Sunburn management on 'Honeycrisp' in the Hudson Valley in 2016

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Sunburn is a serious economic problem in practically all apple-growing regions of the world. Losses of apple fruit due to sunburn can range from 10% to as high as 50%. Damage severity can be influenced by such factors as cultivar, climate fluctuations and orchard management practice. Sunburn has been studied as a problem primarily in semi-arid and arid regions (hot and dry climates), such as Australia, South Africa, Spain, Turkey and Washington State (Rackso and Schrader 2012), among others. However, several years ago this problem started to be a concern in Eastern New York, more particularly in the Hudson Valley region, and especially with the cultivar 'Honeycrisp' (Schupp et al. 2002; Reig et al. 2016).

> **"This study was conducted to evaluate ... different strategies ... to reduce sunburn incidence and severity, the effect of these strategies on horticultural and fruit quality traits, ... and on net return to the grower."**

Based on the results obtained in 2015 by Reig et al. (2016) when they evaluated the reflective particle film ScreenDuo® and the sunscreen product Raynox Plus® at late summer application timings, enough information was obtained (1) to test additional strategies currently used in other parts of the world, such as evaporative cooling (EC) and netting, together with the application of particle film and sunscreen products, and (2) to test season-long treatments for preventing sunburn injury on 'Honeycrisp'. The EC strategy involves overhead application of water using an over-tree sprinkler to reduce heat stress. The ameliorative effect of EC manifests primarily in the reduction of fruit surface temperature (FST) through the evaporation of water from the fruit surface. Using nets over the tree canopy for shading purposes reduces incident sunlight on the fruit surface and FST via a reduction of the transmission of direct solar radiation through the net, thereby decreasing sunburn injury (Rackso and Schrader 2012). Particle film and sunscreen products reflect visible or UV radiation, reducing FST and solar injury. The threshold FST for 'Honeycrisp' and for each type of sunburn have been described in Rackso and Schrader (2012) and Reig et al. (2016).

This study was conducted to evaluate (1) the effectiveness of using different strategies (evaporative cooling, shade net, particle films such as ScreenDuo®, and sunscreens such as Raynox Plus®) to reduce sunburn incidence and severity, (2) the effect of these strategies on horticultural and fruit quality traits, and (3) the effect of these strategies on the net return to the grower after sunburn management cost per acre is deducted.

Material and Methods

Study Site and Orchard Description. Fruits used in this study were harvested from tall spindle 'Honeycrisp' apple trees grown at the Hudson Valley Research Laboratory (HVRL) experimental orchards in Highland, New York. Trees were planted in 2010, grafted on Nic.29, spaced at 3 ft x 14 ft, and grown in loamy soil. Water was applied through a trickle irrigation system in a consistent manner over all treatments, and was timed according to the NEWA irrigation model (http://www.newa.cornell.edu) from the end of May to the end of September. Standard commercial management practices recommended for the area were followed, and all trees were hand-thinned to equalize crop load. The Hudson Valley region of New York State is subject to periods of high summer temperatures ($\geq$ 86ºF) and medium to high rainfall (around 12 in) from June to the end of September.

Experimental Design. A completely randomized block design was used, with four blocks assigned to each of the treatments. Each treatment and block consisted of 10 trees, from which three in the center were selected and considered as an experimental unit, with the rest of the trees considered buffers to prevent overspray between treatments. The treatments consisted of the following (Table 1): (1) untreated control; (2) evaporative cooling (EC); (3) netting with a clear polyester net; (4) ScreenDuo-1, in

Table 1. Treatments, rates and dates of application.

Treatment	Rate	Dates of application
Untreated control	-	-
Netting[1]	-	-
Evaporative cooling[2]	11 gals hour^{-1}	6th-8th July, 12th July, 15th July, 18th July, 21st-29th July, 5th Aug., 8th-9th Aug., 11th-15th Aug., 17th-20th Aug., 24th Aug., 26th-29th Aug., 8th Sept.
Raynox Plus[3]	2.5 gals acre^{-1}	15th June, 22th June, 7th July, and 12th Aug.
ScreenDuo-1[4]	10 lb acre^{-1}	28th May, 7th June, 18th June, 3rd July, 12th July, 26th July, 5th Aug., 16th Aug.
ScreenDuo-2	10 lb acre^{-1}	18th June, 3rd July, 12th July, 26th July, 5th Aug., 16th Aug.

[1] From Pak Unlimited Inc. (Georgia, USA).
[2] From TRICKL-EEZ Company (Michigan, USA), Model Nelson R5 Rotator.
[3] From Valent BioSciences (Ilinois, USA).
[4] From CERTIS USA L.L.C. (Maryland, USA).


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Figure 1. SB-1 sunburn severity symptom.

Figure 2. SB-2 sunburn severity symptom.

which ScreenDuo® was applied every 10–14 days beginning at petal fall (label recommendation); (5) ScreenDuo-2, in which ScreenDuo® was applied 1–3 days before a predicted heat event (≥ 86°F); and (6) Raynox Plus® applied four times during the growing season, beginning nine weeks after full bloom (label recommendation). The EC system was installed in the middle of each of the four blocks used for that treatment. Sprinklers discharged water over the trees at a height of 12.5 ft. Each sprinkler covered a radius of about 18 ft, with a discharge rate of 11 gal/hr. The EC system was controlled manually and was activated every time air temperature was equal to or higher than 86°F (mostly between noon and 5 PM). The netting for each block was installed in mid-June. Treatments 4, 5 and 6 were applied using an airblast sprayer that delivered 85 gpa with tree-row volume calculated at 170 gpa.

Horticultural evaluations. 'Honeycrisp' is a multiple pick cultivar, so three harvest times (henceforth referred to as H1, H2 and H3) were necessary to reflect common commercial practice. For each harvest, all fruits from each tree were counted and weighed to determine total yield per tree (lb/tree). Average fruit weight (FW) was calculated using the total number of fruits and total yield per tree. At the end of the experiment, tree circumference was recorded at 30 cm above the graft union, and the trunk cross-sectional area (TCSA) was calculated.

Sunburn evaluation. The incidence of the three sunburn types (SN, sunburn necrosis; SB, sunburn browning; SP, photooxidative sunburn) for all treatments was evaluated as presence or absence of sunburn on the apple skin, and was expressed as a percentage. The severity of sunburn was calculated only on the sunburn browning type SB, and assessed by adapting the four sunburn browning classes previously described by Felicetti and Schrader (2008) for 'Fuji' to 'Honeycrisp'. Only two classes were used for this 'Honeycrisp' trial based on previous observations during the 2015 season: SB-1, browning or light yellowing spot on the skin (Figure 1); SB-2, strong yellowing spot on the skin (Figure 2).

Fruit quality evaluation. During the evaluation of sunburn at harvests H1 and H2, a random sample of five non-sunburned fruits and five fruits with sunburn browning were arbitrarily selected from each tree and harvest date for evaluation of fruit quality. A total of 1,440 fruits were evaluated (5 fruits/tree × 2 injury categories × 3 trees/block × 2 harvest dates × 6 treatments × 4 blocks). The skin color based on CIELAB coordinates (L, a, b, Chroma and Hue), flesh firmness (FF), soluble solids content (SSC), and titratable acidity (TA) were evaluated separately for each side of the fruit (B, sun-exposed side of the fruit; NB, shaded side of the fruit).

Calculation of Net Returns by Treatment. Commercial value of the crop depends on both fruit size and fruit color. However, in this study we included losses due to sunburn in the determination of the commercial value of the crop. Therefore, we calculated the net return to the grower after sunburn management cost per acre, considering the revenue flows and costs of producing, storing, and marketing apples. To start, we calculated the wholesale value per acre by estimating the sales prices of the various packs (FOB packing facility). Taking into account packing and storage costs per acre and sunburn management costs (Table 2), we calculated the net return to the grower for each treatment, expressed in dollars/acre. For simplification purposes, costs of pest management, fertilizer, irrigation, hand-thinning and chemicals for return bloom were not considered, as they were assumed to be consistent across the different treatments.

Fruits harvested at the first (H1) and the second pick (H2) were weighed and color evaluated individually in the laboratory. Fruit size was expressed in grams, and red color was expressed as percentage of the fruit surface.

Based on New York State standards for grades of apples, fruits from this study were divided into three categories based on the number of fruits per packed box: (1) 88 or fewer fruits per box: fruit size ≥ 201 grams; (2) between 100 and 138 fruits per

Table 2. Estimated annual costs for sunburn management, packing and storage of 500 bushels (H1 and H2 production together) for a one-acre orchard block with 1,037 trees.

Expense items	Cost per unit ($)
Storage (per box)	1.50
1-MCP treatment (per box)	0.25
Marketing (per box)	10% of wholesale value
Netting structure (per acre)[a]	688
Net[b] (per acre)	6,500
Evaporative cooling structure (per acre)[c]	130
Raynox Plus (per acre)	76
ScreenDuo (per acre)	18
Full time tractor driver (per hr)	14.37
Tractor (per hr)	4.89

[a] This cost was obtained by calculating a 20 year structure amortization and a 10% annual maintenance charge. For the purposes of this grower-centric analysis, we considered 20 years to be the expected economic life of the orchard. However, a potential financial lender might want to see an analysis based on a much shorter amortizatio n period. The initial capital investment in the structure was estimated to be $12,500.

[b] This cost was obtained by calculating an 8-year amortization with a 20% installation disposal labor handling charge and a 5% of annual maintenance charge. The initial capital cost of the netting was estimated to be $6,500 per acre.

[c] This cost is obtained by calculating a 20-year structure amortization and a 10% annual maintenance charge. The initial capital investment in the structure was estimated to be $2,357 per acre.

Table 3. Effect of different treatments on yield and fruit size for 'Honeycrisp' apples.

Treatment	Yield (lb)	Fruit weight (g)	Crop load (fruit cm^{-2})
Control	24.0 a	161.0 a	7.5 a
Netting	21.4 a	170.0 a	6.8 a
Evaporative cooling	25.6 a	173.0 a	7.3 a
Raynox Plus	27.6 a	175.0 a	7.2 a
ScreenDuo-1	26.9 a	186.3 a	6.2 a
ScreenDuo-2	22.5 a	161.2 a	6.4 a

Means followed by the same letter in each column are not significantly different at $P \leq 0.05$ according to Tukey HSD test.

Table 4. 'Honeycrisp' sunburn evaluation by harvest date at the Hudson Valley Research Laboratory.

Harvest	Treatment	*Incidence*				*Severity*	
		% Sunburn[1]	% SP	% SN	% SB	% SB-1	% SB-2
H1	Control	41.5 a	0.0 a	0.0 a	41.5 a	74.3 a	25.7 a
	Netting	18.7 b	0.0 a	0.0 a	18.7 b	93.4 a	6.6 b
	Evaporative cooling	33.0 ab	0.0 a	0.0 a	33.0 ab	87.5 a	12.5 ab
	Raynox Plus	32.8 ab	0.2 a	0.2 a	32.4 ab	82.2 a	17.7 ab
	ScreenDuo_1	33.7 a	0.0 a	0.0 a	33.7 a	95.2 a	4.8 b
	ScreenDuo_2	41.1 a	0.0 a	0.0 a	41.1 a	89.7 a	10.3 b
H2	Control	11.0 a	0.2 a	0.0 a	10.7 ab	94.4 a	5.6 a
	Netting	3.8 b	0.0 a	0.0 a	3.8 b	100.0 a	0.0 a
	Evaporative cooling	10.7 ab	0.0 a	0.0 a	10.7 ab	95.8 a	4.2 a
	Raynox Plus	10.6 a	0.7 a	0.0 a	10.0 a	100.0 a	0.0 a
	ScreenDuo_1	9.5 ab	1.4 a	0.0 a	8.1 ab	100.0 a	0.0 a
	ScreenDuo_2	12.5 a	1.3 a	0.0 a	11.2 a	100.0 a	0.0 a

[1]All three sunburn types together.
Means followed by the same letter in each column are not significantly different at $P \leq 0.05$ according to Tukey HSD test.
SB, sunburn browning; SN, sunburn necrosis; SP, photooxidative sunburn.

box: fruit size between 200.9 and 128 grams; and (3) more than 138 fruits per box: fruit size less than 128 grams.

Four general quality grades are used by the USDA as standards for grading apples in the U.S.: U.S. Extra Fancy (ExFy), U.S. Fancy (Fy), U.S. No. 1 (#1), and U.S. Utility (USDA 2002). Apples that do not belong to these grades are considered cullage. Therefore, based on the fruit grade prices per box received in 2016 for each fruit grade, the criteria established to calculate the wholesale value for each harvest was the following: (1) U.S. Extra Fancy apples: $64 per box when fruit color was ≥ 40% of the fruit surface, fruit weight was ≥ 201 g, and sunburn = 0% of the fruit surface; and $42 per box when fruit color was ≥ 40% of fruit surface, fruit weight was between 200.9 g and 128 g, and sunburn = 0% of fruit surface; (2) U.S. No. 1: $16 per box when fruit color was ≥ 10% of the fruit surface, fruit size was larger than 128 g, and sunburn was ≤ 5% of fruit surface; and (3) Culls for juice: $ 0.12/lb when fruit size weight was lower than 128 g, or when fruit weight was ≥ 201 g, and sunburn was > 5% of fruit surface, or when fruit weight was between 200.9 g and 128 g, and sunburn was > 5% of fruit surface.

Results and Discussion

The different treatments applied in 2016 did not significantly affect the horticultural performance of the 'Honeycrisp' trees evaluated in this trial (Table 3), although other studies have reported that the use of netting, evaporative cooling and Surround treatments can reduce fruit weight.

In terms of sunburn incidence, results showed statistically significant differences among treatments at each harvest (H1 and H2) (Table 4) and with both harvests (H1 and H2) combined (data not shown). Netting resulted in the lowest incidence of sunburn. Fruits under netting averaged 50% less sunburn compared with the control treatment. However, netting did not differ significantly from evaporative cooling and the Raynox Plus treatments at H1, and from evaporative cooling and ScreenDuo-1 at H2. Combining all harvests, fruits under the netting had the lowest percentage of sunburn (7.9 %), with the rest of the treatments showing approximately 20% sunburn incidence and as a group not statistically different from one another (data not shown). However, although evaporative cooling, Raynox Plus, ScreenDuo-1 and ScreenDuo-2 treatments did not differ statistically from the control treatment, they generally had a numerically lower percentage of sunburn incidence compared with the control, with the exception of ScreenDuo-2. In addition, although the ScreenDuo-1 and ScreenDuo-2 treatments did not differ statistically (Table 4), 'Honeycrisp' fruits with the ScreenDuo-1 treatment had a lower percentage with sunburn compared with the ones with the ScreenDuo-2 treatment. The omission of two applications at the beginning of the season in the ScreenDuo-2 treatments may explain this.

Around 98% of the sunburn evaluated on all treatments was sunburn browning (SB), as might have been expected, while the remainder mostly presented photooxidative sunburn (SP). This last sunburn type was primarily observed in the second harvest, although a few fruits had this symptom at the first harvest. SP occurs because fruits that had previously grown in the shade and are not acclimated to direct sun can be exposed by removal of fruit during the first harvest and are therefore exceptionally susceptible to sunburn.

With regards to sunburn severity, more than 80% showed the less severe symptom (SB-1) (Table 4), in contrast with the results found by Reig et al. (2016), when most of the 'Honeycrisp' apples with sunburn had SB-2 symptoms. This could be caused by the different timing application of the treatments used during 2016 season compared with the 2015 season or to differences in the environmental conditions that contributed to sunburn events in each year.

During the summer of 2016, we experienced more days of high temperatures (equal to or higher than 86°F) as compared with 2015 and also as compared with the average for 16 years of maximum temperature data for this location (Figure 3). The Hudson Valley region from June to mid-September experienced

38 days in 2016 where the maximum temperature was equal to or higher than 86ºF and 10 days where the maximum temperature was equal to or higher than 90ºF. In particular, August 2016 had more days above 90ºF than any other August on record.

The high temperatures recorded in 2016 may explain the lack of statistical differences among spray particle film and sunscreen products (Raynox Plus and ScreenDuo) and evaporative cooling compared with the control, because when radiation is so intense, temperature reductions affected by these treatments may not have been enough to reduce injury. Solar radiation can burn fruit even when evaporative water droplets are on the fruit surface or even when the film is still present on the fruit, due to the reduced abilities of these films to reflect some solar irradiation (including UV-B).

Raynox Plus and ScreenDuo are being tested on the east coast of the US, where although we can have high temperatures in the summer similar to the west coast, rain, relative humidity, and solar radiation are different than in western production regions. In addition, little published information is available related to the efficiency of these two products to control sunburn on different apple cultivars. In fact, in the Hudson Valley region, only one trial has been carried out to evaluate these materials for control of sunburn on 'Honeycrisp' apples, but in that trial kaolin clay (Surround) was used instead of ScreenDuo or Raynox (Schupp et al. 2002). However, no sunburn on 'Honeycrisp' apples was observed in that trial, due to the cool weather experienced for the duration of the experiment. These products need further testing in season-long spray programs to find the right rates to apply under New York conditions. The rates used in this study may not have been appropriate for the summer conditions that we experienced.

Fruit quality traits such as percentage of red color (blush), flesh firmness (FF), soluble solids content (SSC), titratable acidity (TA) and skin color (a*/b* and Hue) were analyzed separately for each side of the fruit (B, sun-exposed side; NB, shaded side) (Table 5). Although the different treatments did not significantly affect the percentage of red color in the skin (blush), apples under the net tended to have numerically lower values compared with the other treatments. Also, for net-shaded apples, both sides of the fruit (the sun-exposed and the shaded side) were less red (low a*/b* and high hue values) compared with the apples from the rest of the treatments, in agreement with other studies. Fruits treated with Raynox Plus and ScreenDuo tended to have higher blush values and more intense red color (higher a*/b* ratio and hue values) compared with the rest of the treatments. Red color is directly influenced by light, temperature, and cultivar. Therefore, the effect of both high temperatures and significant reductions in the exposure to light associated with the use of nets could explain the reduction in fruit color. Comparing fruit type (healthy *vs* sunburned), the fruits with sunburn on the sun-exposed side had higher FF, SSC, and less TA (data not shown), in agreement with previously published studies done on other apples such as 'Fuji'.

The information shown in Table 6 provides the fruit distribution by U.S. Extra Fancy (ExFy), U.S. No.1 (# 1) and culls based on fruit size, and percentage of red color and sunburn in the skin for both harvests (H1 and H2) together. The first two harvests combined represented, on average, 83% of the total apple production in this study. More than 60% of the fruits from H1 and H2 together were graded as extra fancy. In particular, the netting

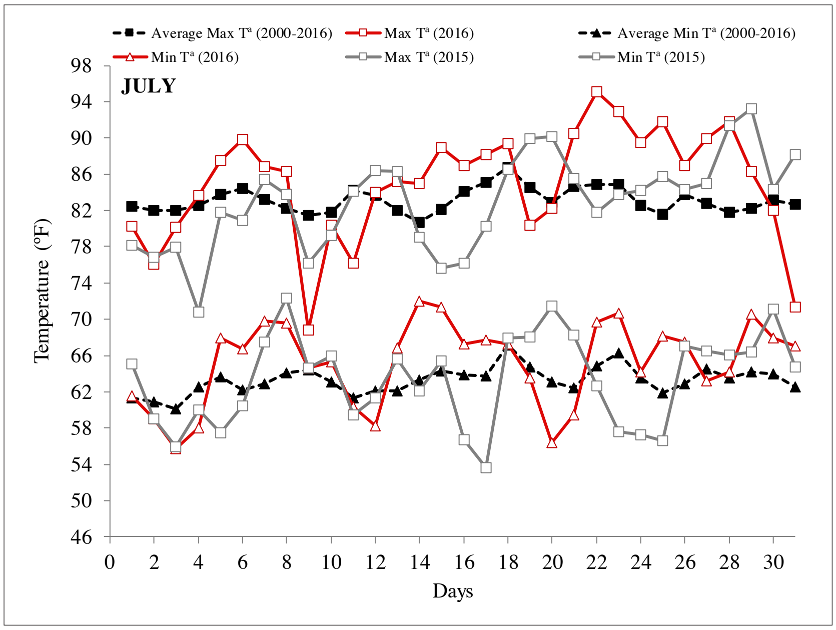

Figure 3. Daily maximum and minimum temperatures during July 2015 and 2016 at HVRL as compared with the average maximum and minimum temperatures for each day in July for 16 years (from 2000 to 2016).

Table 5. Effect of different treatments on fruit quality parameters for 'Honeycrisp' apples without sunburn symptoms.

Fruit type	Treatment	Blush (%)	FF		SSC		TA		a*/b*		Hue	
			B	*NB*	*B*	*NB*	*B*	*NB*	*B*	*NB*	*B*	*NB*
Healthy	Control	67.1 a	63.9 a	61.8 a	11.9 a	11.3 a	3.4 a	3.6 a	1.56 bc	0.18 ab	33.7 ab	81.7 ab
	Netting	65.5 a	65.5 a	62.2 a	12.0 a	11.0 a	3.8 a	3.8 a	1.53 c	0.04 b	34.1 a	88.8 a
	Evaporative cooling	68.5 a	65.0 a	63.1 a	12.0 a	11.3 a	3.5 a	3.6 a	1.60 abc	0.12 ab	33.2 ab	83.6 ab
	Raynox Plus	75.6 a	63.6 a	60.6 a	12.2 a	11.6 a	3.6 a	3.6 a	1.74 abc	0.27 ab	30.5 ab	77.2 ab
	ScreenDuo-1	70.0 a	65.2 a	67.9 a	12.5 a	11.8 a	3.8 a	3.6 a	1.76 ab	0.35 a	30.2 b	73.9 b
	ScreenDuo-2	74.9 a	64.6 a	61.8 a	12.1 a	11.6 a	3.8 a	3.8 a	1.79 a	0.23 ab	29.9 b	79.1 ab

Means followed by the same letter in each column are not significantly different at P $\leq$ 0.05 according to Tukey HSD test.
B, sun-exposed side of the fruit; FF, flesh firmness; NB, shaded side of the fruit; SSC, soluble solids content; TA, titratable acidity.

treatment had more graded into the extra fancy category, followed by Raynox Plus, ScreenDuo-1, ScreenDuo-2, control and evaporative cooling. Mostly the rest of the fruits were graded as culls, mainly because of the sunburn problem. Based on treatment averages, 70% of the total fruits destined for cullage had more than 5% of the skin surface area damaged by sunburn. Reports from other parts of the world suggest that packinghouse cullage of 10% because of sunburn could be expected in typical seasons, although the range can vary from 6 to 30%, depending on the season and the cultivar. Considering the unusually warm summer in 2016, our results are within the abovementioned range.

In terms of net return to the grower, no statistical differences were found among treatments (Table 7), which was totally unexpected. However, ScreenDuo-1 followed by netting, Raynox Plus and Screenduo-2 were the treatments that had higher numerical values compared with the control. The net returns to the grower after sunburn management costs were obtained by subtracting grower charges and sunburn management costs from the wholesale value. The netting strategy requires a substantial up-front capital investment, while the alternative strategy of applying spray materials as needed on an annual basis offers the benefit of capital preservation for use in more profitable applications. One potential economic advantage of a netting strategy may be hail damage mitigation, as is practiced in other tree fruit producing regions of the world. The economic consequences of hail damage mitigation were not considered in this study.

'Honeycrisp' is a popular apple cultivar with American consumers who appreciate the premium fresh apple eating experience. Growers tolerate the challenging production and post-harvest issues associated with 'Honeycrisp' because of the potential for high returns. The wholesale value (FOB at the packing facility) in 2016 was $64 per box, more than twice that of 'Gala' and 'Fuji'. Strong pricing for premium grades, together with the high number of fruits within the extra fancy category, even accounting for the high SBMC, caused the netting strategy to result in a net return to the grower similar to Raynox Plus and ScreenDuo treatments. Thus, the sprayable treatments are arguably the least risky in terms of capital outlay and the most affordable treatments for the growers on an annual basis. However, more research needs to be done to evaluate the effect of treatments over a variety of years and seasonal conditions, so as to have a robust, regionally relevant cost-benefit analysis. The industry needs a better understanding of sunburn triggers and could benefit from further refinement of application rates for evaporative cooling (water), Raynox Plus and ScreenDuo treatments, and the evaluation of alternative netting technology and colors.

Table 6. Effects of treatments on fruit packout.

Treatment	U.S. Extra Fancy (%)		U.S. No. 1 (%)	Culls (%)
	88	100 - 138		
Control	6	57	2	35
Netting	15	61	0	23
Evaporative cooling	9	53	0	37
Raynox Plus	12	61	0	27
ScreenDuo-1	17	56	1	26
ScreenDuo-2	13	60	0	27

Table 7. Net revenue per acre basis.

Treatment	Wholesale[a] ($ acre^{-1})	Total Grower Charges[b] ($ acre^{-1})	Total Annual Sunburn Management Cost (SBMC)[c] ($ acre^{-1})	Net Return to Grower after SBMC[d] ($ acre^{-1})
Control	16,994	6,324	0	10,670 a
Netting	21,014	6,726	1,711	12,576 a
Evaporative cooling	17,833	6,408	660	10,765 a
Raynox Plus	19,484	6,573	440	12,471 a
ScreenDuo-1	19,794	6,604	416	12,774 a
ScreenDuo-2	19,263	6,551	312	12,400 a

[a] FOB sale price at packing facility. This column represents the wholesale value per ha (H1+H2) with equalized yield for all treatments (500 bu acre^{-1}).
[b] Values obtained at equalized yield for all treatments (500 bu acre^{-1}). These charges include storage, 1-MCP treatment, packing, and sales agency fees.
[c] This cost includes: structural cost, labor and machinery charges.
[d] Values obtained at equalized yield for all treatments (500 bu acre^{-1}).

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