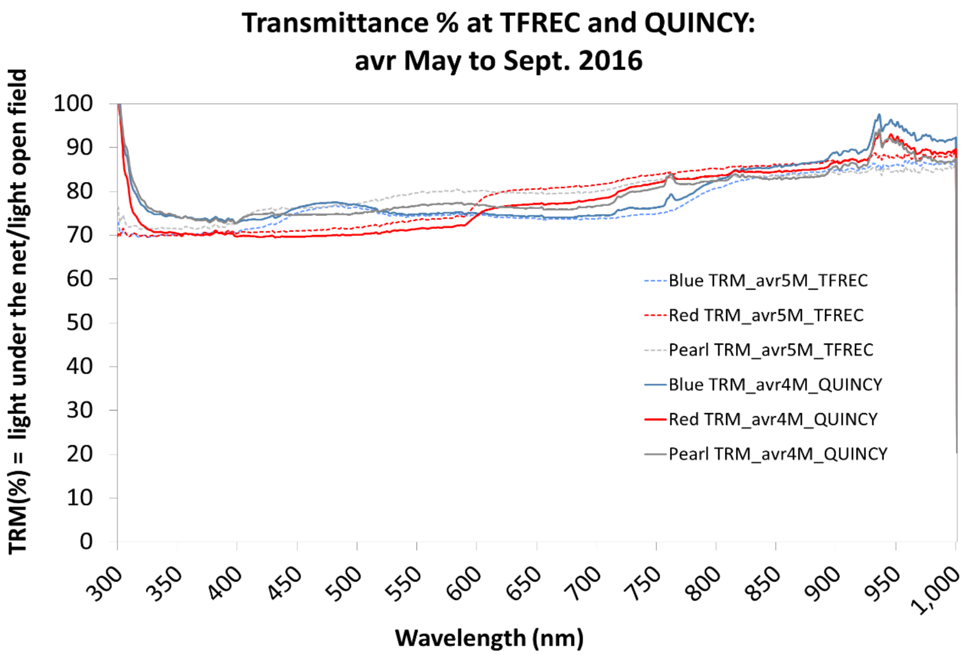


Figure 3: Light interception % from May to July in Quincy: comparison between colored nets and control (left) and within each color net between "fruiting" and "non-fruiting" (right).

Light spectra under the nets

At WSU TFREC and in the commercial orchard in Quincy, spectra of incoming total and diffuse (scattered) radiation were measured under the nets and in open field by using a spectroradiometer (Apogee Instrument, Inc., UT, USA) connected to a light cosine sensor via fiber cable. The open field readings were used as reference for the transmittance measurement. The entire data collection was performed orienting the detector perpendicular to the sun beams as reported in literature (Shahak and Gussakovsky, 2004, Kong et al., 2013). Transmittance of total light (%) for each colored net is expressed as total light under each net divided by the total light outside the net (open field) x 100. Scattered light (%) was expressed as diffuse light under the net divided by the diffuse light in the open field, x 100. Light intensity parameters (PAR, UV, Blue, Red, Far Red) expressed as μmol m^{-2} s^{-1} were calculated in the same ranges as reported by Kong et al., 2013 (Table 2).



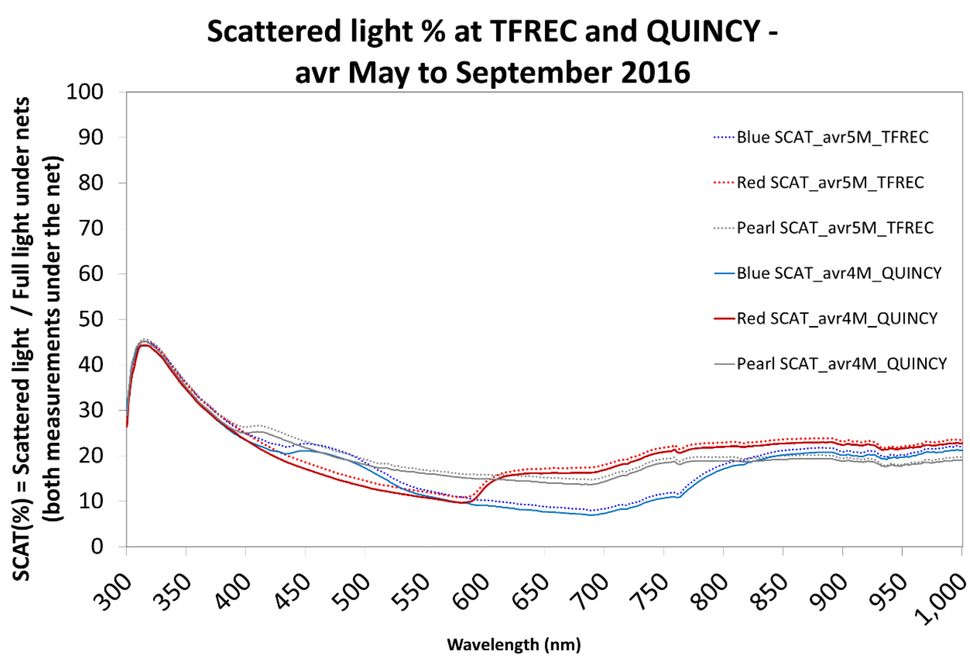


Figure 4: Transmittance spectra of total light under the nets (top) and percentage of scattered light on the total light under the nets (bottom) taken at both locations in 2016.

Table 2: Intensity and quality of total and scattered light under pearl, blue, and red netting compared to an uncovered control in Quincy and TFREC (Wenatchee) in 2016.

Quincy 2016			Light intensity (μmol $m^{-2}s^{-1}$)										Light quality (ratios)					
Light	Color Nets-ctrl	N	PAR: 400–700 nm		UV: 305–380 nm		Blue: 410–470 nm		Red: 640–680 nm		Far Red: 690–750 nm		Blue/Red		Red/Far Red		PAR/UV	
Scattered light (diffuse)	BLUE	48	159.5	B	20.4	B	42.5	A	14.5	C	23.0	C	2.93	A	0.63	B	7.89	C
	RED	48	183.4	B	19.6	B	32.8	B	36.1	A	59.5	A	0.91	D	0.60	C	9.47	B
	PEARL	48	213.0	A	21.0	B	44.7	A	27.5	B	46.5	B	1.63	C	0.59	C	10.21	A
	open field-NO NET	4	199.4	AB	31.5	A	51.7	A	20.2	C	26.6	C	2.55	B	0.76	A	6.44	D
	Significance		***		***		***		***		***		***		***		***	
Total full light (transmitted)	BLUE	48	1407.1	B	63.1	B	217.2	B	222.5	C	303.7	C	0.98	A	0.73	B	22.65	
	RED	47	1405.3	B	60.9	B	203.5	C	240.7	B	335.3	B	0.85	C	0.72	C	23.45	
	PEARL	48	1470.4	B	64.5	B	220.9	B	237.1	BC	329.7	B	0.93	B	0.72	C	23.09	
	open field-NO NET	4	1888.1	A	90.0	A	292.6	A	301.7	A	407.7	A	0.97	A	0.74	A	21.33	
	Significance		***		***		***		***		***		***		***		NS	

Significance: * p<0.05, ** p<0.01, *** p<0.001, NS= not significant. Significance was established with proc GLM in SAS, type III SS and Bonferroni as *post-hoc* test to discriminate means. Same letters means no difference between treatments.

Data were collected in a commercial orchard and reported as averages across the season from May to September 2016 (August measures were removed due to clouds). Open field-no net was measured only as reference (N=4). PAR: 400-700 nm, UV: 305-380 nm, Blue: 410-470 nm, Red: 640-680 nm, Far Red: 690-750 nm.

TFREC (Wen) 2016			Light intensity (μmol $m^{-2}s^{-1}$)										Light quality (ratios)					
Light	Color Nets-ctrl	N	PAR: 400–700 nm		UV: 305–380 nm		Blue: 410–470 nm		Red: 640–680 nm		Far Red: 690–750 nm		Blue/Red		Red/Far Red		PAR/UV	
Scattered light (diffuse)	BLUE	30	194.7	B	22.8	B	50.3	B	18.6	C	28.0	C	2.80	A	0.66	B	8.61	C
	RED	29	230.2	A	23.1	B	42.5	C	42.3	A	65.9	A	1.00	C	0.64	B	10.06	B
	PEARL	30	272.8	A	23.9	B	56.5	A	36.4	B	56.1	B	1.56	B	0.65	B	11.50	A
	open field-NO NET	3	222.0	AB	31.0	A	55.9	AB	23.4	C	32.4	C	2.50	A	0.73	A	7.27	C
	Significance		***		*		***		***		***		***		***		***	
Total full light (transmitted)	BLUE	30	1391.7	C	64.4	B	223.1	C	214.8	C	291.6	C	1.04	A	0.74	A	21.82	
	RED	29	1450.6	BC	65.3	B	217.0	C	243.9	B	335.8	B	0.89	C	0.73	B	22.50	
	PEARL	30	1521.1	B	67.2	AB	235.7	B	240.8	B	330.9	B	0.98	B	0.73	AB	22.90	
	open field-NO NET	3	1793.2	A	82.1	A	279.9	A	285.4	A	385.8	A	0.98	B	0.74	A	22.05	
	Significance		***		*		***		***		***		***		***		NS	

Significance: * p<0.05, ** p<0.01, *** p<0.001, NS= not significant. Significance was established with proc GLM in SAS, type III SS and Bonferroni as *post-hoc* test to discriminate means. Same letters means no difference between treatments.

Data were collected in an experimental shade house and reported as averages across the season from May to September 2016. Open field-no net was measured only as reference (N=3). PAR: 400-700 nm, UV: 305-380 nm, Blue: 410-470 nm, Red: 640-680 nm, Far Red: 690-750 nm.

In both locations, nets reduced the light intensity. Combined PAR, UV, Blue, Red, Far Red light were always significantly lower compared to the uncovered control (Table 2). PAR and UV across the season (May to September 2016) were similar for the three colors, while the intensity for Blue light was the lowest under the red net and Red and Far Red intensities were the lowest under the Blue net. The scattered light data in both locations showed a higher intensity in the PAR range for the Pearl net compared to the other colored nets and similar to the uncovered control as reported in literature (Kong et al., 2013). Blue net showed the lowest amount of scattered light intensity in the PAR range. Scattered light is the type of light that can reach the inner part of the canopy and modifying the physiology of the tree and fruit quality.

Blue/Red ratio was significantly ($p<0.001$) different among the four treatments: the highest under Blue net as total transmitted light and even more as scattered light, while the lowest values were registered under the Red net (as reported in literature, Shahak and Gussakovsky, 2004). Blue/Red ratios for Pearl and the uncovered control fell in between. Those trends in differences were more enhanced in the scattered light data than the total light. Red/Far Red ratio has a key role in phytochromes transition in their stages (activated P_{FR}/inactivated P_R) and therefore in how efficiently the light energy is captured for photosynthesis purposes (Batschauer, 1998). Red/Far Red ratio has the highest values in the uncovered control followed by Blue net. PAR/UV ratio of scattered light was significantly different among treatments showing the highest values under the Pearl net and the lowest in the open field. These results confirmed the beneficial effect of red and pearl nets for improving light quality in orchards.

Objective 2. Identify the impact of photoselective anti-hail netting on fruit quality and horticultural management

Shoot growth significantly increased under the netting compared to the uncovered control. In 2015, shoot growth was approximately 10% higher than the control and in 2016, when the netting was deployed earlier, growth was more than 25% greater under the netting compared to the uncovered control. Netting color did not affect shoot growth. Trunk cross sectional area was not significantly different among treatments (Table 3). However, bloom density was significantly greater for trees under pearl and red netting and the percentage of flowers set to fruit was greater for trees under netting than the uncovered control.

Net photosynthesis was greater under netting compared to the uncovered control (Table 4). This was likely driven by increases in stem water potential and increases in the light harvesting efficiency of the leaves. More work will be done in 2017 as part of the leveraged WSDA/USDA Speciality Crop Block Grant that will carry the project through 2017.

Table 3. Net photosynthesis of apple leaves at 120 days after full bloom in Honeycrisp apple under pearl, blue, and red netting compared to an uncovered control

Treatment	Net carbon assimilation rate ($\mu mol\ m^{-2}\ s^{-1}$)
Control	10.21 b^z
Pearl	13.84 a
Red	15.11 a
Blue	15.44 a
Treatment Pr>F	0.0068

Table 4: The effect of nets and fruiting treatments in Quincy 2016 on averaged trunk cross-sectional area, weight of pruned material, return blossom, fruit set, and crop load of Honeycrisp and statistical results comparing treatments.

Treatment	Winter 2016 TCSA (cm^2)		Weight of wood pruned in winter 2016 (lb/tree)		Blossom cluster density (no. cluster/ cm^2 TCSA)		% Flower set to fruit	
Net								
Control	5.20		0.41		6.20	**b**	10.06	**b**
Pearl	5.07		0.37		11.71	**a**	15.85	**ab**
Blue	4.80		0.30		6.25	**b**	15.82	**ab**
Red	4.83		0.34		10.47	**a**	17.91	**a**
Significance	***NS***		***NS***		***		*	
Fruiting trt								
Non fruiting	5.31	**a**	0.43	**a**	12.75	**a**	10.12	**b**
Fruiting	4.63	**b**	0.28	**b**	4.56	**b**	19.71	**a**
Significance	***				***		***	
Significance net*fruit	***NS***		***NS***		***NS***		***NS***	

p<0.05, *; p<0.01, **; p<0.001, ***; NS, not significant for Type III sums of squares model significance.
Arithmetic means are presented; *post hoc* tests were done with LSMEANS option and the Bonferroni adjustment provided letter.

Objective 3. Evaluate fruit and leaf nutritional balance and fruit quality under different light conditions.

Fruit size was significantly greater under netting compared to the uncovered control in both 2015 and 2016. Netting reduced sunburn to a comparable level compared to evaporative cooling that was installed in 2016 (Figure 5). Blue netting had less sunburn than red or pearl. However, that appeared to come at a cost of slightly reduced color development (Table 6). To see the subtle differences between colors, another year of data is needed.

Table 5. Fruit size in 2015 and 2016 harvested from trees with even crop loads under pearl, blue, and red netting compared to an uncovered control.

	2015	2016
Control	231 *a*	366 *a*
Pearl	274 *c*	394 *b*
Blue	252 *b*	388 *b*
Red	260 *bc*	386 *b*

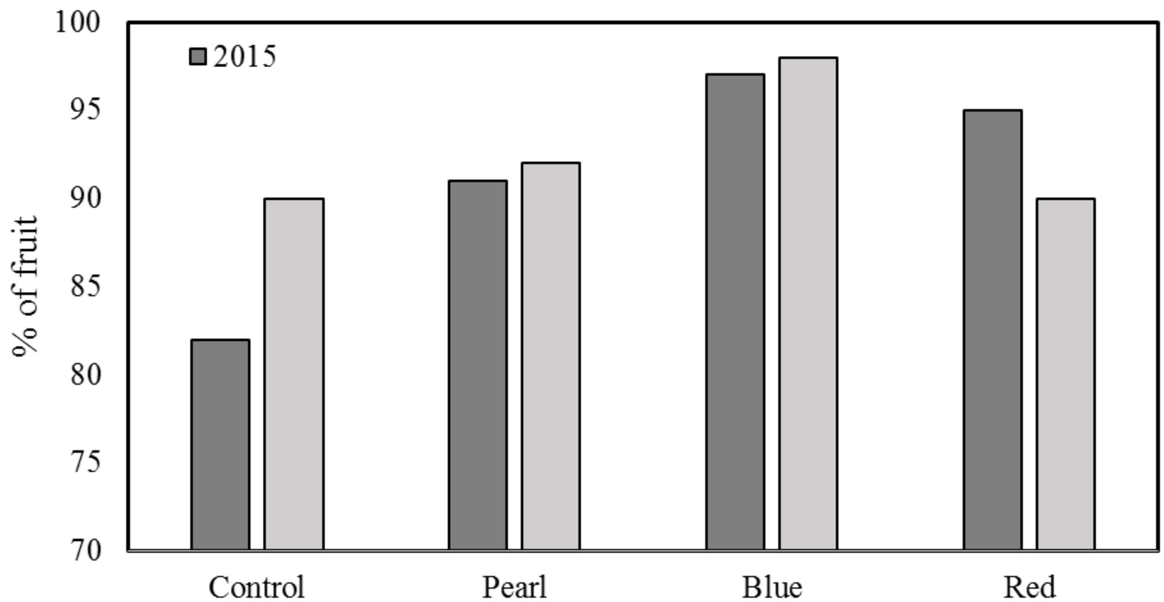


Figure 5. The proportion of harvested fruit (%) belonging to clean, Y1 and Y2 sunburn classes for fruit harvested from under pearl, blue and red protective netting compared to an uncovered control. 2015 had no evaporative cooling in the control and 2016 had evaporative cooling for sunburn protection in the control.

Table 6. Soluble solids content and foreground color development on apple fruit harvested from trees under pearl blue, and red netting compared to an uncovered control

	SSC (°Brix)	Foreground Color
Control	15.0 *a*	2.63 *a*
Pearl	14.7 *ab*	2.47 *ab*
Blue	14.5 *b*	2.39 *b*
Red	14.5 *b*	2.42 *b*

Leveraged External Grants

(2015-2018) 'Physiological responses of apple under photoselective hail netting'. Washington State Department of Agriculture Specialty Crop Block Grant. ($248,608).

Publications

Kalcsits LA, Mupambi G, Serra A, Musacchi S, Layne DR, Schmidt T, Mendoza M, Asteggiano L, Jaralmasjed S, Sindhuja S, Khot LR, Zúñiga Espinoza C. 2017. Above and below-ground environmental changes associated with the use of photoselective protective netting to reduce sunburn in apple. *Pending minor revisions*

Kalcsits LA, Asteggiano L, Schmidt T, Serra A, Layne D, Mupambi G. Shade netting reduces sunburn damage and soil moisture depletion in 'Granny Smith' apples. *Submitted to Acta Horticulturae October 15th, 2016.*

Presentations

Kalcsits L, Wheeler C, Asteggiano L, Jarolmasjed S, Khot L, Layne D, Mendoza M, Musacchi S, Sankaran S, Schmidt T, Serra S, Zuniga C**. Horticultural Management and Environmental Manipulation to Limit the Effects of Water Stress.** Washington State Tree Fruit Association Horticultural Show. Yakima, WA. December 7, 2015.

Kalcsits L, Wheeler C, Asteggiano L, Jarolmasjed S, Khot L, Layne D, Mendoza M, Musacchi S, Sankaran S, Schmidt T, Serra S, Zuniga C. Managing Stress in Tree Fruit. Washington State Tree Fruit Association Horticultural Show. Yakima, WA. December 8, 2015.

Kalcsits L. Netting to reduce risk and stress in tree fruit. Wenatchee Apple Day. Wenatchee, WA. January 21, 2016.

Kalcsits L. Update on photoselective netting trials in Washington State. International Fruit Tree Association. Grand Rapids, Michigan, February 10, 2016.

Kalcsits LA. Update on photoselective netting trials in Washington State. Olympia Fruit Annual Meeting. February 16, 2016

Kalcsits L, Wheeler C, Asteggiano L, Jarolmasjed S, Khot L, Layne D, Mendoza M, Musacchi S, Sankaran S, Schmidt T, Serra S, Zuniga C. Light, Air, and Soil Environment Manipulation Using Photoselective Anti-Hail Netting in a High Latitude, Desert Environment. ISHS Symposium on orchard systems, rootstocks and environmental physiology. Bologna, Italy. August 29 - September 2, 2016.

Kalcsits L, Wheeler C, Asteggiano L[‡], Jarolmasjed S, Khot L, Layne D, Mendoza M, Musacchi S, Sankaran S, Schmidt T, Serra S, Zuniga C**.** Overhead Netting to Modify Orchard Environments. Washington State Tree Fruit Association Horticultural Show. Yakima, WA. December 7, 2016. Invited Presentation

Media Coverage

http://www.goodfruit.com/orchards-under-cover/
http://www.wenatcheeworld.com/news/2016/aug/20/local-color-researchers-find-multi-hued-netting-could-benefit-apple-production/
http://fruitgrowersnews.com/article/project-evaluates-photoselective-netting/
http://www.capitalpress.com/Orchards/20160512/researcher-studies-tools-ranging-from-netting-to-x-ray-meters
http://www.goodfruit.com/if-netting-is-the-future-what-color/

Extension Bulletin

http://treefruit.wsu.edu/news/photoselective-anti-hail-netting/

Field Days

Netting Field Day - August 17, 2016

The project team hosted 4 additional tours to the industry netting experiment in 2016

EXECUTIVE SUMMARY

This project tested the effect of pearl, blue, and red netting on the orchard environment, physiology and fruit quality of Honeycrisp apples compared to an uncovered control. Environmental sensors recorded air temperature, relative humidity, wind speed, light intensity, soil temperature and soil moisture in each treatment through the 2015 and 2016 seasons. In both years, fruit sunburn data and fruit quality was recorded at harvest and after four months of regular atmosphere storage. Vegetative growth, flower induction and fruit set was also measured. Plant water status, photosynthesis and light-use efficiency was recorded throughout the growing season in 2016.

Netting reduces wind speed, even when the sides are not closed. The netting material (sold as a 22% reduction in light) used reduced light intensity by 20-25% depending on the color or netting. Netting did not reduce the air temperature of the netting. It altered the spectra and intensity of light reaching the plant canopy and the soil. These changes in light produced cooler plant canopies, fruit and soil. This produced higher soil moisture under the netting, more growth and reductions in sunburn. Depending on the color of netting, the spectra of light reaching the plant canopy is different. Pearl netting, appearing white but is semi-transparent, scattered the light under the canopy providing a more uniform light environment and less shadowing (Table 2). It also transmitted more photosynthetically active radiation relative to UV light compared to other colors or the uncovered control.

Apple trees cannot use the total light made available on almost all summer days in Washington State. This excess light can be a cost to the tree as it needs to use energy to deal with this excess light. In many cases, a reduction in 20-25% light would not cause photosynthetic limitations that would lead to reduction in carbon assimilation and lower plant productivity. Plant productivity increased through increased photosynthetic rates, particularly later in the day. The light harvesting efficiency of trees under netting was higher than trees in the uncovered control. These gains in productivity led to increased growth shown through a 25% increase in terminal shoot growth and a 15% increase in light interception in tree under netting compared to the uncovered control. Flower induction was also greater under netting compared to the uncovered control.

Netting reduces fruit surface temperature below the sunburn threshold on days when the sunburn risk is high. Fruit sunburn was lower under the blue netting than the pearl or red. However, all netting reduced the incidence of sunburn to the same or lower sunburn severity as when using evaporative cooling. Fruit size was approximately 10% larger under netting. While this could be a concern for a cultivar like Honeycrisp, this is an advantage for other cultivars. Furthermore, the fruit size increase is likely a result of increased soil moisture and a less stressful environment. When evaporative cooling was not used in 2015, fruit maturity was accelerated outside the netting. However, when evaporative cooling was used in 2016, there were no differences in fruit maturity at harvest between netting treatments and the uncovered control. Blue appears to slightly limit color development but one more year of data is needed to confirm this. Pearl and red netting did not negatively affect color development in these trials.

As with any new horticultural approach, there are positives and negatives. Reductions in sunburn, increased plant productivity, hail, and wind protection are major positive aspects of netting. Increased fruit size and increased shoot vigor can be either positive or negative depending on the cultivar. Horticultural management could limit some of these potential negative effects of netting and each operation will need to develop their own strategies to manage their orchards under netting. We report than netting is a viable alternative for evaporative cooling for sunburn protection and other environmental stresses.