FINAL PROJECT REPORT

Project Title: Optimizing light and water for orchards covered with netting

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Cooperators: Manoella Mendoza (WTFRC): Extenday USA Inc

Total Project Request: **Year 1:** $99,921 **Year 2:** $89,176

Other funding sources

Agency Name: Extenday USA Inc
Amt. requested/awarded:
Notes: In kind contribution of protective netting materials, reflective ground cover, consumables for installation, field visit to identify trial sites and consultancy services at trial establishment.

WTFRC Budget:

Item	2018	2019
Salaries	7,000	7,000
Benefits	3,000	3,000
Wages	1,000	1,000
Benefits	600	650
Shipping	150	180
Travel	500	500
Total	12,250	12,330

Footnotes:

Budget 1

Organization Name: WSU **Contract Administrator: Katy Roberts/**Shelli Tompkins

Telephone: (509) 663-8181 **Email address:** shelli.tompkins@wsu.edu

Item	2018	2019
Salaries[1]	49,920	51,917
Benefits[2]	18,201	18,929
Equipment[3]	13,550	-
Supplies[4]	3,000	3,000
Travel[5]	3,000	3,000
Total	87,671	76,846

Footnotes:

[1]Salary for 100% Postdoc Research Fellow (Kalcsits)

[2]Benefits rate @ 36.5%

[3]Purchase Flow32-1K Sap Flow System

[4]Lab consumables

[5]Travel to Sunrise and field cooperator sites

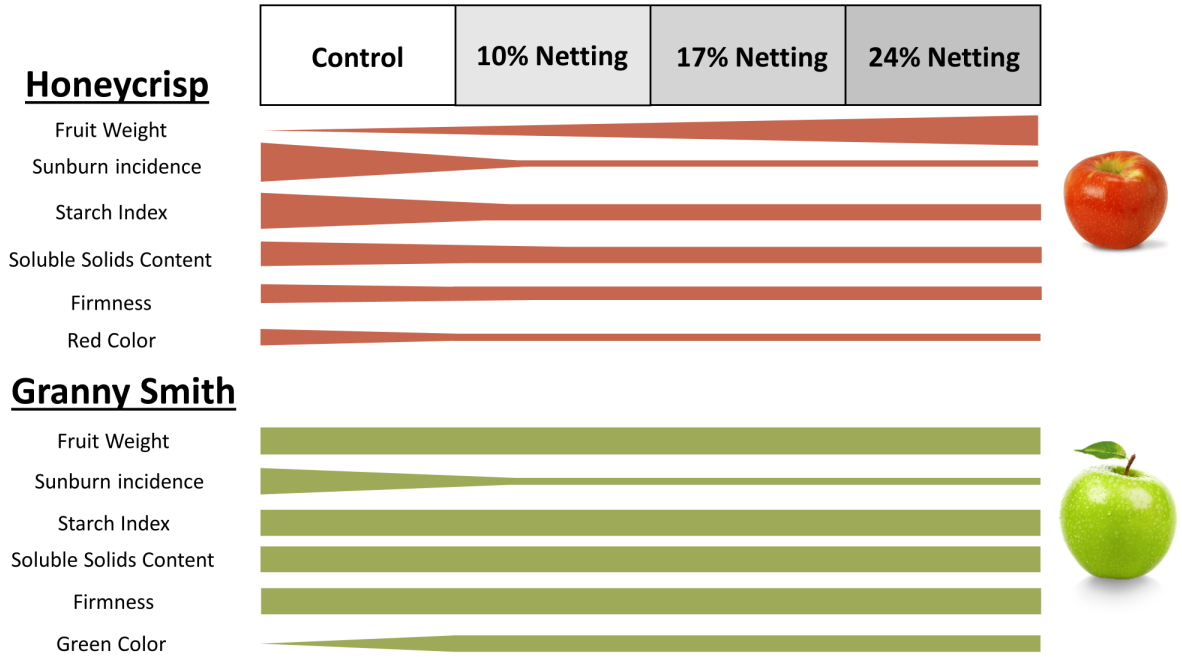
OBJECTIVES

1. Determine the optimal shade percentage for the most common cultivars under protective netting in WA (Honeycrisp and Granny Smith)
2. Test whether reflective ground fabrics improve light penetration under protective netting to improve fruit quality, flower bud formation, return bloom, and fruit set in 'Honeycrisp' and 'Granny Smith' apple.
3. Quantify changes in water needs for orchards under protective netting in 'Honeycrisp' apple.

SIGNIFICANT FINDINGS

- All objectives were completed as planned with two years of data acquired for each experiment
- In 'Honeycrisp', 10%, 17%, 24% shade factor significantly reduced sunburn incidence compared to an uncovered control. 10% protective netting had slightly higher proportions of fruit with severe sunburn symptoms compared to higher shading factors.
- In 'Granny Smith', 17% and 24% had higher sunburn reduction compared to 10% shade which performed significantly better than the control
- In 'Honeycrisp', 10%, 17%, 24% shade factor significantly reduced red color compared to an uncovered control, with no differences being observed between the different shade factors.
- In 'Granny Smith' 17% and 24% shade factor had lower incidence of red blush compared to 10% shade which performed significantly better than the control
- In 'Granny Smith', Extenday deployed in early summer improved light penetration and return bloom in Granny Smith directly contributing to higher yields in 2019.
- In Honeycrisp, Mylar and Extenday improved red coloration significantly under 17% protective net compared to protective netting without reflective ground cover as a control
- Under protective net, mylar had significantly higher sunburn incidence compared to protective netting without reflective ground cover as a control which was not significantly different from the control
- Despite increased leaf area under 17% protective netting compared to an uncovered control, overall water use was approximately 20% lower in 'Honeycrisp' because of reduced tree transpiration and soil evaporation.

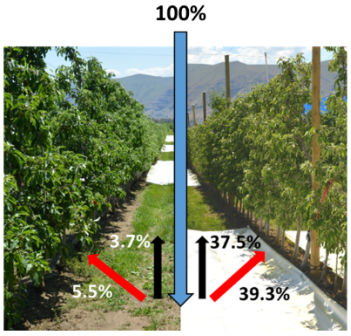
SHADING FACTORS AND ITS EFFECT ON FRUIT QUALITY



REFLECTIVE FABRICS UNDER PROTECTIVE NETTING

- No changes to photosynthetic rates or light use efficiency
- Return bloom increased in 2019 when reflective deployed for Granny Smith
  - 112 clusters for Extenday from 98 clusters for control
- Stem water potential lower when reflective was used
  - -0.9 MPa for the control and -1.2 Mpa when Extenday was used for Granny Smith
  - -1.4 MPa for the control and -1.48 and -1.52 MPa for Extenday and mylar, respectively for Honeycrisp

- No changes to fruit color for Granny Smith
- Both Extenday and Mylar increased red color equally for Honeycrisp under 17% netting
- Color development with reflective under 17% netting (2.8) was greater than an uncovered control with no reflective fabric (2.5)
- Reflective fabrics did not change fruit quality or maturity



METHODS

Site 1: McDougall & Sons, Inc., Quincy, WA.

5th leaf "Cameron Select Honeycrisp" on Bud-9 rootstock; trees trained on 4-wire V-trellis and spaced 2' x 12' (1815 trees/acre). The trees were planted in winter 2013. The netting was first deployed in the spring of 2015. Trees were managed commercially including crop load management that included bloom and hand thinning. Fruit was harvested on September 4, 2018 and September 6, 2019 at full maturity in a single pick. Full bloom was on May 5, 2018 and May 3, 2019 for Honeycrisp. The reflective ground cover was installed on 30th July 2018 and 2nd August 2019 (Extenday), 20th August 2018 and 19th August 2019 (Mylar) and removed immediately after harvest. The netting was deployed the third week of June in 2018 and the middle of May for 2019. Installation of weather equipment for monitoring environmental conditions was done on 8th of May 2018.

Site 2: McDougall & Sons, Inc., Mattawa, WA.

12th leaf 'Granny Smith' on M9 trees were trained on a 4-wire tall spindle trellis and spaced at 3' X 12'. The trees were planted in winter 2006. Full bloom was on 19 April 2018 and April 29, 2019. The reflective ground cover (Extenday) was installed after bloom and was removed the last two weeks of June in 2018 and 2019. The netting was deployed 5th of May for the shade% trial and 2nd of July for the reflective. Installation of weather equipment for monitoring environmental conditions was done on the last week of May 2018.

Objective 1: Determine the optimal shade percentage for the most common cultivars under protective netting in WA (Honeycrisp and Granny Smith)

At both Quincy and Mattawa, 10%, 17% and 24% protective netting was deployed in 'Honeycrisp' and 'Granny Smith' respectively. Ecophysiological measurements comprising of leaf gas exchange, leaf spectral reflectance, leaf chlorophyll fluorescence and plant water status were done at 30 and 60 days after deployment. Meteorological conditions were measured at the Quincy site, namely; solar radiation, ambient temperature and relative humidity (above and in-canopy). Fruit quality, including standard metrics, was assessed at harvest and after 3 months of regular cold storage. This objective helped determine whether different cultivars might have different optimum shade requirements under protective netting in Washington.

Objective 2: Test whether reflective ground fabrics improve light penetration under protective netting to improve fruit quality, flower bud formation, return bloom, and fruit set in 'Honeycrisp' and 'Granny Smith' apple.

The trial was conducted under 17% white neutral protective net for both 'Honeycrisp' and 'Granny Smith', respectively. The treatments in 'Honeycrisp' were protective netting without reflective ground cover as a control and protective netting with late reflective ground cover deployed ≈5 weeks (Extenday®) and ≈2 weeks (Mylar®) before harvest. Ecophysiological measurements comprising of leaf gas exchange, leaf spectral reflectance, leaf chlorophyll fluorescence and plant water status were

done at 4 weeks after installation in 'Granny Smith' to better understand how improved light penetration affected return bloom, photosynthesis, and tree growth in a mature orchard under netting. For Honeycrisp, the entire focus was on improving red color development under netting.

Objective 3: Quantify changes in water needs for orchards under protective netting in 'Honeycrisp' apple.

The trial was conducted in a 'Honeycrisp' orchard under 17% neutral white protective netting at Quincy, WA. The Dynagage Flow32-1K Sap Flow system with SGEX Exo Stem gages was used to measure tree water use. The Exo Stem gage is based on heat balance method for sap flow measurement. The two treatments were 17% neutral protective white net and an uncovered control. Four sap flow sensors were installed in each treatment to monitor water use. Trunk diameter was measured at the height where each sap flow sensor was installed. Sap flow was then be normalized per trunk cross sectional surface area. Measurement of evapotranspiration from the orchard floor was performed using microlysimeters. The microlysimeters were pushed into the soil either by hand. After removing the microlysimeter from the field, cleaning soil from the outside, and trimming the soil even with the bottom, a cap was used to seal the bottom of the cylinder. The microlysimeter was then weighed, put in an outer envelope and placed in a preformed hole in the soil. Following exposure to environmental conditions for 24 hours, the microlysimeter was removed from the hole and outer envelope and its mass is determined again. The difference between the two masses divided by the circular cross-sectional area of the cylinder was the cumulative soil evaporative flux density during the time period. This work helped to determine the change in irrigation requirements of trees under protective netting.

RESULTS & DISCUSSION

<u>OBJECTIVE 1 - Determine the optimal shade percentage for the most common cultivars under protective netting in WA (Honeycrisp and Granny Smith)</u>

There were no differences in the probability of sunburn incidence between the different shade factors 'Honeycrisp' (Figure 1). Sunburn was much more likely to occur on fruit without netting. In 'Granny Smith', the two highest shade factors (17% and 24%) reduced sunburn incidence probability compared to 10% shade factor. Sunburn was likely to occur in 20% of the fruit for 10% shade netting but only about 15% of the fruit for higher shade factors in 'Granny Smith'. Shade factor does not seem to matter in a blushed cultivar like 'Honeycrisp', whereas in a green cultivar like 'Granny Smith', higher shade factors could help with sunburn reductions. Honeycrisp has significantly less fruit without any sunburn symptoms that 'Granny Smith' (Table 1). Patterns in sunburn development were similar across both cultivars with netting being the main effect and shade factors having little influence over sunburn incidence. However, 10% netting had more severely damaged apples (Y3 or Tan) for Honeycrisp than the two other shade factors (17% and 24%).

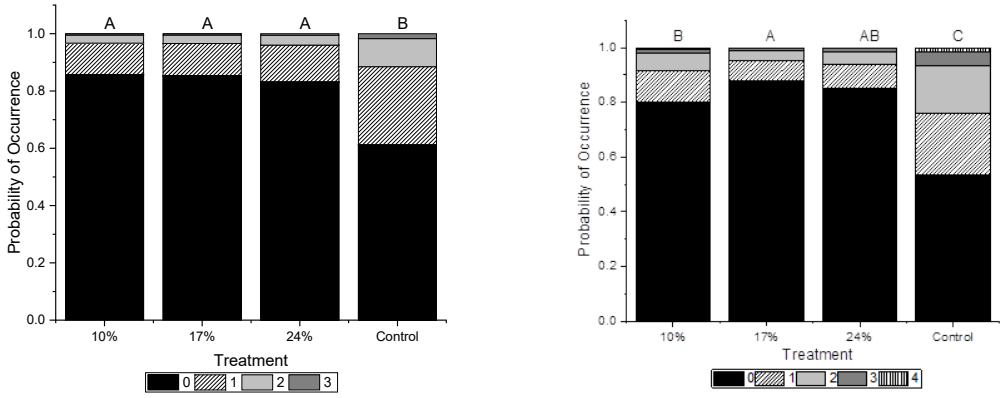


Figure 1. Overall probability of sunburn occurrence in 'Honeycrisp' (left) and 'Granny Smith' (right) apple grown under 10%, 17% and 24% protective netting compared to an uncovered control. 0 is equal to no sunburn incidence and 1, 2, 3, and 4 are increasing severities of sunburn incidence. Letters denote significant differences between treatments.

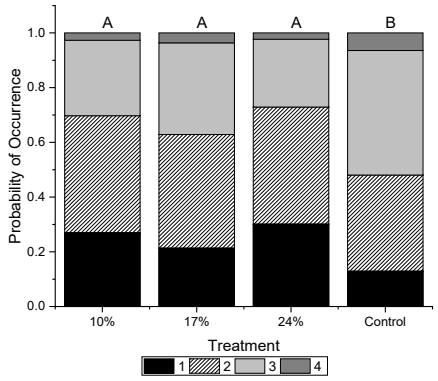
Table 1. Mean percentage of fruit belonging to each sunburn category following a modified sunburn scale for bi-color cultivars (Mendoza and Hanrahan 2012). Letters denote significant differences between treatments determined using a Fisher's LSD test (α=0.05).

	Clean	Y1	Y2	Y3	Tan
Honeycrisp					
Control	48.7 a	23.4	15.9 b	8.1 b	3.8 b
10%	69.7 b	20.9	7.5 a	0.6 a	1.3 a
17%	69.3 b	21.2	8.1 a	1.4 a	0.0 a
24%	74.7 b	15.9	7.8 a	1.3 a	0.3 a
Granny Smith					
Control	55.8 a	23.2	13.1 b	5.0 b	2.9 b
10%	81.2 b	12.7	4.8 a	1.0 a	0.2 a
17%	83.3 b	11.7	4.6 a	0.4 a	0.0 a
24%	78.8 b	16.5	4.6 a	0.2 a	0.0 a
Significance					
Cultivar	0.03	0.08	0.14	0.26	0.41
Treatment	<0.001	0.13	0.009	<0.01	<0.01
Cultivar x Treatment	0.83	0.35	0.99	0.69	0.94

All shade factors had lower probability of occurrence for fruit with >50% red color coverage compared to the control (Figure 2). There were no significant differences between the shade factors in of red fruit coloration. In 'Granny Smith', shade factor played an important part in occurrence of red blush (Figure 3). The incidence of red blush occurrence was significantly reduced under 17% and 24% shade factor compared to 10% shade factor and the control and may be a key factor in decisions on shading factor for protective netting for Granny Smith.

Fruit weight was significantly larger in 2019 than 2018 for both Honeycrisp and Granny Smith (Table 2 and 3). Fruit was the smallest for Honeycrisp grown without netting compared to any

of the netting treatments. These results were consistent with previous results reporting increased fruit size under 20% netting (Kalcsits et al, unpublished). Fruit firmness was not affected by netting treatment. However, consistent with the observed reductions in fruit size and corresponding increases in carbohydrate pools in the fruit, soluble solids content was greater for fruit from the control compared to fruit that was grown under protective netting.



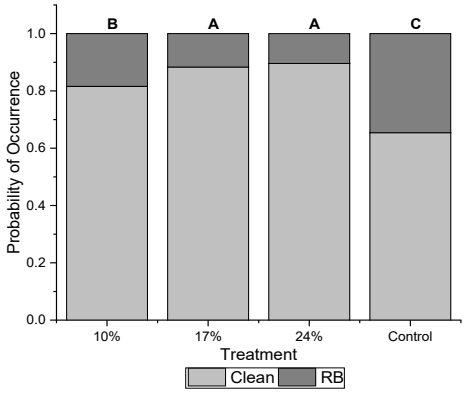


Figure 2 (left). Probability analysis of red color coverage in 'Honeycrisp' apple grown under 10%, 17% and 24% protective netting compared to an uncovered control

Figure 3 (right). Probability analysis of red blush occurrence in 'Granny Smith' apple grown under 10%, 17% and 24% protective netting compared to an uncovered control

Table 2. The effect of protective netting with 10%, 17% or 24% on fruit weight, fruit firmness, total soluble solids, and titratable acidity of 'Honeycrisp' apple at harvest at Quincy, WA in 2018 and 2019

Treatment	Fruit weight (g)	Fruit firmness (lb)	Total Soluble solids (°Brix)	Titratable acidity (% MA)
		2018		
Control	260.7	15.8	13.6 a	0.67
10% Shade	246.2	15.7	13.0 b	0.66
17% Shade	271.1	15.4	13.0 b	0.67
24% Shade	282.6	15.5	12.9 b	0.68
		2019		
Control	298.5	14.0	15.3 a	0.67
10% Shade	312.7	14.1	14.7 ab	0.71
17% Shade	310.9	13.6	15.0 ab	0.72
24% Shade	324.7	13.4	14.3 b	0.71
		Significance		
Treatment	0.046	0.63	0.02	0.22
Year	<0.001	<0.0001	<0.0001	<0.01
Treatment x Year	0.68	0.74	0.71	0.18

Table 3. The effect of 10%, 17% and 24% protective net on fruit quality of 'Granny Smith' apple at harvest at Mattawa, WA in 2018 and 2019

Treatment	Fruit weight (g)	Fruit firmness (lb)	Total Soluble solids (°Brix)	Titratable acidity (% MA)
		2018		
Control	228.8	17.4	13.14	1.03
10% Shade	235.3	17.6	13.40	1.06
17% Shade	228.5	16.8	13.05	1.08
24% Shade	226.5	16.3	12.91	1.01
		2019		
Control	243.3	17.1	11.65	1.07
10% Shade	247.5	16.9	11.50	1.06
17% Shade	243.8	16.5	11.31	1.09
24% Shade	241.7	17.2	12.61	0.98
		Significance		
Treatment	0.56	0.38	0.62	0.11
Year	<0.01	0.73	<0.001	0.56
Treatment x Year	0.73	0.33	0.28	0.81

OBJECTIVE 2 - Test whether reflective ground fabrics improve light penetration under protective netting to improve fruit quality, flower bud formation, return bloom, and fruit set in 'Honeycrisp' and 'Granny Smith' apple.

Light quality was significantly affected by the use of reflective material either immediately following bloom (Granny Smith) or near harvest (Honeycrisp) (Table 4). More than 35% of the incoming light was scattered into the lower canopy of the trees for both cultivars. Even with different ages and training systems the estimates of reflected and scattered light were similar between the two cultivars. There was less reflected and diffuse light in the tree canopy for the Honeycrisp location. This may be, in part, due to a narrow v-trellis training system that intercepted more light than the simple upright training system for Granny Smith.

Table 4. The effect of reflective ground covers on incoming, reflected and diffuse photosynthetically active radiation measured 1.5m above the ground in a 'Honeycrisp' apple orchard under 17% pearl protective net for Honeycrisp (near harvest) or Granny Smith (post bloom) apple orchards

Treatment	Center of drive row			Tree Canopy	
	Incoming PAR	Reflected PAR	Diffuse PAR	Reflected PAR	Diffuse PAR
			Honeycrisp		
Control	1296	50.0 c	60.8 c	15.7 c	22.3 b
Extenday®	1289	418.8 b	415.0 b	148.4 b	79.8 a
Mylar®	1307	449.3 a	530.1 a	206.2 a	99.3 a
			Granny Smith		
Control	1765	65.3 b	97.1 b	28.2 b	31.8 b
Extenday®	1786	669.8 a	701.9 a	355.4 a	346.5 a

Reflective fabrics deployed in early summer did not affect fruit size or overall yield in the first year of deployment (2018) (Table 4). However, the number of flower clusters was greater in 2019 and trees where Extenday was deployed in 2018 had a greater yield in 2019 for Granny Smith. Deployment of either Mylar or Extenday in August did not affect fruit size or overall yield in either year for Honeycrisp.

Table 5. Yield, fruit weight for Granny Smith and Honeycrisp apple and flower cluster counts for Granny Smith (±SEM; N=4-5) when reflective fabrics were used either in early summer for Granny Smith or in August for Honeycrisp apple. Letters denote significant differences among treatments determined using a Fisher's LSD test (α=0.05).

	Granny Smith			Honeycrisp	
	Yield (lb)	**Fruit weight (g)**	**Flower Clusters**	**Yield (lb)**	**Fruit weight (g)**
2018					
Control	57.9 ± 3.25 a	232 ± 4.8 a		33.9 ± 1.72 a	299 ± 12.5 a
Extenday	60.3 ±3.17 a	233 ±18.9 a		34.8 ± 1.74 a	301 ± 12.7 a
Mylar				36.7 ± 1.70 a	297 ± 12.2 a
2019					
Control	33.9 ± 3.89 a	231 ± 9.1 a	98 ± 4.2 a	32.6 ± 2.00 a	245 ± 14.7 a
Extenday	43.8 ± 4.49 b	232 ± 7.1 a	112 ± 5.3 b	28.6 ± 2.20 a	246 ± 12.7 a
Mylar				31.9 ± 1.69 a	254 ± 8.7 a

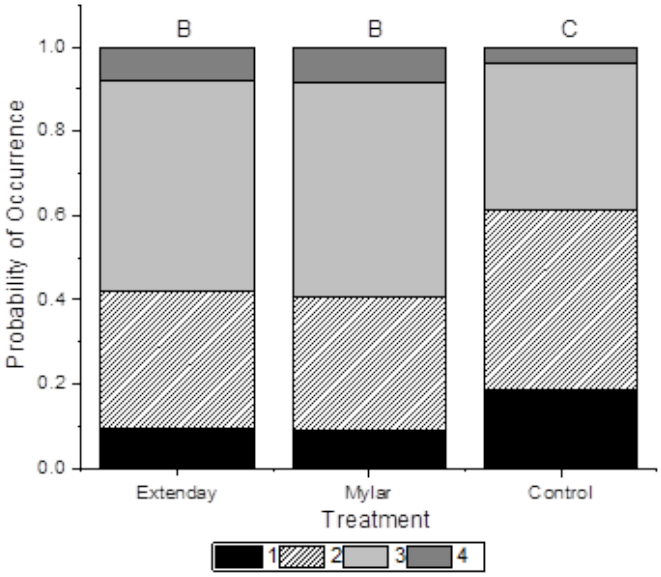


Figure 4. Probability analysis of red color coverage in 'Honeycrisp' apple grown under 17% protective netting with Extenday® and Mylar® reflective ground covers compared to a control with grass cover. 1 = 0-25% red coverage, 2 = 25-50% coverage, 3 = 50-75% coverage, and 4 = 75-100% coverage.

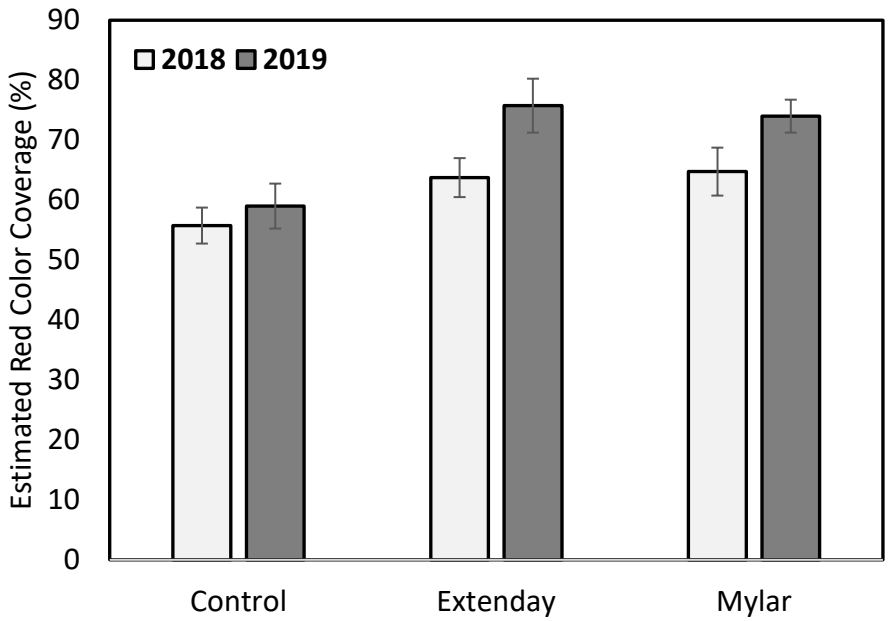


Figure 5. Estimated red color coverage (%) for Honeycrisp with either Extenday or Mylar deployed prior to harvest in 2018 and 2019. Error bars indicate SEM (N = 5 Honeycrisp).

Red color development was greater when reflective fabrics were used under netting. The probability of having fruit with low color development (<50%) was much greater in the control than either of the reflective fabric treatments (Figure 4). Extenday was deployed earlier but did not have significantly better red color development compared to Mylar that was deployed two weeks before harvest. Differences in red color development between the control and reflective fabrics was greater in 2019 than 2018 (Figure 5).

OBJECTIVE 3 - Quantify changes in water needs for orchards under protective netting in 'Honeycrisp' apple.

Protective netting reduced whole tree transpiration by approximately 20% compared to an uncovered control. In addition, soil evaporation was reduced under protective netting compared to an uncovered control. This ties in with previous research which showed improved soil moisture status under protective netting. In a year with water restrictions, growers using protective netting will be able to protect their trees better in addition to the sunburn protection afforded by netting. When averaged over 70 days of water-use measurements, cumulative water use was approximately 20% lower where mean tree water use was approximately 4 L (1.06 Gal) per day in the uncovered control compared to 3.2 L (0.85 Gal) per day under protective netting. Furthermore, evapotranspiration was also lower between rows reducing the need to microsprinkler use.

Table 5. Mean water-use, leaf number and leaf number (±SEM; N=4) for trees under protective netting compared to an uncovered control. Letters denote significant differences between means determined using a Fisher's LSD test (α=0.05).

	Water Use	Leaf Area	Leaf Number
	(mL H_2O m^{-2} day^{-1})	m^2	
Control	1400 ± 201.2 b	3.23 ± 0.22 a	1310 ± 85 a
Netting	911 ± 182.2 a	3.76 ± 0.37 a	1622 ± 109 b

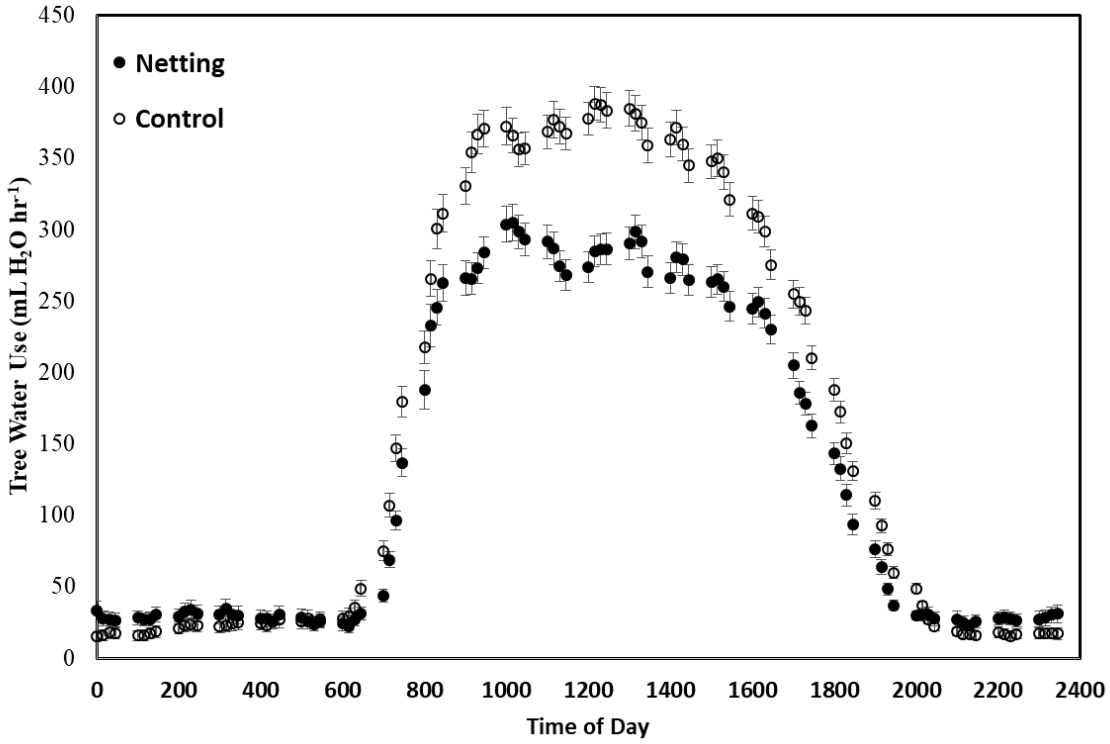


Figure 6. Influence of protective netting on whole tree transpiration (mL H_2O hr^{-1}) for 40 recorded days in 2018 and 30 recorded days in 2019.

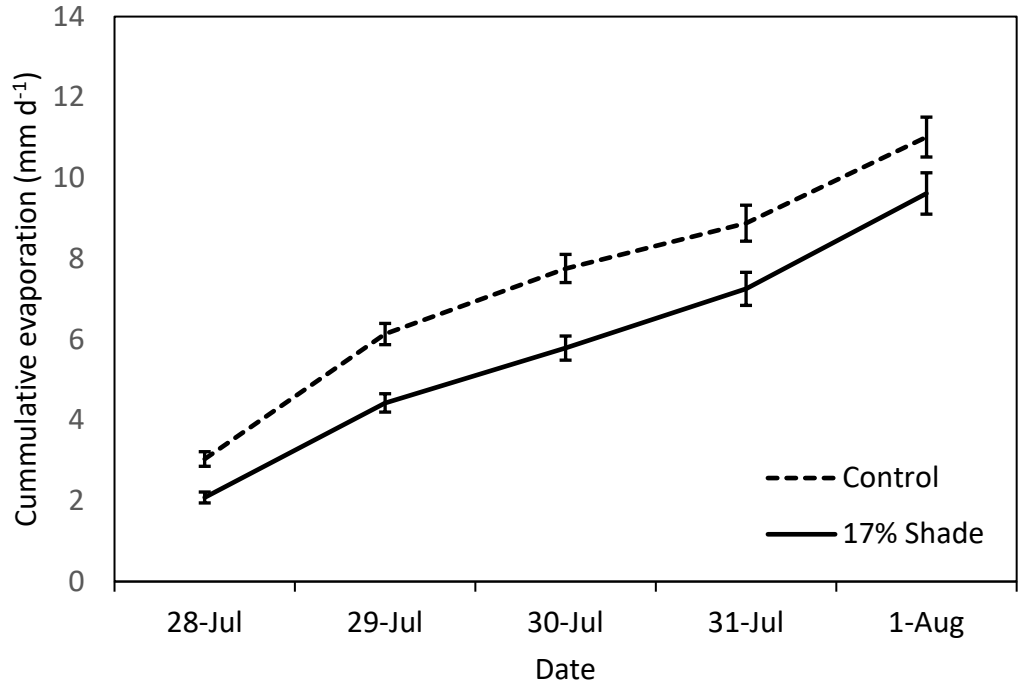


Figure 7. Mean evapotranspiration from the orchard grass between rows for a five-day period under protective netting compared to an uncovered control area (N=4).

EXECUTIVE SUMMARY

Project title: Optimizing light and water for orchards covered with netting
Key words: Protective Netting, Sunburn, Color, Reflective Fabric
Abstract: Netting is used for apple sunburn and hail protection. This project determined the effect of shading factor and reflective fabric on apple fruit quality. 10-17% and 17-24% shade is sufficient for Honeycrisp and Granny Smith apple, respectively. Reflective fabric improved fruit color under netting. Water-use is 20% lower under nets.

The apple growing season in Washington State is characterized by high winds, light intensities, and temperatures which can all negatively impact both the tree and fruit. The adoption of protective netting is increasing as a way to reduce environmental stress in apple production by growers. Most of the research on protective netting use in apple production in WA was focused on microclimatic changes in the orchard environment, sunburn reduction and fruit quality, impact of netting on tree stress and light use efficiency, and evaluating different colors of photoselective protective netting. The optimum shading percentage still needs to be determined for 'Honeycrisp' and 'Granny Smith' which make up most of the acres under protective netting. Identifying the optimum shade factors for Honeycrisp, a bi-color cultivar, as well as Granny Smith will also enable more specific recommendations to be made in future for other cultivars. The optimal shading factor was determined by studying the response of 'Honeycrisp' and 'Granny Smith' at 10%, 17%, or 24% shade factors. The effect of reflective ground fabric on fruit quality in 'Honeycrisp' and 'Granny Smith' was tested by comparing plots under protective netting either with or without the reflective ground fabric to better understand its effect on light penetration and fruit quality. The reduction in incident solar radiation and wind under protective netting has implications for tree water use. This was measured in a Honeycrisp orchard covered in 17% netting.

Shade factor affected sunburn incidence. In 'Honeycrisp', 10%, 17%, 24% shade factor significantly reduced sunburn incidence compared to an uncovered control. For both 'Honeycrisp' and 'Granny Smith', 10% protective netting had slightly higher proportions of fruit with severe sunburn symptoms compared to higher shading factors. In 'Honeycrisp', 10%, 17%, 24% shade factor significantly reduced red color compared to an uncovered control, with no differences being observed between the different shade factors. The incidence of red blushing was lower in 'Granny Smith' under 17% and 24% shade compared to 10% shade which was also lower than the uncovered control. In 'Honeycrisp', Mylar and Extenday improved red coloration significantly under 17% protective net compared to protective netting without reflective ground cover. In 'Granny Smith', Extenday deployed in early summer improved light penetration and return bloom in 'Granny Smith', directly contributing to higher yields in 2019. Under protective net, mylar had significantly higher sunburn incidence compared to protective netting without reflective ground cover as a control which was not significantly different from the control.
Despite increased leaf area under 17% protective netting compared to an uncovered control, overall water use was approximately 20% lower in 'Honeycrisp' because of reduced tree transpiration and soil evaporation.

10 or 17% were optimal shade factors for 'Honeycrisp' but 10% would need additional sunburn protection measures if used. 17 or 24% netting is recommended for Granny Smith to limit red blush development. Reflective fabric installed prior to harvest can improve red color development under net equal to an uncovered control. Reflective fabric used earlier in the season improved return bloom and yield in a mature Granny Smith orchard. The reductions in water use under netting are important for water conservation measures and for cultivars like Honeycrisp that require more careful water management to limit disorder development.