The efficacy of four sunburn mitigation strategies and their effects on yield, fruit quality, and economic performance of 'Honeycrisp' cv. apples under eastern New York (USA) climatic conditions

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Abstract

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% as high as 50%. Several years ago, this problem started to be a concern in Eastern New York State, especially in the Hudson Valley region with the cultivar 'Honeycrisp'. The study was conducted in three 'Honeycrisp' apple tree orchards in Hudson Valley region (Southeast, New York State) during the 2015 and 2016 growing seasons. Four sunburn mitigation strategies were tested (evaporative cooling, 20% crystal net, the sunscreen Raynox Plus® and the particle film ScreenDuo®) at a variety of timings throughout each growing season. Yield, sunburn incidence/severity, quality, and economic returns were evaluated. Treatments did not affect horticulture performance and fruit quality, but they did reduce sunburn damage to varying degrees. The greatest sunburn mitigation was achieved with the use of netting, followed by spray applications of Raynox Plus® and ScreenDuo®. Apples with sunburn damage had higher flesh firmness, soluble solids content and titratable acidity. Treatment differences in sunburn mitigation did not result in higher net returns to the grower.

Keywords: ScreenDuo®, Raynox Plus®, shade netting, economic return

Introduction

The 'Honeycrisp' apple is a product of the University of Minnesota apple breeding program and a result of a 1969 cross of Macoun and Honeygold (Cabe et al., 2005), released for commercial propagation in 1991. Since then, the 'Honeycrisp' variety has become a very popular fresh market apple in North America and Europe (Luby and Bedford, 2015). Commercial plantings are found in all apple producing regions of the United States and Canada, as well as New Zealand, and Europe (licensed as the 'Honeycrunch'). 'Honeycrisp' is now in the top ten of all varieties produced and sold in the United States (Reig et al., 2019), a remarkable performance for a variety commercially introduced less than three decades ago, with a total production of 449 t in 2018 in U.S. (usapple.org). The 'Honeycrisp' cultivar falls into a category of 'JFC high quality' indicating a juicy and crisp-textured flesh (Schaeffer et al., 2016). Additional notable characteristics include superior flavor, large size, long storage life, and a color profile which is 40-60% orange/red stripe on a yellow base, all of which have helped to revitalize the apple industries in those areas where 'Honeycrisp' is grown (Luby and Bredford, 1988, 1992; Schaeffer et al., 2016; Telias et al., 2006).

'Honeycrisp' presents growers and marketers with several production and storage difficulties such as bitter pit and sunburn. Sunburn is an abiotic tissue damage of apples and other fruit species mainly caused by excessive solar radiation and high air temperature during the ripening period (Glenn et al., 2002; Schrader et al., 2003; Mupambi et al., 2018b). According to Racsko and Schrader (2012), apple fruit can develop three types of sunburn: sunburn necrosis (SN), sunburn browning (SB) and photooxidative sunburn (SP). SN is a thermal response that occurs when the fruit surface temperature (FST) exceeds 52 ± 1 °C for a minimum of 10 min. SB is characterized by a yellow, brown, bronze or dark tan spot on the sun-exposed side of the fruit and is caused by a combination of high FST and light exposure for a minimum of 60 minutes with a threshold FST of between 45 ºC and 49 ºC. The third type, SP, occurs on shaded (non-acclimated) apples that are suddenly exposed to full sunlight (Zupan et al., 2014), independent of FST. Unlike the other two types, SP is triggered only by high light intensity (Racsko and Schrader et al., 2012).

Sunburn has been identified as challenge primarily in semiarid and arid regions with warmer climates, such as among others, Australia, Chile, South Africa, Spain, Turkey and Washington State. Losses of apple fruit due to sunburn can range from 10% as high as 50% (Racsko and Schrader, 2012; Mupambi et al., 2018b; Soto et al., 2018). Several years ago, this problem started to be a concern in Eastern New York State, especially in the Hudson Valley region with the cultivar 'Honeycrisp' (Schupp et al., 2002). The efficacy of evaporative cooling (EC), particle films, sunscreens, and photo-selective anti-hail nets to control sunburn and their effects on fruit quality has been documented with other sunburn-susceptible apple cultivars (Glenn et al., 2002; Gindaba and Wand, 2005; Iglesias and Alegre, 2006; do Amarante et al., 2011; Racsko and Schrader 2012). However, no information has been published related to the use of EC, photo-selective anti-hail nets, sunscreens or particle films other than Surround®WP to control sunburn on 'Honeycrisp' apples under New York conditions. Therefore, this study was conducted to evaluate: 1) the effectiveness of four alternative strategies (evaporative cooling, shade net, particle films such as ScreenDuo®, and sunscreens such as Raynox Plus®) to reduce 'Honeycrisp' sunburn incidence and severity, 2) the effect of these strategies on horticultural and fruit quality parameters, and 3) the effect of these strategies on net economic return to the producer.

Material and methods

2015 Experiment

Twenty-five plots of 3 contiguous 14-year old trees each, located in the Hudson Valley Research Laboratory (HVRL) experimental orchard (Highland, New York, USA) were utilized in this experiment. Each plot consisted of one 'Honeycrisp' tree on EMLA.111 rootstock with 'M.9' interstem (the experiment unit), followed by two guard trees of similar size. Trees were spaced at 3 m x 4.5 m, trained to a slender spindle tree form and grown in Bath Series gravelly silt loam soil. A RainWise Agromet weather station (MK-III-SP1, RainWise Inc., Trenton, USA) was located close to the experimental orchard to record dew point, heat index, humidity, rainfall, solar radiation, temperature, and wind chill. Trees received supplemental drip irrigation when necessary according to the Northeast Weather Association (NEWA) irrigation model (http://www.newa.cornell.edu). Fertilizers, herbicides and pesticides were applied according to recommended commercial best practices (https://store.cornell.edu/c-875-pmep-guidelines.aspx). All trees were hand thinned to equalize crop load to 4 fruit per cm^2 trunk cross-sectional area (TCSA).

Experimental design

Treatments were assigned to plots in a completely randomized block design with five replications. Applications were made to each 3-tree plot using an airblast sprayer calibrated to apply 856 L ha^{-1}, with the 'Honeycrisp' as the target and the two remaining trees serving as buffers to prevent overspray. Treatments applied were: 1) untreated control; 2) Raynox Plus® at 21.5 L ha^{-1}; and 3) ScreenDuo® at 8.3 Kg ha^{-1}, using an airblast sprayer calibrated to apply 856 L ha^{-1}. Application dates were July 28 and August 14.

Horticultural evaluation

'Honeycrisp' apples ripen unevenly on the tree and require multiple picks. Fruits were harvested in three picks (H1: 09/02/2015, H2: 09/10/2015, H3: 09/20/2015). Fruits harvested from each tree were counted and weighed to determine total yield per tree (kg tree^{-1}). 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. Yield efficiency (YE) was calculated as the ratio between the yield (Kg tree^{-1}) and TCSA (cm^2).

Sunburn evaluation

All fruits from each tree and treatment were individually examined for signs of three sunburn types (SN: Sunburn Necrosis; SB: Sunburn Browning; SP: Photooxidative Sunburn), incidence recorded, and results presented as a percentage of the total number of fruit evaluated. In addition, the severity of SB sunburn was assessed by assigning the percentage of sunburn on the red/blushed surface area (SA) category rating: Category 1 up to 10% SA, Category 2 >10 and <30%, and Category 3 >30%.

Fruit quality evaluation

A random sample of five clean fruits and five sunburned fruits were selected from each harvest date (5 fruit tree^{-1}× 5 trees treatment^{-1} × 3 harvest dates). Flesh firmness (FF), soluble solids content (SSC), and titratable acidity (TA) were evaluated. FF, expressed in Newtons, was determined with a pressure tested (EPT, Lake City Technical Products, USA) with an 11 mm diameter tip. Two readings were taken from opposite peeled sides of each fruit. SSC and TA were determined using juice extracted with an automatic juicer (Maverick). One juice contained 2 pieces of each fruit, a total of 10 pieces of fruit to make juice (5 fruits per sample of clean fruits, and 5 fruits per sample of sunburn fruit). SSC was determined using a digital hand-held refractometer (Atago Pal-1, Tokyo, Japan), with the results presented as °Brix. TA was determined by titrating 10 mL of juice with 0.1 sodium hydroxide (NaOH) to an end point of pH

8.2 using phenolphthalein, and the results were expressed as g malic acid L^{-1}.

2016 Experiments

Experiments were conducted on 'Honeycrisp' apple trees at two locations. Experiment 1 was located in an HVRL orchard with Bath-series gravelly silt loam soil. Experiment 2 was located in a commercial orchard (Milton, New York, USA) with a Bath-Nassau Complex gravelly silt loam soil, approximately 13 km south of Experiment 1.

The trees utilized in Experiment 1 were 6-years old, grafted onto Nic.29 rootstock, planted 0.9 m x 4.3 m, and trained to the Tall Spindle tree form. Trees received supplemental drip irrigation timed according to the Northeast Weather Association (NEWA) irrigation model (http://www.newa.cornell.edu) from the end of May to the end of September. Fertilizers, herbicides and pesticides were applied according to recommended commercial best practices, and all trees were hand thinned to equalize crop load (6 fruits per cm^2 trunk cross-sectional area, TCSA).

The trees utilized in Experiment 2 were 9-years old, Bud.9 rootstock, planted 1.1 m x 4.3 m, and trained to the Tall Spindle tree form. Trees received supplemental drip irrigation when necessary. Fertilizers, herbicides and pesticides were applied according to recommended commercial best practices, and all trees were chemically thinned with naphthalene acetic acid and carbaryl. Harvista^{TM} (1-methylcyclopropene) was applied to this orchard at a rate of 9 L ha^{-1} on 1st September.

Experimental Design

A completely randomized block design with four replicates was used in both experiments, each replicate consisted of 10 trees, from which three center trees were used for data collection, and the rest as buffers to prevent overspray between treatments. Six treatments were conducted for each experiment. The treatments for experiment 1 were the following: 1) Control; 2) Netting; 3)

Evaporative cooling; 4) Raynox Plus; 5) ScreenDuo-1; 6) ScreenDuo-2. The treatments for experiment 2 were the following: 1) Control; 2) Raynox-1; 3) Raynox-2; 4) Raynox-3; 5) ScreenDuo-1; 6) ScreenDuo-2. The rates and dates of application are described in Table 1.

The Evaporative Cooling (EC) system was installed in the middle of each of the four replicates using sprinklers that discharged water over the trees at a height of 3.5, covering a radius of approximately 5.4 m with a discharge rate of 41.7 L h^{-1}. The EC system was controlled manually and was activated every time air temperature was equal to or higher than 30 ºC (mostly between 12:00 and 17:00 HR). Netting for each replicate was installed in mid-June, and the plot was covered until beginning of October. It was a clear polyethylene net, which reduced light intensity by 20% (Pak Unlimited Inc., Georgia, USA). Five-meter high poles were located at 10 m intervals were used to support the nets. The sprayable films used in Experiment 1 were applied using an air blast sprayer that delivered 795 L ha^{-1} with tree/row/volume calculated at 1590 L ha^{-1}, whereas treatments from Experiment 2 were applied using an airblast sprayer that delivered 655 L ha^{-1} with tree/row/volume calculated at 1871 L ha^{-1}.

Evaluation of orchard environmental parameters

For Experiment 1, the effect of the net on orchard temperature, rainfall, relative humidity and solar radiation was recorded using a RainWise Agromet weather station (MK-III-SP1-LR, RainWise Inc., Trenton, USA), installed within the canopy and located 2.5 m above the ground level at the center of one of the four plots. A second RainWise Agromet weather station (MK-III-SP1) was located outside but close to the experimental orchard to record temperature, rainfall, relative humidity and solar radiation independent of the netting. For Experiment 2, a RainWise Agromet weather station (MK-III-SP1-LR) was located close to the experimental plot in the commercial orchard, and was used to record temperature, rainfall, relative humidity and solar radiation.

Fruit surface temperature (FST) was measured through July and August, three times on both sunny and cloudy days for Experiment 1, and two times on both sunny and cloudy days for Experiment 2. Measurements were made using a dual laser infrared video thermometer (model VIR50, Extech Instruments, Waltham, Massachusetts). With the sensor directed towards the side of fruit directly exposed to the sunlight, temperatures of 15 fruit per treatment (5 fruits tree^{-1} × 3 trees) selected from among fruit located 1.4-1.8 m above the ground level was recorded during the period of maximum daily temperature (from 15:00 to 16:30 HR).

Horticultural Evaluation

Fruits were harvested in three picks (H1: 09/01/2016, H2: 09/08/2016, H3: 09/21/2016) for Experiment 1, and four picks (H1: 9/07/2016, H2: 9/20/2016, H3: 9/28/2016, H4: 10/10/2016) for Experiment 2.

For each pick, fruit harvested from each tree were counted and weighed in bulk to determine total yield per tree (kg tree^{-1}). Average fruit weight (FW) was calculated by dividing total yield per tree by the total fruit number. At the end of each experiment, tree circumference was recorded at 30 cm above the graft union, and the trunk cross-sectional area (TCSA) was calculated. Yield efficiency (YE) was calculated as the ratio between the yield (Kg tree^{-1}) and TCSA (cm^2).

Sunburn Evaluation

Based on results from 2015 where more than 80% of the fruits with sunburn were in between these two harvests, for each tree (3 trees replicate^{-1} × 4 replicates), all fruits from H1 and H2 picks of each experiment (a total of 3,255 fruits for experiment 1 and a total of 4,712 fruits for experiment 2) were individually examined for signs of three sunburn types (SN: Sunburn Necrosis; SB: Sunburn Browning; SP: Photooxidative Sunburn), incidence recorded, and results presented as a percentage of the total number of fruit evaluated. This total number of fruits, which represents the 83% of the total apple production in this study on average, is a good number of fruits to have a real perception of the sunburn problem in this region with the 'Honeycrisp' cultivar.

Based on 2015 season observations and the increase of the number of apples to evaluate in 2016, sunburn severity was evaluated differently from 2015 by adapting to 'Honeycrisp' two of the four sunburn browning classes previously described by Felicetti and Schrader (2008) for 'Fuji', as shown in Fig. 1: SB-1, browning or light yellowing spot on the fruit skin; and SB-2, strong yellowing spot on the skin. Each class was expressed as percentage of the total sunburned fruit evaluated.

Fruit size and color evaluation

Fruits harvested at H1 and H2 from Experiment 1 (a total of 3,255 fruits) were individually weighed and assessed for fruit color as a visual score and expressed as percentage of total fruit red surface area.

United States Department of Agriculture standards for apple grades (USDA-AMS, 2002) were used to classify fruits from this study into three common commercial size categories, expressed as the number of fruit required to fill a box with at least 18.5 kg: (1) 88 $\geq$ fruits per box, fruit size $\geq$ 201 grams; (2) between 100 and 138 fruits per box: fruit size between 200.9 and 128 grams; and (3) more than 138 fruits per box: fruit size lower than 128 grams.

Fruit quality evaluation

Fruit quality parameters were evaluated only for Experiment 1. A sample of five clean fruit and five fruit with sunburn browning were randomly selected from each tree and pick date. A total of 1,440 fruit were evaluated (5 fruit tree^{-1}× 3 trees plot^{-1} × 4 plots × 2 injury categories × 2 harvest dates × 6 treatments). The skin color (CIELAB coordinates L, a*, b*, C, H), flesh firmness (FF), soluble solids content (SSC), and titratable acidity (TA) were evaluated separately for the sun-exposed side (B) and the shaded side (NB) of each fruit. Skin color was assessed using a Minolta Chroma meter CR-200 portable tristimulus colorimeter (Minolta Corp, Osaka, Japan). FF, SSC, and TA were assessed as described previously.

Evaluation of Economic Performance

For Experiment 1, the wholesale value of the crop per ha (2,562 trees per hectare) was calculated by estimating the sales prices (grower communication) of the various packs (FOB packing facility). After considering packing, storage, and sunburn management costs, the net return to the grower (US Dollars ha^{-1}) was calculated for each of the sunburn treatments. Costs of pest and disease management, fertilizer, irrigation, hand thinning and plant growth regulators were not considered as they are assumed to be constant across the different treatments.

To calculate the wholesale value (FOB packing facility) for each harvest date, fruit quality grade standards of U.S. Extra Fancy and U.S. No. 1 were followed (USDA-AMS, 2002), excluding U.S. Fancy and U.S. Utility grades, which are not commonly implemented by commercial marketers in the Northeastern U. S. Based on the prices per box (1 box = 18.5 kg) commonly received in 2016 for each fruit grade (grower communication), criteria described in Table 2 was used to calculate wholesale value (FOB Packing Facility) for each pick date.

Grower packing, storage and marketing charges (grower communication), as well as costs related to sunburn management, are described in Table 3. The packing, storage, and marketing charges used in this analysis are specific to the Hudson Valley of New York State, but can be considered representative of those charged throughout New York State.

Statistical Analysis

Analysis of variance was performed separately for each experiment using the JMP software (Version 12, SAS Institute Inc., Cary, North Carolina). A completely randomized block model was used with treatment as fixed factor and block being a replication unit as a random effect. When the analysis showed significant ($P \leq 0.05$) treatment effects, means were separated by Tukey's test. Data expressed as percentages were adjusted to proportions using the arcsine square root transformation prior to analysis of variance.

Results

The Hudson Valley region of New York State is subjected to periods of high summer temperatures (≥ 30ºC) and medium to high rainfall (around 300 mm) from June to the end of September (SME 1 and SME 2).

In 2015, yield, average fruit weight, crop load and yield efficiency were not influenced by sunburn treatments (Table 4). Approximately 98% of the sunburn observed was sunburn browning (SB), and at least half of the apples with sunburn browning had between 10.1% and 30% of the skin surface affected. As expected, the percentage of sunburn, mainly SB, was higher at the first harvest (between 20-25% of the apples), and lessened progressively through H2 and H3 (data not shown). Overall, in terms of fruit quality, titratable acidity (TA) was generally higher, and flesh firmness and soluble solids content (SSC) were lower in fruits without sunburn (Table 5). The clean fruits from the Raynox Plus® treatment had higher SSC and TA compared to ScreenDuo® and control (Table 5).

In 2016, fruit surface temperature (FST) measurements recorded during the period of maximum daily orchard temperatures generally showed the positive effects of the treatments on reduction in fruit temperature in both experiments (Table 6), but treatments had less effect on the incidence and severity of sunburn (Table 7). The fruit temperatures associated with sunny days in summer were around 12 ºC higher than air temperatures due to the direct sunlight exposure (Table 6).

Yield and fruit weight were not significantly affected by treatments in either 2016 experiments, whereas crop load and yield efficiency were generally reduced by sunburn mitigation treatments in Experiment 2 (Table 7), with treatments Raynox-1 and Raynox-3 showed the lowest values, significantly different from control for both parameters.

In terms of sunburn incidence and severity, treatments were significantly different (*$P \leq 0.05$)* in Experiment 1 for both H1 and H2 (data not shown) and for both harvests combined in 2016 (Table 7). Fruits produced under the netting showed the lowest incidence of sunburn, above 50 % compared to control. However, netting did not differ significantly from EC and Raynox Plus® treatment at H1, from the evaporative cooling and ScreenDuo-1 treatments at H2 (data not shown), and from the evaporative cooling, Raynox Plus® and ScreenDuo-1 treatments when the data from both harvests was combined (Table 7). Although EC, Raynox Plus®, ScreenDuo-1 and ScreenDuo-2 treatments did not differ statistically from the control, they often had a numerically lower percentage of sunburn incidence, with the exception of ScreenDuo-2.

Fruit quality traits of experiment 1 such as percentage of red color (blush), FF, SSC, TA and skin color (a*/b* and Hue) were analyzed separately by fruit type (clean vs. sunburned fruit) and fruit side (B vs. NB) in 2016 (Table 8). Although the treatments did not significantly affect the percentage of red color in the skin (blush), 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 to the apples from the rest of the treatments. Comparing fruit type (clean *vs* sunburned), the fruits with sunburn on the sun exposed side had higher FF, SSC, and less TA (data not shown).

In 2016 at Experiment 1, both harvests, H1 and H2, combined represented, on average, 83% of the total apple production in this study. Based on fruit size, percentage of red color and the incidence of sunburn for H1 and H2 together, more than 60% of the fruits graded U.S. Extra Fancy (Table 9). By treatment, the netting treatment tended to have higher number of fruits at the U.S. Extra Fancy category, followed by Raynox Plus®, ScreenDuo-1, ScreenDuo-2, control and evaporative cooling (Table 9). Mostly the remaining fruits were graded as culls, predominantly due to sunburn injury. Based on treatment averages, 70% of the total fruits classified as cullage had more than 5% of the skin surface area damaged by sunburn (data not shown). Bitter pit disorder can be a severe problem in ENY 'Honeycrisp' orchards, and a significant contributor to cullage. Data from a 2016 survey of 36 ENY 'Honeycrisp' orchards showed bitter pit incidence to range from 0–71.1%, with four orchards at less than 5% (Donahue personal communication). Our test orchard showed less than 5% BP incidence in 2015, and was estimated to show the same in 2016; therefore, BP incidence data was not collected in our study.

In terms of economics, no statistical differences in net return to the grower were found among treatments from Experiment 1 in 2016 (Table 10). However, ScreenDuo-1 followed by netting, Raynox Plus® and ScreenDuo-2 had higher numerical values compared to the control. On the basis of a total yield of 23.5 t per ha, which is a measure that represents the 83% of total apple production (H1 and H2 together) of the seventh-leaf 'Honeycrisp' trees orchard evaluated, the costs related to sunburn management were then calculated per hectare and found to vary substantially among treatments (Table 10). It is worth noting that the high gross wholesale value of the fruit produced under netting was effectively neutralized by the substantial investment and maintenance costs associated with the netting installation over the expected life of the orchard.

Discussion

ScreenDuo® is a kaolin-based product which reduces heat and light stress. Raynox Plus® is a water-soluble lipid spray (clear carnauba wax) that easily binds with fruit cuticle and, although invisible after it dries, protects the fruit by reflecting mostly UV-B and to a less extend UV-A (Schrader et al., 2008). Netting intercepts solar radiation, reduces light intensity and temperature, decreases evapotranspiration and wind speed, while humidity in the orchards increases (Racsko and Schrader, 2012; Bosančić et L., 2018; Mupambi et al., 2018b). Evaporative cooling (EC) which involves an overtree irrigation system cools down fruit when air temperature exceeds a certain threshold (Racsko and Schrader, 2012). The air around the trees is also cooled, and the relative humidity increases, thus reducing water loss through transpiration (van den Dool, 2006).

Horticulture performance

The different treatments evaluated over the two years did not affect yield, fruit weight, crop load, or yield efficiency of 'Honeycrisp', except in 2016 Experiment 2 for the Raynox-1. This treatment resulted in lower crop load and yield efficiency. Earlier studies have reported some conflicting results. do Amarante et al. (2011) reported that the anti-hail nets reduced photosynthesis, increased vegetative growth and, therefore, reduced yield and fruit size of apples. Iglesias and Alegre (2006) reported that yield and fruit weight were not significantly affected using nets over three years of study, in agreement with our one-year results. Mupambi et al. (2018a) reported that in environments where trees are not stressed and light limitation is possible because of shading, protective netting has the potential to reduce fruit size from reduced tree photosynthesis. However, in regions where trees regularly experience abiotic stress due to excessive solar radiation, netting may have a positive effect on fruit size through the mitigation of some of the effects of stress by maintaining higher photosynthetic rates later in the day, especially, when compared to trees in full sun that may be experiencing photoinhibition. Gindaba and Wand (2005) and Iglesias et al. (2002) reported that evaporative cooling increased fruit size on 'Gala' and 'Cripps Pink' apple cultivars. Schupp et al. (2002) reported that weekly applications from the beginning of July to mid-August of a kaolin clay product, Surround, reduced fruit weight of 'Honeycrisp'. In our study, the ScreenDuo® product, which belongs in the same class as Surround, did not show this result.

Sunburn evaluation

The observed temperature difference of 12ºC between the sun-exposed fruit skin and air temperature clearly show that apple fruit have a high affinity to absorb solar radiation (Gindaba and Wand, 2005). Fruit are unable to utilize or dissipate the excess radiation; therefore under hot climate this excess results in localized burning of the fruit skin and cortex. ‘Honeycrisp’ is a susceptible cultivar to sunburn. In our study, losses of apple fruit due to sunburn ranged from 4% to 40% depending on the year, harvest and treatment. These results are in agreement with authors working in other apple-growing regions of the world, who have reported losses of apple fruit due to sunburn in the range of 10% to 50% (Gindaba and Wand, 2005; Racsko and Schrader, 2012; Kalcsits et al., 2017). Sunburn damage can also be influenced by other factors such as cultivar, climate fluctuations and orchard management practices (Gindaba and Wand, 2005). Due to the high temperatures experienced in 2015 and 2016 seasons in the Hudson Valley area, ‘Honeycrisp’ apples from slender spindle and tall spindle trees suffered moderate to high sunburn incidence. Approximately 98% of the sunburn evaluated on all treatments for both years was categorized as sunburn browning (SB), while the remainder mostly represented photo-oxidative sunburn (SP). SP was primarily observed in the second harvest although a few fruits from H1 had this symptom. SP occurs because fruits that had previously grown in the shade and are not acclimated to direct sun can be exposed by removal of proximate fruit during the first harvest (Racsko and Schrader, 2012).

In 2016, ‘Honeycrisp’ trees from Experiment 2 experienced less sunburn incidence (14%) that those from Experiment 1 (26%). Trees used in Experiment 2 were older, larger, and therefore had more foliage to cover the fruits and protect them from the sun exposure. Despite similar weather conditions in both experiments, significant differences among treatments were only found on Experiment 1. Netting was the treatment that produced a marked reduction in sunburn incidence (Table 7), in agreement with previous sunburn studies on other apples cultivars in other parts of the world (Schrader et al., 2001; Glenn et al., 2002; Gindaba and Wand, 2005; Iglesias and Alegre, 2006; do Amarante et al., 2011). In general, they reported that a lower incidence of sunburn by using netting is due to lower direct incidental radiation on the fruit combined with the reduction in fruit temperature. In fact, netting significantly reduced mean fruit surface temperature (FST) compared to control.

Year 2016 provided more summer days of above-average high temperatures when compared to maximum temperature data for the previous 16 years in this region (data not shown). The Hudson Valley experienced 38 days with temperatures equal or higher than 30 ºC and 10 days at temperatures equal or higher than 32.2 ºC. The high temperatures recorded may explain the lack of statistical effects of the spray particle film (ScreenDuo®), sunscreen product (Raynox Plus®), and evaporative cooling compared to the control. With such intense solar radiation, temperature reductions alone are not sufficient to prevent sunburn even when evaporative water droplets are on fruit surface (Gindaba and Wand, 2005) or when the sprayable films are present because these films fail to reflect some solar irradiation (including UV-B).

Fruit quality

The results observed for ‘Honeycrisp’ apples in both years confirm previous reports on other apple cultivars. Fruits with sunburn, specifically SB type, had higher FF and SSC and lower TA values than fruits with no SB (Racsko and Schrader, 2012), regardless of the treatment evaluated. Relative water content of the tissue beneath sunburned area decreases as the severity of sunburn increase, with concomitant increases in the percentage of dry matter and the solute concentration (Racsko and Schrader, 2012).

With regards to the effect of the netting on fruit quality, our data agree with previous results on other apple studies. do Amarante et al. (2011) reported less FF and SSC, but no effect on TA, on Gala trees under white net (with aperture size of 4mm × 7 mm). A reduced SSC was also reported by Iglesias and Alegre (2006) for ‘Mondial Gala’ under black hail-net, but no effect on TA was observed under white or black nets. Leite et al. (2002) did not find any reduction in flesh firmness or SSC of ‘Fuji’ and ‘Gala’ apples in a five-year study in orchards protected by black anti-hail nets that provided 12–30% reductions in light transmission. Gindaba and Wand (2005) reported higher ‘Royal Gala’ fruit firmness in both sun-exposed and shaded sides of fruit under netting compared to fruit from trees with evaporative cooling or Surround application; however no differences in SSC were observed among those treatments. In addition, it is worth noting that several authors reported that orchard management practices, crop load management and climate had stronger effects on external and internal apple fruit quality than any of the measured influences from netting (Campbell and Marini, 1992; Stampar et al., 2002).

Apple fruit skin coloration is affected by light exposure for bi-color cultivars. The more red coloration usually results in a greater economic return for the grower (Mupambi et al., 2018a). A minimum of 40% of the fruit surface should have red color to comply with the guidelines for the U.S.D.A. Extra Fancy grade. From our 2016 Experiment 1, the average values for fruit color for all treatments exceeded 40%. Although the different treatments did not affect significantly the percentage of red color (blush) in the skin, apples without sunburn, produced under the net, had numerically lower blush values compared to 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 to the apples from the rest of the treatments, a result consistent with other studies (Stampar et al., 2001; Gindaba and Wand, 2005; Iglesias and Alegre, 2006). Red color is directly regulated by light, temperature, and cultivar. Protective netting reduces light levels for fruit over the entire season. 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. In contrast to reduced fruit coloring under netting, fruit treated with the particle film

(ScreenDuo®) and the sunscreen (Raynox Plus®) tended to have higher blush values and more intense red color (higher a*/b* ratio and hue values) compared to control fruit. However, Schupp et al. (2002), who applied the particle film Surround at different timings on 'Honeycrisp' trees in New York, reported no effects on fruit color.

Net return to the grower

Results from the cost-benefit analysis failed to show any statistical differences among treatments. Based on the total annual sunburn management cost (SBMC), among the strategies we evaluated, the netting was the most expensive option, followed by evaporative cooling and the sprayable particle films, results that are similar to other published reports (Gindaba and Wand, 2005; Iglesias and Alegre, 2006; Racsko and Schrader, 2012). Nevertheless, 'Honeycrisp' apples under the netting suffered less sunburn compared to rest of the treatments, meaning an increased income from an increased percentage of clean fruit with no sunburn symptoms. Besides reducing sunburn, other authors reported that netting can also improve fruit finish while also protecting the crop from hail and other environmentally-induced fruit defects (wind-rub, skin cracking and russet), as well as insect pests and bird damage if netting is fully skirted to the ground (do Amarante et al., 2011), reduction in irrigation costs from reduced soil water loss (McCaskill et al., 2016), and reduced hand thinning costs if protective netting is up during pollination and reducing spraying costs due to increased spray efficacy (Smit, 2007). These additional benefits may improve the economics of using netting in tree production. However, in order to offset its cost, orchard productivity under netting must be maximized via high yields of premium quality fruit and efficient tree management (do Amarante et al., 2011). Finally, Iglesias and Alegre (2006) reported that in the case of a replacement orchard, the same poles used to support the nets can support the trees, thereby further reducing costs assigned to constructing support systems for nets.

‘Honeycrisp’ is a very popular apple cultivar among American consumers who appreciate the premium fresh apple eating experience (Rosenberger et al., 2004). Growers tolerate the production challenges and post-harvest issues associated with ‘Honeycrisp’ because of the potential for high returns (Embree et al., 2007). The wholesale value (FOB at the packing facility) for ‘Honeycrisp’ produced in New York in 2016 was $62-$69 per box fruits (1 box = 18.5 Kg), 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 offset the high sunburn management cost of the netting strategy, result in net returns to the grower similar to that of the Raynox Plus® and ScreenDuo® treatments. Sprayable treatments are arguably the least risky in terms of capital outlay and the most affordable for growers. More research is needed under the reduced sunlight, high humidity, and relatively rainy environment experienced in the Northeastern United States to evaluate the effects of treatments over a longer time period and under a broader variety of seasonal conditions so as to have a robust regionally relevant cost-benefit analysis. The industry needs a better understanding of conditions that trigger sunburn as well as more information on application rates for evaporative cooling (water), Raynox Plus® and ScreenDuo® treatments and options/benefits for alternative netting technology and netting colors.

Conclusions

The results from this research showed that the greatest sunburn suppression was achieved with the use of netting, followed by spray applications of Raynox Plus® and ScreenDuo®, although significant effects were noted in only one of the three trials completed. Reductions in sunburn damage did not result in increased net returns to the grower after accounting for costs of sunburn management. In general, fruit yield and quality were not affected by treatment in either of the seasons, although treatments did affect fruit color (intensity of red color). The geography and the climatology of the Hudson Valley region of New York State is quite different compared to other areas where sunburn has been studied more intensively. More years of data collection are required to provide Northeaster U.S. growers with more accurate assessments of cost-effective approaches for reducing sunburn and optimizing fruit quality of ‘Honeycrisp’.

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Table 1. Treatments, rates and dates of application (2016) at Hudson Valley Research Laboratory orchard (Experiment 1) and commercial orchard (Experiment 2).

Code	Treatment	Rate	Dates of application
Experiment 1	Control	-	-
	Netting[1]	-	-
	Evaporative cooling[2]	41.7 L hour^{-1}	6th-8th July, 12th July, 15th July, 18th July, 21st-29th July, 5th August, 8th-9th August, 11th-15th August, 17th-20th August, 24th August, 26th-29th August, 8th September
	Raynox Plus®[3]	23.4 L ha^{-1}	15th June, 22th June, 7th July, 12th August
	ScreenDuo-1[4]	11.2 kg ha^{-1}	28th May, 7th June, 18th June, 3rd July, 12th July, 26th July, 5th August, 16th August
	ScreenDuo-2[5]	11.2 kg ha^{-1}	18th June, 3rd July, 12th July, 26th July, 5th August, 16th August
Experiment 2	Control	-	-
	Raynox-1[3]	23.4 L ha^{-1}	18th June, 25th June, 16th July, 11th August
	Raynox-2[5]	23.4 L ha^{-1}	18th June, 15th July, 11th August
	Raynox-3[6]	23.4 L ha^{-1}	18th June, 25th June, 16th July, 11th August
	ScreenDuo-1[4]	11.2 kg ha^{-1}	8th June, 18th June, 2nd July, 12th July, 26th July, 3rd August, 17th August
	ScreenDuo-2[5]	11.2 kg ha^{-1}	18th June, 12th July, 26th July, 5th August, 17th August

[1] From Pak Unlimited Inc. (Georgia, USA).

[2] From TRICKL-EEZ Company (Michigan, USA), Model Nelson R5 Rotator.

[3] From Valent BioSciences (Ilinois, USA). Applied four times during growing season, beginning nine weeks after full bloom as per label recommendations.

[4] From Crop Microclimate Management Inc. (North Carolina, USA). Applied every 10-14 days beginning at petal fall as per label recommendations

[5] Applied 1-3 days before a predicted heat event ($\geq$ 30 ºC).

[6] Applied four times during growing season, beginning nine weeks after full bloom as per label recommendations, but with applications made only to the west-facing side of the trees

Table 2. Criteria to calculate the wholesale value for 'Honeycrisp' grown at the Hudson Valley Research Laboratory orchard (Experiment 1) during the 2016 season.

Fruit size category	Fruit characteristics	Price ($ box^{-1})
U.S. Extra Fancy (ExFy)		
88 or larger (201-316 g)	0% sunburn on the red/blushed surface area > 40% red color on the skin	62-69[a]
138-100 (128-200.9 g)	0% sunburn on the red/blushed surface area > 40% red color on the skin	40-48[a]
U.S. No.1 (# 1)		
138 or larger (≥ 128 g)	< 5% sunburn on the red/blushed surface area > 10% red color on the skin	16
Culls for juice[b]		
Lower than 138 (< 128 g)	0% sunburn on the red/blushed surface area ≥ 40% red color on the skin	0.12
Lower than 138 (< 128 g)	< 5% sunburn on the red/blushed surface area ≥ 10% red color on the skin	0.12
Lower than 138 (< 128 g)	> 5% sunburn on the red/blushed surface area	0.12
88 or larger (201-316 g)	> 5% sunburn on the red/blushed surface area	0.12
138-100 (128-200.9 g)	> 5% sunburn on the red/blushed surface area	0.12

[a] An average price was used: $64 and $42, respectively.

[b] Our test orchard showed less than 5% BP incidence in 2015, and was estimated to show the same in 2016, therefore, BP incidence data was not collected in our study.

Table 3. List of estimated annual costs for sunburn management, packing and storage of ‘Honeycrisp’ grown at the Hudson Valley Research Laboratory orchard during the 2016 season 2016.

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 hectare)[a]	1,699
Net[b] (per hectare)	2,530
Evaporative cooling structure (per hectare)[c]	320
Raynox Plus (per spray application)[d]	76
ScreenDuo (per spray application)[d]	18
Full time tractor driver (per hour)	14.37
Tractor (per hour)	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 amortization period. The initial capital investment in the structure was estimated to be $30,889 per hectare.

[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 $16,062 per hectare.

[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 $5,824 per hectare.

[d] Material cost

Table 4. Treatment effect on 'Honeycrisp' yield, fruit weight, crop load, yield efficiency, and sunburn incidence/severity during the 2015 season.

Treatment	Yield (kg)	Fruit weight (g)	Crop load (fruit cm^{-2})	Yield efficiency (Kg cm^{-2})	Sunburn incidence[a] (%)	Sunburn severity[b] (%)		
						Cat. 1	Cat. 2	Cat. 3
Control	45.4 a	209.1 a	3.6 a	0.7 a	9.2 a	1.9 a	5.0 a	1.8 a
Raynox Plus®	40.9 a	216.7 a	4.3 a	0.9 a	12.3 a	1.9 a	7.5 a	1.8 a
ScreenDuo®	48.3 a	195.9 a	4.4 a	0.9 a	12.3 a	1.6 a	6.0 a	4.5 a

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

[a] Include all three types of sunburn (SN, SB and SP). The value is the average for all three harvests together.

[b] Cat. 1, Category 1 (0.1-10% of red/blused surface area with sunburn browning); Cat. 2, Category 2 (10.1-30% of red/blused surface area with sunburn browning); Cat. 3, Category 3 (greater than 30% of red/blused surface area with sunburn browning).

Table 5. Treatment effect on fruit quality of both healthy and sunburned 'Honeycrisp' fruits during 2015 season. Mean values represent observations from all three harvests pooled together.

Treatment	FF (N)		SSC (°Brix)		TA (g malic acid L^{-1})	
	Healthy	Sunburned	Healthy	Sunburned	Healthy	Sunburned
Control	54.7 aB	61.5 abA	12.5 bB	13.3 aA	3.1 bA	2.5 aB
Raynox Plus®	54.6 aA	55.3 bA	12.9 aA	12.9 bA	3.3 aA	2.5 aB
ScreenDuo®	55.4 aB	64.6 aA	12.6 bB	13.0 bA	3.1 bA	2.5 aB

Tukey HSD test ($P \leq 0.05$) analysis was performed. For the same fruit type (healthy and sunburned), data followed by the same lowercase within a column are not significantly different. For the same treatment, data followed by the same uppercase letter are not significantly different.

Abbreviations: FF, flesh firmness; SSC, soluble solids content; TA, titratable acidity.

Table 6. Treatment effect on fruit surface temperature (FST) of ‘Honeycrisp’ and the orchard air temperature (ºC) observed on three dates in the Hudson Valley Research Laboratory orchard (Experiment 1) and on two dates in the commercial orchard (Experiment 2) during the 2016 season.

Experiment	Treatment/ conditions	Dates			Mean
		21st July	*26th July*	*27th July*	
Experiment 1	**Sunny**				
	Control	43.7 a	41.3 a	40.9 ab	41.9
	Evaporative Cooling	38.4 c	40.9 ab	40.3 b	39.8
	Netting	37.8 c	39.5 b	39.3 c	38.9
	Raynox Plus®	40.4 bc	35.8 d	42.1 a	39.4
	ScreenDuo-1	40.0 bc	37.8 c	41.4 a	39.7
	ScreenDuo-2	41.5 ab	39.4 b	39.9 bc	40.2
	Air Temperature	31.9	30.3	31.8	31.3
	Cloudy	*18th July*	*12th Aug.*	*15th Aug.*	
	Control	42.8 a	46.3 a	47.7 a	45.6
	Evaporative Cooling	33.5 cd	41.3 b	46.0 b	40.3
	Netting	37.6 b	41.8 b	40.0 e	39.8
	Raynox Plus®	37.8 b	45.9 a	41.1 d	41.6
	ScreenDuo-1	31.3 d	45.6 a	40.0 e	39.0
	ScreenDuo-2	36.4 bc	46.7 a	43.9 c	42.3
	Air Temperature	31.8	32.7	31.4	32.0
Experiment 2	**Sunny**	*21st July*	*27th July*		
	Control	45.6 a	48.7 a	-	47.1
	ScreenDuo-1	40.2 c	44.5 bc	-	42.3
	ScreenDuo-2	41.6 b	48.2 a	-	44.9
	Raynox-1	43.9 ab	47.1 ab	-	45.5
	Raynox-2	43.9 ab	44.4 bc	-	44.2
	Raynox-3	40.4 c	41.4 c	-	40.9
	Air Temperature	32.5	32.3	-	32.4
	Cloudy	*15th July*	*26th Aug.*		
	Control	35.6 ab	46.5 b	-	41.1
	ScreenDuo-1	34.6 bc	44.8 c	-	39.7
	ScreenDuo-2	36.0 ab	48.1 a	-	42.1
	Raynox-1	35.6 ab	48.2 a	-	41.9
	Raynox-2	37.0 a	47.5 a	-	42.3
	Raynox-3	33.3 c	42.6 d	-	37.9
	Air Temperature	30.1	30.4	-	30.2

Each value is the mean of 15 measurements on the exposed side of the fruit.

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

Table 7. Treatment effects on 'Honeycrisp' yield, fruit weight, sunburn incidence and severity for 2016 season experiments 1 and 2.

Experiment	Treatment	Yield (kg)	Fruit weight (g)	Crop load (fruit cm^{-2})	Yield efficiency (Kg cm^{-2})	Sunburn incidence[a] (%)	Sunburn severity[b] (%)	
							SB-1	SB-2
Experiment 1	Control	10.9 a	161.0 a	7.5 a	1.3 a	26.7 a	82.9 a	17.0 a
	Netting	9.7 a	170.0 a	6.8 a	1.3 a	11.2 b	96.4 a	3.9 b
	Evaporative cooling	11.6 a	173.0 a	7.3 a	1.4 a	21.8 ab	91.0 a	8.9 ab
	Raynox Plus®	12.5 a	175.0 a	7.2 a	1.4 a	21.8 ab	91.1 a	8.9 ab
	ScreenDuo-1	12.2 a	186.3 a	6.2 a	1.3 a	21.6 ab	97.5 a	2.5 b
	ScreenDuo-2	10.2 a	161.2 a	6.4 a	1.1 a	26.8 a	94.4 a	5.6 ab
Experiment 2	Control	25.0 a	190.3 a	6.7 a	1.2 a	13.3 a	94.1 a	5.9 a
	Raynox-1	19.0 a	216.4 a	3.9 c	0.8 b	12.5 a	96.5 a	3.5 a
	Raynox-2	22.5 a	177.2 a	5.8 abc	1.0 ab	14.3 a	92.5 a	7.5 a
	Raynox-3	22.1 a	191.9 a	4.6 bc	0.9 b	12.4 a	94.8 a	9.7 a
	ScreenDuo-1	26.1 a	181.0 a	6.1 ab	1.1 ab	16.0 a	93.0 a	7.0 a
	ScreenDuo-2	21.5 a	192.0 a	5.2 abc	1.0 ab	14.7 a	91.9 a	8.1 a

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

[a] Include all three types of sunburn (SN, sunburn necrosis; SB, sunburn browning; SP, photooxidative sunburn). The value is the average for the two first harvests together.

[b] These values (SB-1 + SB-2) represent the percentage of the total sunburn incidence.

Abbreviations: SB, sunburn browning; SN, sunburn necrosis; SP, photooxidative sunburn.

Table 8. Treatment effect on the fruit quality of non-sunburned ‘Honeycrisp’ apples, Hudson Valley Research Laboratory orchard (Experiment 1), 2016 season.

Treatment	Blush (%)	FF		SSC		TA		a*/b*		Hue	
		B	*NB*	*B*	*NB*	*B*	*NB*	*B*	*NB*	*B*	*NB*
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.

Abbreviations: B, sun exposed side of the fruit; FF, flesh firmness; NB, shaded side of the fruit; SSC, soluble solids content; TA, titratable acidity.

Table 9. Treatment effect on the fruit size and grade classification of ‘Honeycrisp’ apples, Hudson Valley Research Laboratory orchard (Experiment 1), 2016 season.

Treatment	U.S. Extra Fancy (%)[1]		U.S. No. 1	Culls
	88	100 - 138	(%)	(%)
Control	6	57	2	35
Netting	15	61	0	24
Evaporative cooling	9	53	0	38
Raynox Plus®	12	61	0	27
ScreenDuo-1	17	56	1	26
ScreenDuo-2	13	60	0	27

[1] United States Department of Agriculture grade standards.

Table 10. Net revenue per hectare basis from Experiment 1 during the 2016 season.

Treatment	Wholesale[a] (\$ ha^{-1})	Total Grower Charges[b] (\$ ha^{-1})	Total Annual Sunburn Management Cost (SBMC)[c] (\$ ha^{-1})	Net Return to Grower after SBMC[d] (\$ ha^{-1})
Control	41,771	15,545	0	26,226 a
Netting	51,652	16,533	4,229	30,890 a
Evaporative cooling	43,834	15,752	1,631	26,451 a
Raynox Plus®	47,892	16,157	1,087	30,647 a
ScreenDuo-1	48,654	16,234	1,028	31,392 a
ScreenDuo-2	47,348	16,103	771	30,474 a

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

[a] FOB sale price at packing facility. This column represents the wholesale value per ha (H1+H2) with equalized yield for all treatments (23,538 Kg ha^{-1}).

[b] Values obtained at equalized yield for all treatments (23,538 Kg ha^{-1}). These charges include storage, 1-MCP treatment, packing, and sales agency.

[c] This cost includes: structural cost, labor and machinery cost.

[d] Values obtained at equalized yield for all treatments (23,538 Kg ha^{-1}).

Figure 1. The two severity levels of sunburn browning used for assessments of ‘Honeycrisp’ apples in 2016.

SME1. Maximum (Max) and minimum (Min) temperatures (ºC), precipitation (mm) and solar radiation (Langley) 2015 from Hudson Valley Research Laboratory NEWA weather station.

Date	June				July				August				September			
	Max (°C)	Min (°C)	Rain (mm)	Solar Rad (langley)	Max (°C)	Min (°C)	Rain (mm)	Solar Rad (langley)	Max (°C)	Min (°C)	Rain (mm)	Solar Rad (langley)	Max (°C)	Min (°C)	Rain (mm)	Solar Rad (langley)
1	11.7	9.2	17.8	67	25.7	18.4	7.8	406	29.9	18.1	0.0	562	28.8	18.2	0.0	580
2	13.6	8.4	27.2	56	24.9	15.0	0.0	476	29.8	15.0	0.0	623	32.2	16.8	0.0	558
3	20.8	9.9	0.0	62	25.5	13.3	0.0	652	31.3	19.6	0.0	549	30.6	18.0	0.0	495
4	21.1	11.3	0.0	406	21.6	15.6	1.3	187	30.3	19.3	0.0	472	27.6	20.2	0.0	293
5	22.7	12.4	0.0	140	27.7	14.2	0.0	565	28.7	16.2	0.0	504	28.1	16.2	0.0	596
6	21.5	14.7	0.0	271	27.2	15.8	0.0	405	26.7	14.9	0.0	495	29.8	15.2	0.0	571
7	23.8	8.5	0.0	408	29.7	19.7	0.5	356	26.7	14.1	0.0	580	32.3	16.6	0.0	543
8	24.8	15.2	22.6	522	28.8	22.4	0.5	315	27.4	16.0	0.0	508	34.1	21.6	0.0	530
9	24.7	17.9	12.4	242	24.6	18.1	0.2	321	27.9	16.8	0.0	526	33.0	21.6	0.8	489
10	26.6	13.1	0.0	252	26.2	18.9	0.5	486	26.0	17.4	0.0	242	24.1	17.9	1.5	127
11	30.8	20.2	0.0	448	28.9	15.3	0.0	629	24.2	19.4	1.3	168	25.6	17.3	0.0	455
12	29.4	16.7	1.8	367	30.2	16.3	0.0	563	27.9	16.3	0.0	538	24.1	14.0	0.2	231
13	25.3	18.1	0.7	351	30.2	18.7	0.0	466	27.8	14.3	0.0	570	24.1	15.0	0.0	360
14	28.6	14.7	0.2	455	26.1	16.7	0.0	340	29.7	13.8	0.0	585	22.8	12.6	39.9	400
15	21.7	17.7	20.6	428	24.2	18.6	0.0	318	31.3	19.1	0.2	557	27.2	11.0	0.0	515
16	26.3	17.2	6.6	124	24.6	13.7	0.0	526	30.6	18.1	0.0	510	28.1	12.8	0.0	389
17	24.2	17.5	0.0	184	26.8	12.0	0.0	508	32.8	19.6	0.0	565	29.1	13.3	0.0	418
18	21.0	16.3	0.0	437	30.3	19.9	10.4	164	32.4	20.9	0.5	523	28.5	14.5	0.0	228
19	26.4	18.3	0.0	113	32.2	20.0	0.2	339	30.4	20.8	0.0	448	27.1	14.7	0.0	263
20	21.0	14.7	3.3	343	32.3	21.7	0.0	505	29.1	21.1	0.0	332	21.0	14.1	0.0	523
21	30.9	17.7	33.5	152	29.7	18.3	0.0	277	27.1	16.6	0.5	573	19.7	11.1	0.0	251
22	28.8	18.4	0.0	372	27.7	17.0	0.0	482	25.4	16.9	0.0	556	19.4	8.9	0.0	120
23	28.8	19.2	6.6	330	28.8	14.2	0.0	608	28.0	15.1	0.0	518	24.0	9.2	0.0	287
24	27.7	14.8	0.0	301	29.0	14.1	0.0	578	28.7	17.7	0.0	496	24.5	9.4	0.0	322
25	26.3	12.7	0.0	496	29.8	13.7	0.0	604	28.8	19.3	0.5	434	23.2	13.2	0.0	109
26	24.7	16.9	0.0	493	29.1	19.4	5.3	323	25.3	14.4	0.0	497	20.6	11.7	0.0	209
27	20.1	12.7	14.2	475	29.4	19.2	0.0	444	25.8	14.8	0.0	532	22.7	7.8	0.0	165
28	16.8	12.4	15.5	137	33.0	18.9	0.0	591	25.4	12.4	0.0	545	24.0	14.8	0.0	102
29	22.9	14.5	0.0	94	34.0	19.1	0.0	577	28.1	12.7	0.0	554	25.3	19.2	7.4	153
30	22.2	15.7	2.5	463	29.1	21.7	4.3	237	28.1	16.9	0.2	296	21.2	11.7	66.3	97
31	-	-	-	150	31.2	18.2	0.0	630	30.6	19.1	0.0	399	-	-	-	-
High / Low / Total / Total	30.9	8.4	185.6	9139	34.0	12.0	31.2	13878	32.8	12.4	3.3	15257	34.1	7.8	116.1	10379

SME2. Maximum (Max) and minimum (Min) temperatures (ºC), precipitation (mm) and solar radiation (Langley) 2016 from Hudson Valley Research Laboratory NEWA weather station.

Date	June				July				August				September			
	Max (°C)	Min (°C)	Rain (mm)	Solar Rad (langley)	Max (°C)	Min (°C)	Rain (mm)	Solar Rad (langley)	Max (°C)	Min (°C)	Rain (mm)	Solar Rad (langley)	Max (°C)	Min (°C)	Rain (mm)	Solar Rad (langley)
1	28.8	15.9	0.0	607	26.8	16.4	18.5	356	24.8	18.9	5.3	197	26.2	19.3	1.8	289
2	26.6	13.8	0.0	589	24.5	15	0.3	579	24.0	17.9	6.1	332	24.9	14.3	0.0	466
3	20.5	15.7	2.8	119	26.7	13.2	0.0	531	27.6	15.7	0.0	562	24.2	15.1	0.0	381
4	27.0	17.4	0.0	430	28.7	14.4	0.0	636	28.3	15.6	0.0	585	26.2	15	0.0	432
5	21.3	17.7	36.1	107	30.8	19.9	1.8	393	28.6	18.0	0.0	558	27.7	13.5	0.0	357
6	27.6	18.1	0.3	610	32.1	19.3	0.0	584	30.8	21.3	1.3	431	26.5	19.6	0.0	258
7	26.4	16.6	1.5	548	30.4	21	1.3	357	30.0	17.4	0.0	561	28.0	18.8	0.0	272
8	16.9	12.7	0.8	310	30.1	20.8	13.7	460	28.2	16.0	0.0	563	32.2	18.3	1.3	370
9	20.5	10.4	0.0	595	20.4	18.1	10.7	91	29.3	15.2	0.0	555	32.0	23.3	0.0	283
10	24	9.27	0.0	657	26.8	18.5	0.3	406	29.7	22.1	21.6	223	30.0	20.2	4.1	277
11	25.2	8.72	9.4	275	24.5	15.7	0.0	489	31.3	23.6	2.0	355	25.8	16.7	0.8	319
12	24.6	14.3	0.3	405	28.8	14.5	0.0	507	32.8	21.7	6.4	489	25.3	9.5	0.0	443
13	20.7	11.9	0.0	437	29.5	19.3	0.0	451	33.3	22.5	1.5	461	27.7	13.2	0.0	409
14	25.0	10.6	0.0	492	29.4	22.2	0.0	231	32.4	22.6	8.6	461	31.2	17.5	0.0	354
15	27.6	12.5	0.0	474	31.6	21.8	0.0	476	30.3	21.3	0.0	475	21.7	11.3	0.0	424
16	25.8	17.0	1.0	343	30.5	19.6	0.0	505	29.3	21.1	0.8	247	23.5	8.05	0.0	362
17	26.6	16.5	0.0	457	31.2	19.8	0.0	507	27.3	21.3	0.0	432	24.5	12.2	0.0	318
18	29.8	13.2	0.0	369	31.8	19.6	17.8	387	30.1	19.7	3.0	512	26.2	19.2	0.3	169
19	31.7	16.6	0.0	416	26.8	17.5	0.3	609	28.7	19.7	0.0	511	24.6	20.0	7.4	144
20	30.8	15.3	0.0	420	27.8	13.5	0.0	564	30.6	17.8	0.0	522	27.6	18.8	0.3	295
21	28.1	18.0	0.0	225	32.5	15.2	0.0	600	29.3	21.3	19.8	265	26.2	16.7	0.0	332
22	26.5	12.8	0.8	409	35.0	20.9	0.0	538	23.6	15.5	0.0	544	29.3	12.7	0.0	383
23	27.6	12.6	0.0	486	33.8	21.5	0.0	513	26.5	10.8	0.0	536	28.8	13.6	0.0	262
24	29.2	15.8	0.0	565	31.9	17.8	0.0	499	29.1	14.5	0.0	509	19.6	11.1	0.0	387
25	30.1	14.8	0.0	604	33.2	20.1	10.4	343	28.2	18.2	0.0	303	19.1	6.94	0.0	384
26	30.6	17.6	0.0	563	30.5	19.7	0.3	585	31.2	22.4	0.0	424	21.3	5.27	0.0	232
27	29.4	18.6	4.6	436	32.1	17.3	0.0	591	30	17.2	0.0	443	22.2	13.5	11.4	232
28	24.9	18.7	8.9	218	33.2	17.8	0.0	474	30.6	18.6	0.0	492	19.1	9.94	0.0	152
29	27.7	18.6	0.3	415	30.1	21.4	2.8	473	29.6	21.0	0.0	466	19.0	13.4	0.0	209
30	28.3	15.7	0.0	624	27.7	19.9	3.0	331	28.3	15.1	0.0	498	16.1	11.5	5.1	126
31	-	-	-	-	21.8	19.4	57.2	89	25.8	17.7	0.0	185	-	-	-	-
High / Low / Total / Total	31.8	8.7	66.55	13205	35.1	13.2	138.2	14155	33.4	10.9	76.4	13697	32.2	5.3	32.3	9321