

Communication

# Shading Nets Reduce Canopy Temperature and Improve Photosynthetic Performance in ‘Pinkerton’ Avocado Trees during Extreme Heat Events

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**Abstract:** Frequent extreme heat events cause major financial losses for the avocado industry. Shading nets are used to protect crops from harsh environmental hazards. To determine their ability to improve photosynthetic performance under extreme heat in avocado, we examined the impact of a resilient high-density silver 60% shading net on mature ‘Pinkerton’ avocado trees during such conditions. We hypothesized that reduced solar irradiation will lower canopy temperature and improve tree performance. During extreme heat events, photosynthetic photon flux density (PPFD), air temperature ( $T_{air}$ ) and leaf temperature ( $T_{leaf}$ ) reached  $1188 \mu\text{mol m}^{-2} \text{s}^{-1}$ ,  $43.1 \text{ }^\circ\text{C}$  and  $43.8 \text{ }^\circ\text{C}$  in the control plots, respectively. In the net-covered plots, these parameters significantly decreased to  $401 \mu\text{mol m}^{-2} \text{s}^{-1}$ ,  $40.3 \text{ }^\circ\text{C}$  and  $39.8 \text{ }^\circ\text{C}$ , respectively. Interestingly, leaf  $\text{CO}_2$  assimilation, stomatal conductance to water vapor ( $g_s$ ) and substomatal internal  $\text{CO}_2$  concentration ( $C_i$ ) were significantly higher, by 94%, 120% and 13%, respectively, than in controls. On days with regular fall temperatures, PPFD,  $T_{air}$  and  $T_{leaf}$  reached  $814 \mu\text{mol m}^{-2} \text{s}^{-1}$ ,  $31.2 \text{ }^\circ\text{C}$  and  $31.6 \text{ }^\circ\text{C}$  in the control plots, respectively. In the net-covered plots, these parameters significantly decreased to  $291 \mu\text{mol m}^{-2} \text{s}^{-1}$ ,  $29.5 \text{ }^\circ\text{C}$  and  $29.4 \text{ }^\circ\text{C}$ , respectively. However, leaf  $\text{CO}_2$  assimilation was significantly (20%) lower,  $g_s$  was similar and  $C_i$  was 10% higher than in control trees. These findings suggest that silver 60% shading nets may potentially reduce heat stress during extreme heat events, calling for long-term studies on their effects on flowering and fruit set, load, size and quality.

**Keywords:** climate change; extreme heat; subtropical; *Persea americana*; carbon assimilation; stomatal conductance



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## 1. Introduction

Climate change, associated with global warming, is a worldwide phenomenon that presents negative impacts on global food production [1,2]. Climate change is expected to result in more frequent and severe heat waves, as global mean annual temperatures are predicted to increase by up to  $3 \text{ }^\circ\text{C}$  and  $4.8 \text{ }^\circ\text{C}$  by 2050 and 2100, respectively [3,4]. Plants may be severely damaged by high temperatures, sensed as heat stress (HS) [2]. HS may be harmful to plant development and eventually result in significant yield loss [5]. For example, HS may cause sunburns in leaves, branches and stems, leaf abscission, shoot and root growth inhibition, decreased fruit set, elevated fruit drop and reduced fruit quality [6]. Physiological effects of HS include inhibition of protein synthesis and degradation, enzymes inactivation, increased fluidity of membrane lipids and loss of membrane integrity. Furthermore, HS may impair crucial physiological processes in the plant, such as photosynthesis and respiration rates, stomatal conductance and leaf water homeostasis [7].

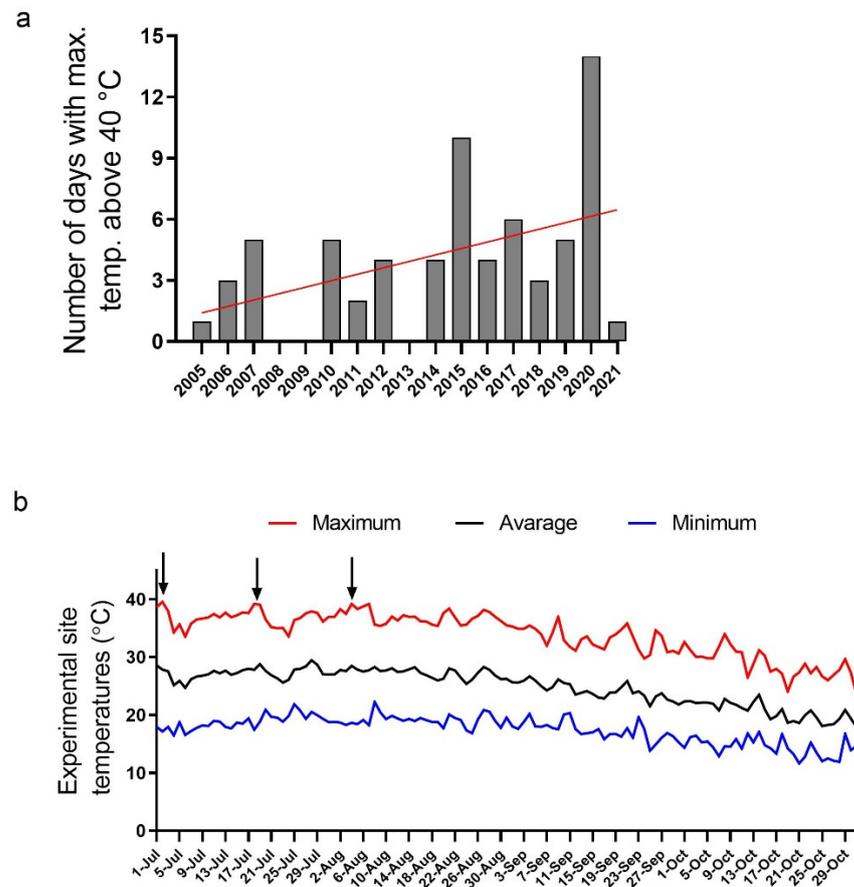
Avocado (*Persea americana* Mill.) is a commercially important subtropical fruit tree in many countries, with increasing worldwide demand [8,9]. In Israel, the avocado cultivation area covers 14,000 ha, with an annual growth of 1000 ha/year (data obtained from the Israeli avocado board, <http://www.plants.org.il/>, accessed on 1 March 2022). Although the black-skinned avocado cv. ‘Hass’ dominates world commerce [10], the green-skinned avocado cv. ‘Pinkerton’ accounts for 45% of the avocado cultivated in the north-eastern part of Israel (data obtained from the Israeli avocado board, <http://www.plants.org.il/>, accessed on 1 March 2022). In recent years, extreme climatic events, including frequent extreme heat events, significantly impaired avocado production in Israel. For instance, during the spring of 2020, an extreme and prolonged heat wave occurred, and the maximum daily air temperature in north-eastern Israel reached 45 °C (<https://ims.data.gov.il/>, accessed on 1 March 2022). As a result, avocado yields in the region decreased dramatically that year, causing major financial losses to both growers and packing houses (data obtained from Avocado Gal packing house in the Galilee). Besides yield loss, extreme heat events in avocado may severely damage and even destroy young trees. Damage to mature avocado trees may be milder, as some of the leaves, branches and fruits are shaded by the canopy. Thus, it is expressed primarily on exposed sides of the trees. In addition, fruits exposed to extreme heat may soften, sunburned and become unmarketable (<https://www.californiaavocadogrowers.com/cultural-management-library/managing-avocado-heat-damage>, accessed on 30 May 2022).

The efficiency of different HS mitigation measures has been examined in various crops [5]. Shading nets are commonly used to protect different crops from heat, as well as other harsh environmental hazards, such as cold, hail, wind and excess sunlight [11–16]. For example, a white 25% shading net reduced the HS effect on mature Washington navel orange trees in Egypt [17]. In another study, covering potted ‘Honeycrisp’ apple trees under HS and high light conditions with a blue 22% shading net reduced incoming solar radiation, improved leaf-level photosynthetic light-use efficiency and reduced the symptoms of photoinhibition [18]. Still, little is known about the ability of shading nets to mitigate the adverse effects of extreme heat climate events in avocado. We therefore examined the impact of shading nets on physiological parameters of mature avocado trees during extreme heat events. Specifically, we aimed to investigate the effect of the shading nets on (i) micro-climatic parameters and (ii) leaf gas-exchange parameters. As the combination of high temperature and high irradiance has been shown to increase plant stress [19], the hypothesis of this study was that reduced solar radiation will result in lower canopy temperature and improved the physiological performance of the trees. In this study, we tested the effect of a resilient high-density woven silver 60% shading net, which had shown positive effects in preliminary measurements (data not shown). As controlled experiments do not fully simulate field conditions, we chose to perform this experiment in a commercial avocado orchard.

## 2. Materials and Methods

### 2.1. Experimental Site

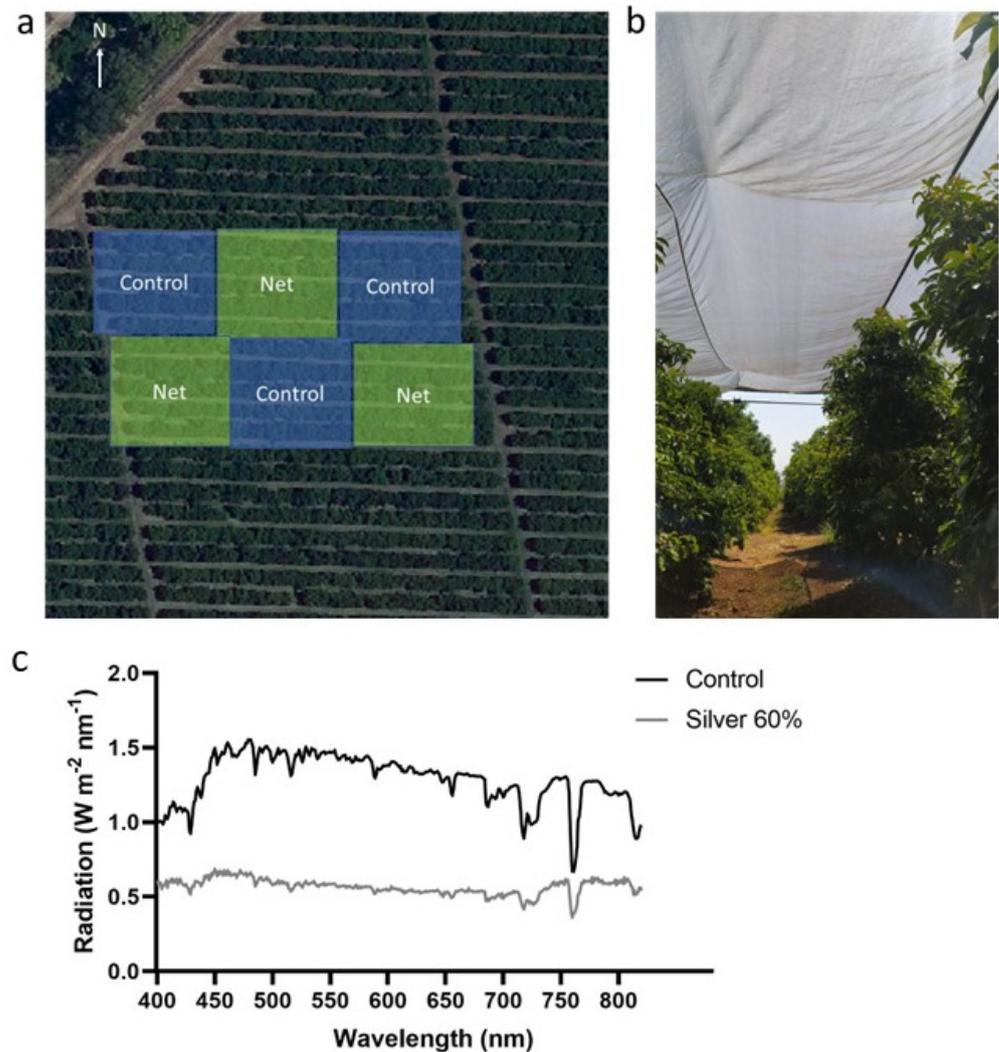
The experiment was conducted from July to October of 2021 in a 0.6-ha commercial ‘Pinkerton’ avocado plot located in Kibbutz Mahanaim in northeastern Israel (32°98′ N; 35°56′ E, 285 m a.s.l.). The trees were planted in 2007 with 6 m spacing between rows and 3.5 m between trees. The rows were oriented east–west. The experimental site was chosen in a location with high HS risk. Data from a nearby weather station showing the number of days on which maximum air temperature exceeded 40 °C (Figure 1a) indicated the increasing frequency of extreme heat waves in the last 16 years. Maximum, average and minimum air temperatures at the experimental site from the beginning of July to the end of October 2021 are shown in Figure 1b. Extreme climatic heat events, characterized by high temperatures along with high light intensity, occurred in the experimental orchard mainly during the summer, in July and August.



**Figure 1.** Increasing frequency of extreme heat waves over the last 16 years and experimental site temperatures. (a) Daily maximum temperatures recorded from January 2005 to October 2021 at Amiad station, close to the experimental site. The graph shows the number of days on which maximum temperature exceeded 40 °C. Nonlinear regression is drawn with a red line. (b) Maximum, average and minimum air temperatures collected by Hobo temperature data loggers at the experimental site from beginning of July to end of October 2021. Arrows indicate days with highest air temperatures.

## 2.2. Shading Nets and Experimental Design

Combined (woven) Leno 5039 pearl/silver 60% shading nets (Silver 60%, Ginegar Plastic Products Ltd., Ginegar, Israel) were chosen for the experiment. The shading nets were supported by a metal construction built over the trees in the treatment plots (net-covered, Figure 2). Trees from the control plots were not covered with shading nets (control treatment). The experimental plots were randomized, with 3 repeats for each treatment and 0.1 ha for each plot. The shading nets were deployed over the canopy only on selected days from early July through the end of October 2021. During extreme heat events, the nets were deployed a day before the anticipated temperature. Nets were also deployed during days with regular fall temperatures.



**Figure 2.** The experimental avocado plot and solar irradiation spectra. Experimental plots were completely randomized, with three 0.1-ha repeats for each treatment (a); control/net). Picture taken in August 2021, during an actual extreme heat event (b). Spectra of total solar irradiation under the silver 60% shading nets and control (sunlight) were measured at midday in August 2021 (c). Values are means of five replicates for each of the two treatments.

### 2.3. Light Spectrum Measurements

Spectra of the total solar radiation under the shading nets and in the control plots (sunlight) were measured at midday in August 2021 using a field spectrometer (SS-110 VIS range spectroradiometer, Apogee Electronics, Santa Monica, CA, USA). Before the measurements, dark balance was performed with the light-sealed cap supplied with the sensor. At least five different measurements were performed for each treatment.

### 2.4. Leaf Light Intensity, Temperature, and Gas-Exchange Measurements

Continuous under-canopy air temperature data were collected by Hobo temperature data loggers (catalogue no. UA-001-64; Onset Corp., Bourne, MA, USA) that were placed 2 m above the ground and shaded from radiation.

Leaf measurements for both the control and net-covered treatments were taken from 4 different trees in the middle of each of the 3 repeats ( $n = 12$ ). All measured trees had similar external general phenological characterizations. Measurements were taken and averaged from at least 4 mature leaves per tree. All measured leaves were positioned 4 to 5 leaves from the branch tip. Measured branches were selected from the southern face of the trees,

around 1.5 m above the ground. Data are presented as a grand mean of all trees in the same treatment group ( $n = 12$ ).

Leaf-level temperature, photosynthetic photon flux density (PPFD), CO<sub>2</sub> assimilation and transpiration rates were measured using a LI-6800 portable photosynthesis system (clear-top 9 cm<sup>2</sup> chamber, LI-COR, Lincoln, NE, USA). CO<sub>2</sub> fed into the leaf chamber was set to 400 ppm, the air flow into the chamber was 1000 μmol s<sup>-1</sup>, and boundary-layer conductance to water vapor was ~3 mol m<sup>-2</sup> s<sup>-1</sup>. Chamber climatic conditions (temperature and relative humidity) were set to ambient. Measurements were performed in the orchard at midday on mature attached leaves. Only leaves facing the sun at the time of measurement were measured, and care was taken not to change their orientation to the sun while inside the chamber. Stomatal conductance to water vapor ( $g_s$ ) and sub-stomatal internal CO<sub>2</sub> concentration ( $C_i$ ) were calculated by the LI-COR device.

To evaluate the effect of the shading nets on trees during potential HS, leaf measurements were taken on 18 July and 4 August, during extreme heat events. To evaluate the effect of the shading nets on trees without HS, leaf measurements were taken on 25 and 26 October, during regular fall temperatures. To compare the performance of the trees from the different experimental plots, leaf measurements were also taken from the control and net-covered plots on days with regular fall temperatures (14 and 21 October), but without deploying the nets. During these measurements, trees from the net-covered plots were termed 'net-uncovered'. It is important to note that during March 2021 trees were intensively pruned. As a consequence, flowering intensity during spring was very low (data not shown). Thus, during all of the above measurements, fruit load on the trees of both plots (net and control) was similar and very low (data not shown).

### 2.5. Statistical Analysis

All results from the same measurement time points were subjected to an unpaired *t*-test using GraphPad Prism version 9.1.2. software (GraphPad Software, LLC, San Diego, CA, USA).

## 3. Results

To characterize the effects of shading nets on micro-climatic and physiological parameters, measurements were taken from control (uncovered) and covered trees during two naturally occurring climatic events of extreme heat: 18 July 2021 and 4 August 2021. Measurements were also taken from the same trees on days with regular fall temperatures, with or without the net cover.

### 3.1. Effect of Shading Nets on the Solar Spectrum, Photosynthetic Photon Flux Density (PPFD), and Air and Leaf Temperatures

Solar spectrum measurements showed a similar radiation pattern for the control and net treatments, but with differences in the radiation intensity (Figure 2c). At all wavelengths, the net transmitted less light than the control (sunlight). Standard error values of the measurements ranged between 0.00041 to 0.0024 W m<sup>-2</sup> nm<sup>-2</sup> in the control and 0.00087 to 0.0065 W m<sup>-2</sup> nm<sup>-2</sup> in the Silver 60%.

During the extreme heat event of 18 July 2021, PPFD measured by the LI-COR system reached 1188 μmol m<sup>-2</sup> s<sup>-1</sup> in the uncovered (control) plots, and only 401 μmol m<sup>-2</sup> s<sup>-1</sup> in the net-covered plots, which was significantly lower (by ~66%) (Table 1). Air temperature ( $T_{air}$ ) measured by the Li-6800 in the control plots reached 43.1 °C, and was significantly lower, by about 3 °C, in the net-covered plots (Table 1). Continuous measurements by the Hobo data loggers show a similar trend, as daytime air temperature was generally lower in the net covered plots compared to the control plots (Figure S1a). Leaf temperature ( $T_{leaf}$ ) of the control trees reached 43.8 °C, and was significantly lower, by about 4 °C, on the trees of the net-covered plots (Table 1). Similar results were obtained for the extreme heat event of 4 August 2021 (Table 1 and Figure S1b).

**Table 1.** Effects of shading nets on solar irradiation incident on the leaves, air and leaf temperatures, CO<sub>2</sub> assimilation, stomatal conductance and sub-stomatal internal CO<sub>2</sub> concentration measured and calculated by the LI-COR system. Parameters were measured in the orchard at midday during an extreme heat event (+extreme heat) when nets were deployed (18 July and 4 August 2021) and under regular fall temperatures (-extreme heat) when nets were deployed (25 and 26 October 2021) or not deployed (14 and 21 October 2021). PPFD—photosynthetic photon flux density; T<sub>air</sub>—air temperature; T<sub>leaf</sub>—leaf temperature; A—CO<sub>2</sub> assimilation; g<sub>s</sub>—stomatal conductance to water vapor; and C<sub>i</sub>—substomatal internal CO<sub>2</sub> concentration. Measurements were taken from trees that were not covered (control or net-uncovered) or covered with silver 60% shading net (net-covered). Each treatment was replicated three times with four different trees per replicate. Values are means ± SE of 12 trees (*n* = 12, at least four different leaves were measured from each tree). Treatments marked with an asterisk differ significantly (unpaired *t*-test, \* *p* < 0.05; \*\* *p* < 0.01; \*\*\* *p* < 0.001; \*\*\*\* *p* < 0.0001; NS, not significant).

	Date	Parameter \ Treatment	PPFD ( $\mu\text{mol m}^{-2}\text{s}^{-1}$ )	T <sub>air</sub> (°C)	T <sub>leaf</sub> (°C)	A ( $\mu\text{mol m}^{-2}\text{s}^{-1}$ )	g <sub>s</sub> ( $\text{mol m}^{-2}\text{s}^{-1}$ )	C <sub>i</sub> ( $\mu\text{mol mol}^{-1}$ )
+extreme heat	18.7.2021	Control	1188 ± 27	43.1 ± 0.3	43.8 ± 0.3	3.8 ± 0.6	0.06 ± 0.01	237 ± 12
		Net-covered	401 ± 12 ****	40.3 ± 0.5 ***	39.8 ± 0.4 ****	7.34 ± 0.6 ***	0.14 ± 0.02 **	267 ± 7 *
	4.8.2021	Control	1190 ± 53	41.6 ± 0.4	42.3 ± 0.4	3.25 ± 0.4	0.08 ± 0.01	299 ± 6
		Net-covered	440 ± 11 ****	28.6 ± 0.8 **	38 ± 0.8 ****	7.77 ± 0.7 ****	0.18 ± 0.02 ****	293 ± 6 <sup>NS</sup>
-extreme heat	25.10.2021	Control	814 ± 39	31.3 ± 0.2	31.6 ± 0.2	13.2 ± 0.5	0.2 ± 0.01	259 ± 5
		Net-covered	291 ± 23 ****	29.6 ± 0.3 ***	29.4 ± 0.3 ****	10.66 ± 0.7 ***	0.2 ± 0.02 <sup>NS</sup>	287 ± 3 ****
	26.10.2021	Control	693 ± 29	30.2 ± 0.4	30.7 ± 0.4	12.29 ± 0.8	0.19 ± 0.02	256 ± 3
		Net-covered	229 ± 18 ****	28.3 ± 0.3 **	28.1 ± 0.3 ***	10.59 ± 0.7 <sup>NS</sup>	0.2 ± 0.01 <sup>NS</sup>	284 ± 7 **
	14.10.2021	Control	800 ± 19	35.5 ± 0.2	35.7 ± 0.2	10.24 ± 0.7	0.17 ± 0.01	260 ± 3
		Net-uncovered	775 ± 26 <sup>NS</sup>	35.2 ± 0.4 <sup>NS</sup>	25.3 ± 0.3 <sup>NS</sup>	9.84 ± 0.6 <sup>NS</sup>	0.17 ± 0.01 <sup>NS</sup>	270 ± 5 <sup>NS</sup>
21.10.2021	Control	1062 ± 35	34.9 ± 0.2	34.8 ± 0.3	9.46 ± 0.9	0.13 ± 0.02	238 ± 7	
	Net-uncovered	1127 ± 35 <sup>NS</sup>	33.4 ± 0.2 <sup>NS</sup>	34.2 ± 0.3 <sup>NS</sup>	11.06 ± 0.7 <sup>NS</sup>	0.16 ± 0.01 <sup>NS</sup>	244 ± 6 <sup>NS</sup>	

Measurements were also gathered from net-covered and control trees during October 2021, on days with regular fall temperatures. On 25 October 2021, PPFD reached 814  $\mu\text{mol m}^{-2}\text{s}^{-1}$  in the control plots and only 291  $\mu\text{mol m}^{-2}\text{s}^{-1}$  in the net-covered plots, which was significantly lower (by ~64%) (Table 1). T<sub>air</sub> in the control plots reached 31.3 °C, whereas in the net-covered plots, it was significantly lower, by about 1.7 °C (Table 1). Continuous measurements by the Hobo data loggers show a similar trend, as daytime air temperature was generally lower in the net covered plots compared to the control plots (Figure S1c). T<sub>leaf</sub> of the control trees reached 31.6 °C; in the net-covered plots it was significantly lower, by about 2.2 °C (Table 1). Similar results were obtained on 26 October 2021, which also had regular fall temperatures (Table 1 and Figure S1d).

Additional measurements were taken during October 2021 on days with regular fall temperatures. This time, the trees from the net treatment were not covered with the shading nets (net-uncovered) to determine whether the differences between the control and net trees were related to the specific plots or to the particular treatment. On 14 October 2021, PPFD in both plots was about 800  $\mu\text{mol m}^{-2}\text{s}^{-1}$  (Table 1). T<sub>air</sub> and T<sub>leaf</sub> were similar for both plots and reached ~35 °C (Table 1). Continuous measurements by the Hobo data loggers show a similar trend, as daytime air temperature was generally similar in both plots (Figure S1e). Similar results were obtained on 21 October 2021 (Table 1 and Figure S1f).

### 3.2. Effect of Shading Nets on Gas-Exchange Parameters

During the extreme heat event of 18 July 2021, no apparent external leaf damage was observed on either control or net-covered trees (data not shown). CO<sub>2</sub> assimilation rate in the leaves of control trees reached 3.8  $\mu\text{mol m}^{-2}\text{s}^{-1}$ , whereas that in leaves of the net-covered trees was significantly higher, by 94%, reaching 7.34  $\mu\text{mol m}^{-2}\text{s}^{-1}$

(Table 1). Stomatal conductance to water vapor ( $g_s$ ) in the leaves of control trees reached  $0.06 \text{ mol m}^{-2} \text{ s}^{-1}$ , whereas  $g_s$  in the leaves of the net-covered trees was significantly higher, by 120%, reaching  $0.14 \text{ mol m}^{-2} \text{ s}^{-1}$  (Table 1). Substomatal internal  $\text{CO}_2$  concentration ( $C_i$ ) in the leaves of control trees was  $237 \text{ } \mu\text{mol mol}^{-1}$ , and in leaves of the net-covered trees, it was significantly higher, by 13% (Table 1). Similar results were obtained during the extreme heat event of 4 August 2021, except that there was no significant difference in  $C_i$  value between the net-covered and control trees (Table 1).

Measurements taken on 25 October 2021 (regular fall temperatures) showed  $\text{CO}_2$  assimilation rates of up to  $13.2 \text{ } \mu\text{mol m}^{-2} \text{ s}^{-1}$  in leaves from the control trees. In leaves from the net-covered trees, assimilation rate reached  $10.66 \text{ } \mu\text{mol m}^{-2} \text{ s}^{-1}$ , significantly lower, by 20%, than in the control trees (Table 1).  $g_s$  in the leaves of control and net-covered trees was similar, reaching  $0.2 \text{ mol m}^{-2} \text{ s}^{-1}$  (Table 1).  $C_i$  in the leaves of control trees was  $259 \text{ } \mu\text{mol mol}^{-1}$ ; that in the leaves of the net-covered trees was significantly higher, by 10% (Table 1). Similar results were obtained on 26 October 2021, except that there was no significant difference in assimilation rate between the net-covered and control trees (Table 1).

Measurements taken on 14 October 2021 (regular fall temperatures without deploying the nets) gave a similar  $\text{CO}_2$  assimilation rate for the leaves of control and net-uncovered trees of  $\sim 10 \text{ } \mu\text{mol m}^{-2} \text{ s}^{-1}$  (Table 1).  $g_s$  was also similar for both treatments, reaching  $0.17 \text{ mol m}^{-2} \text{ s}^{-1}$  (Table 1).  $C_i$  for the leaves of trees from both treatments was similar, ranging between 260 and  $270 \text{ } \mu\text{mol mol}^{-1}$  (Table 1). Similar results were obtained on 21 October 2021 (Table 1).

#### 4. Discussion

This study examined the effects of covering mature ‘Pinkerton’ avocado trees with silver 60% shading nets on micro-climatic and leaf physiological parameters on days with or without extreme heat events. The results from extreme heat events and days with regular fall temperatures indicated that the silver 60% shading net significantly reduces PPFD by about 65% and cools air and leaf temperatures by up to  $4 \text{ } ^\circ\text{C}$  (Table 1). This is not surprising, as these environmental conditions are notably reduced by shading nets [20]. For example, PPFD was decreased by about 20%, and maximum leaf temperature was also significantly reduced by  $4 \text{ } ^\circ\text{C}$  in apple orchards covered with pearl 20% shading nets [21]. Still, the reduction of  $4 \text{ } ^\circ\text{C}$  observed under the silver 60% shading net may be critical for avocado tree performance. For example, results from our recent study showed that the heat-damage threshold for young potted avocado plants under low light conditions is between  $49 \text{ } ^\circ\text{C}$  and  $51 \text{ } ^\circ\text{C}$  [7]. Moreover, no damage or severe and irreversible leaf damage occurs following exposure to  $47 \text{ } ^\circ\text{C}$  or  $53 \text{ } ^\circ\text{C}$ , respectively. Thus, the shading net’s ability to reduce air and leaf temperature, even by a few degrees, may potentially significantly reduce HS damage in mature avocado trees. It is important to note that LI-COR air temperature measurements are usually higher than the actual air temperature; hence, LI-COR leaf temperature measurements may not accurately represent actual leaf temperature. Still, differences in air and leaf temperature were consistent throughout the measuring days, thus strengthening the impact of the shading nets in reducing canopy temperatures (Table 1 and Figure S1). It is also important to note that the combination of high light intensity and high temperature may have a synergistic adverse effect on the integrity and activity of the photosynthetic system, higher than that of each individual stress alone [19]. Thus, the significant reduction in PPFD by the silver 60% shading net may have further positive effects in alleviating avocado HS under field conditions.

Under ambient conditions, assimilation rate is generally positively correlated with increasing PPFD, up until a certain point at which a further increase in light fails to increase photosynthesis [22]. Interestingly, this study demonstrated that during extreme heat events, assimilation rates and  $g_s$  were significantly lower in leaves of the control trees vs. net-covered trees, even though PPFD was higher. These phenomena suggest that covering the trees with silver 60% shading nets managed to improve photosynthetic performance under

extreme heat conditions, which may indicate a reduction in HS-related symptoms, such as damage to the photosynthetic system [7]. Similar results were found in other studies; for example, in orange and grapefruit plants, shading nets were effective in alleviating HS and higher CO<sub>2</sub> assimilation and stomatal conductance rates were observed in the net-covered plants vs. the uncovered control plants [23,24]. In addition, shading nets managed to increase photosynthesis rate and stomatal conductance in young orange trees during summer days with high temperatures accompanied with high solar irradiation rates, in southern Israel [25]. The relatively elevated C<sub>i</sub> (under reduced g<sub>s</sub> and high light) in the control trees (Table 1) suggests that photosynthesis is constrained. We speculate that this constraint in photosynthesis can be due to elevated respiration rates and/or by the deactivation of rubisco due to HS [26,27]. Supporting this idea, similar gas-exchange parameters were measured on days with regular fall temperatures when none of the trees were covered with shading nets (Table 1). Similar results were also shown in a study conducted in southeast Spain, where white shading nets with 76% light transmission elevated net photosynthesis and stomatal conductance in lime trees during the summer, suggesting that it may be considered an alternative to open air for use in semi-arid areas threatened by climate change [28]. Still, as the assimilation rate decreased by 20% in the net-covered trees compared to the control trees on days with regular fall temperatures (Table 1), high-density shading nets are likely to have a negative effect on tree growth and development if deployed for long periods. They may also lead to reduced yields by inducing vegetative growth over productivity [29].

A previous study showed that covering 'Reed' avocado trees during the winter with silver 50% or silver 70% shading nets may also alleviate cold stress [14]. Therefore, from a broader perspective, use of the silver 60% shading nets during both winter and heat events in spring and summer may be beneficial for avocado growers. The proposed use of the same net for both adverse climatic conditions may be simpler and more economical than using a different net for each stress.

## 5. Conclusions

In conclusion, this study confirmed our hypothesis that covering mature 'Pinkerton' avocado trees with silver 60% shading nets during extreme heat events significantly reduces both air and leaf temperatures, as well as solar irradiance, in turn elevating leaf carbon-assimilation rate and stomatal conductance. However, whether the positive effects of the shading net on the trees were due to the reduction of air temperature or solar irradiation, or a combination of the two, remains unclear. To answer this question, further experiments should be conducted under controlled-climate conditions, in which the effects of each parameter and their combined effects can be studied. Solar spectrum measurements showed differences in the radiation intensity, but not in its spectral quality, between sunlight and the light under a silver 60% shading net (Figure 2c). Thus, it is possible that the use of different nets with similar shading rates and spectral quality may also show an improvement in photosynthetic performance under extreme heat conditions in avocado orchards [25]. As data show that the frequency of extreme heat waves has increased over the last 16 years (Figure 1), follow-up long-term studies should be carried out to examine the effects of shading nets and other shading strategies on avocado tree stress related markers and gas-exchange parameters, as well as production parameters such as flowering, fruit set and eventually, fruit load, size and quality [30].

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/agronomy12061360/s1>, Figure S1: Continuous under-canopy air temperature.

**Author Contributions:** Methodology, E.A. and L.R.; Validation, E.A. and L.R.; Conceptualization, O.S., T.A.-S. and L.R.; Writing—Original Draft Preparation, O.S., T.A.-S. and L.R.; Writing—Review & Editing, O.S., T.A.-S. and L.R.; Formal Analysis, L.R.; Investigation, L.R.; Funding Acquisition, L.R.;

Supervision, L.R.; Project Administration, L.R. All authors have read and agreed to the published version of the manuscript.

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