

# Decrease in artificial radiation with netting reduces stress and improves rabbit-eye blueberry (*Vaccinium virgatum* Aiton) 'Ochlockonee' productivity

Jorge Retamal-Salgado<sup>1\*</sup>, Robert Vásquez<sup>1</sup>, Susana Fischer<sup>2</sup>, Juan Hirzel<sup>3</sup>, and Nelson Zapata<sup>2</sup>



## ABSTRACT

Blueberry production under netting has increased in recent years to mitigate the adverse effects of climate change. The objective of the present study was to evaluate the effect of different radiation intensities on rabbit-eye blueberry (*Vaccinium virgatum* Aiton) 'Ochlockonee' photosynthetic efficiency and productive parameters. Four treatments were established: T1 (control), T2, T3, and T4 at 0%, 30%, 60%, and 90% radiation decrease (RD), respectively, with black shedding netting. The following were recorded for each treatment: environmental conditions, photosystem II (PSII) maximum quantum yield ( $F_v/F_m$ ), photosystem II effective quantum yield ( $\Phi_{PSII}$ ), leaf stomatal conductance ( $g_s$ ), quality parameters, and fruit yield. Results showed an increase of 4.6 °C in mean minimum temperatures for the different netting treatments, which promote development and fruit set, as well as prevent damage at temperatures near 0 °C. The RD treatments increased  $\Phi_{PSII}$  between 175% and 325% ( $P < 0.05$ ) compared to the control. It can be concluded that netting decreased soil temperature between 1 and 3 °C and increased minimum temperatures between 1 and 6 °C, which promoted plant development and decreased frost damage during flowering and fruit development. Current direct radiation levels over 1000  $\mu\text{mol m}^{-2} \text{s}^{-1}$  in *V. virgatum* inhibited productivity in T1. Netting decreased the degree of photoinhibition and increased photosystem II photochemical efficiency throughout the day, and T4 and T3 exhibited the highest efficiency.

**Key words:** Photosystem II, photoinhibition, photosynthetically active radiation, stomatal conductance.

<sup>1</sup>Universidad Adventista de Chile, Facultad de Ingeniería y Negocios, km 12 camino a Tanilvorro, Chillán, Chile.

\*Corresponding author (joretama@gmail.com).

<sup>2</sup>Universidad de Concepción, Facultad de Agronomía. Av. Vicente Méndez 595, Chillán, Chile.

<sup>3</sup>Instituto de Investigaciones Agropecuarias, INIA Quilamapu. Av. Vicente Méndez 515, Chillán, Chile.

Received: 17 April 2017.

Accepted: 23 June 2017.

doi:10.4067/S0718-58392017000300226

## INTRODUCTION

Blueberry production under plastic cover and photosensitive netting has increased considerably in recent years. These covers selectively filter direct solar radiation by modifying the amount of radiation passing through them (Bastías et al., 2012b). In addition to this protective function against radiation, this technique could be increasingly needed to mitigate adverse effects of climate change on fruit trees (Demchak, 2009). At the same time, it has been observed that production under netting generates environmental changes in temperature and relative humidity; both factors play an important role in physiological parameters, such as stomatal conductance ( $g_s$ ), transpiration rate, and plant photosynthesis (Bastías et al., 2012a). Bassett et al. (2006) point out that photosensitive netting substantially reduces environmental temperature and generates morphological and physiological variations in the plant, which could lead to late production of fruit ripening. Colored netting generates a spectral modification that promotes light-regulated physiological responses; it delays photoassimilate partitioning up to 3 wk compared to shoots exposed to full light and affects fruit growth (Corelli-Grappadelli, 2003). This management technique postpones the harvest period and the delay can be taken advantage of as a management alternative in blueberry orchards by covering the late demand for this fruit and achieving better sales prices (Demchak, 2009). Studies conducted with other fruit tree species have suggested that reduced radiation levels positively affect net plant photosynthesis by increasing  $g_s$  and intercellular  $\text{CO}_2$  concentration (Corelli-Grappadelli and Lakso, 2007). Decreased photosynthetically active radiation (PAR) availability can also induce an altered phytochrome response, which alters shoot elongation and leaf area (Bastías et al., 2012a). However, increased leaf area could generate a decrease in PAR availability within the canopy because of excessive shading by the photosensitive netting, which can become a limiting factor in blueberry production (Sandri et al., 2003). In highbush blueberries, a reduction of up to 40% in PAR light intensity would not affect photosynthetic efficiency of plants (Lobos et al., 2012). It has been demonstrated in other species that photosynthetic capacity can increase when PAR decreases and reduce photoinhibition caused by excessive radiation, which would improve the photochemical efficiency of photosystem (PS) II (Medina et al., 2002).

In countries such as the USA, Switzerland, Germany, Italy, and Spain, netting has been necessary to decrease damage



generated by extreme climatic conditions (rain, hail, high temperatures, and excessive radiation), as those observed in Chile in recent years (Lobos et al., 2012; 2013; Retamal-Salgado et al., 2015). This should affect not only environmental and soil conditions (Bastías et al., 2012b; Cowan et al., 2014), but also in the photosynthetic apparatus (Lobos et al., 2013). Therefore, the objective of the present study was to evaluate the effect of different radiation intensities on chlorophyll fluorescence variations, fruit quality and productive parameters in blueberry (*Vaccinium virgatum* Aiton) 'Ochlockonee' plants.

## MATERIALS AND METHODS

### Study location and treatments

The research study was conducted in the 2015-2016 season in a commercial blueberry 'Ochlockonee' orchard established in 2013 and located in Santa Bárbara (39°55' S, 41°16' W), Los Ángeles, Chile. The soil type is isotopic typic Xeropsamments with parent material of sandy volcanic origin (Stolpe, 2006).

A randomized complete block design was used and four radiation intensity treatments were established: T1, control (without radiation decrease), T2, 30% radiation decrease (RD), T3, 60% RD, and T4, 90% RD. Each treatment was carried out with four replicates. Black shedding netting was used to establish the treatments (Malla raschel, Polytex, Santiago, Chile).

A 2.5 m high, 9 m wide, and 5 m long wood structure was used to implement the experiment. Each treatment included four plants, and the two central plants of each experimental unit were evaluated. Each block consisted of 16 plants and 64 plants in the study. Treatments were implemented 20 d before full flowering and were coded with a yellow plastic identification tape. Agronomic management was standardized for the four treatments for phytosanitary control, fertilization, and irrigation. To increase pollination effectiveness, this process was supported by introducing seven bumblebees (*Bombus terrestris*) beehives ha<sup>-1</sup> in all the treatments (Natupol, Class C hive, Koppert Biological Systems, Berkel en Rodenrijs, The Netherlands).

### Characterization of environmental conditions

Air temperature ( $T_a$ , °C) and relative humidity (RH, %) were recorded for each treatment every 15 min during the whole crop development from 0 to 70 d after flowering (DAF) with automatic Key Tag model sensors (KeyTag Recorders, Leiderdorp, The Netherlands) located 1.5 m above ground level. The variation of light conditions was quantified in terms of incident PAR over the plant according to the method proposed by Al-Helal and Abdel-Ghany (2010), with an AccuPAR LP-80 ceptometer (Decagon Devices, Pullman, Washington, USA) that provides a mean of 80 quantum sensors. Photosynthetically active photon flux density (PPFD,  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) was measured three times per day at 09:00, 12:00, and 15:00 h under

clear environmental conditions. Likewise, soil temperature ( $T_s$ ; °C) was measured with a digital thermometer (Multi Thermometer, Shanghai, China) three times per day (09:00, 12:00, and 15:00 h); the instrument was located at 0.1 m depth over the row and between the plants of each treatment. Leaf temperature ( $T_L$ , °C) was estimated with a portable OS5p fluorometer (Opti-Sciences, Hudson, New Hampshire, USA) at 09:00, 11:00, 13:00, 15:00, and 17:00 h; exposed leaves in the second third of the season offshoot were considered for all treatments.

### Chlorophyll fluorescence and stomatal conductance

Maximum chlorophyll fluorescence ( $F_m$ ) and minimum fluorescence intensity ( $F_o$ ) were measured with a portable model OS5p fluorometer (Opti-Sciences, USA) five times on a clear day (09:00, 11:00, 13:00, 15:00, and 17:00 h) according to Kooten and Snel (1990). Mature leaves exposed to the sun and shoots of the season located in the second third of the offshoot were evaluated; 10 measurements per plant were taken on different leaves because of their natural variability (Cordon et al., 2016). For all the photosystem II maximum quantum yield ( $F_v/F_m$ ) measurements, the evaluated leaves were adapted to darkness for 30 min (Retamal-Salgado et al., 2015), and leaf clips with a movable shutter plate were used for this procedure. The photosystem II (PSII)  $F_v/F_m$  was quantified with these indicators by the following relationship proposed by Kooten and Snel (1990) and Maxwell and Johnson (2000):  $F_v/F_m = (F_m - F_o)/F_m$ . The degree of photoinhibition was quantified by the  $F_v/F_m$  relationship at different times of day compared to the value recorded in the morning. Simultaneously, and with the same frequency and equipment used for the  $F_v/F_m$  measurements, PSII effective quantum yield ( $\Phi_{\text{PSII}}$ ) and electron transport rate (ETR) in light-adapted leaves were calculated (Maxwell and Johnson, 2000). Along with the chlorophyll fluorescence measurements, stomatal conductance ( $g_s$ ,  $\text{mmol m}^{-2} \text{s}^{-1}$ ) was determined with a portable model SC-1 leaf porometer (Decagon Devices, USA). The  $g_s$  measurements were performed on completely illuminated leaves on the same plants, shoots, location, and frequency as those used to calculate chlorophyll fluorescence (Retamal-Salgado et al., 2015).

### Determination of productive parameters, fruit quality, and leaf and chlorophyll indices

Total fruit weight per plant was calculated at the beginning of the harvest. Fruit harvest was carried out according to fruit maturity (100% blue) and fruit weight was determined with a precision balance (Precisa Instruments AG, Dietikon, Switzerland) and corresponding to the average of five harvests. In parallel, measurements fruit firmness (F) was performed, which corresponds to grams of force to deflect or deform a millimeter the diameter of the fruit ( $\text{gf mm}^{-1}$ ), using a Berriteck firmness meter (model Berriteck Cv2, Universidad de Concepción, Chillán, Chile). For the measurements of F, 30 fruits were collected at each harvest randomly for each treatment and repetition; the measurements were performed immediately after the

fruits were harvested. Leaf chlorophyll content, quantified as SPAD units, was determined on the same day as leaf fluorescence and  $g_s$ . Chlorophyll index readings were taken with a chlorophyll meter (Minolta SPAD-502DL Plus, Konica Minolta, Osaka, Japan) equipment, which quantitatively evaluates the intensity of leaf green color (650 a 940 nm). Readings always occurred at 12:00 h and the mean of two plants per treatment was obtained by measuring 10 leaves per plant and 20 leaves for each treatment (Cunha et al., 2015). The leaf area index (LAI) was estimated with a ceptometer (AccuPAR LP-80, Decagon Devices, USA). Measurements of LAI and chlorophyll fluorescence were both taken at 12:00 h (Sonntag et al., 2007) and the mean of two plants per treatment was calculated.

### Statistical analysis

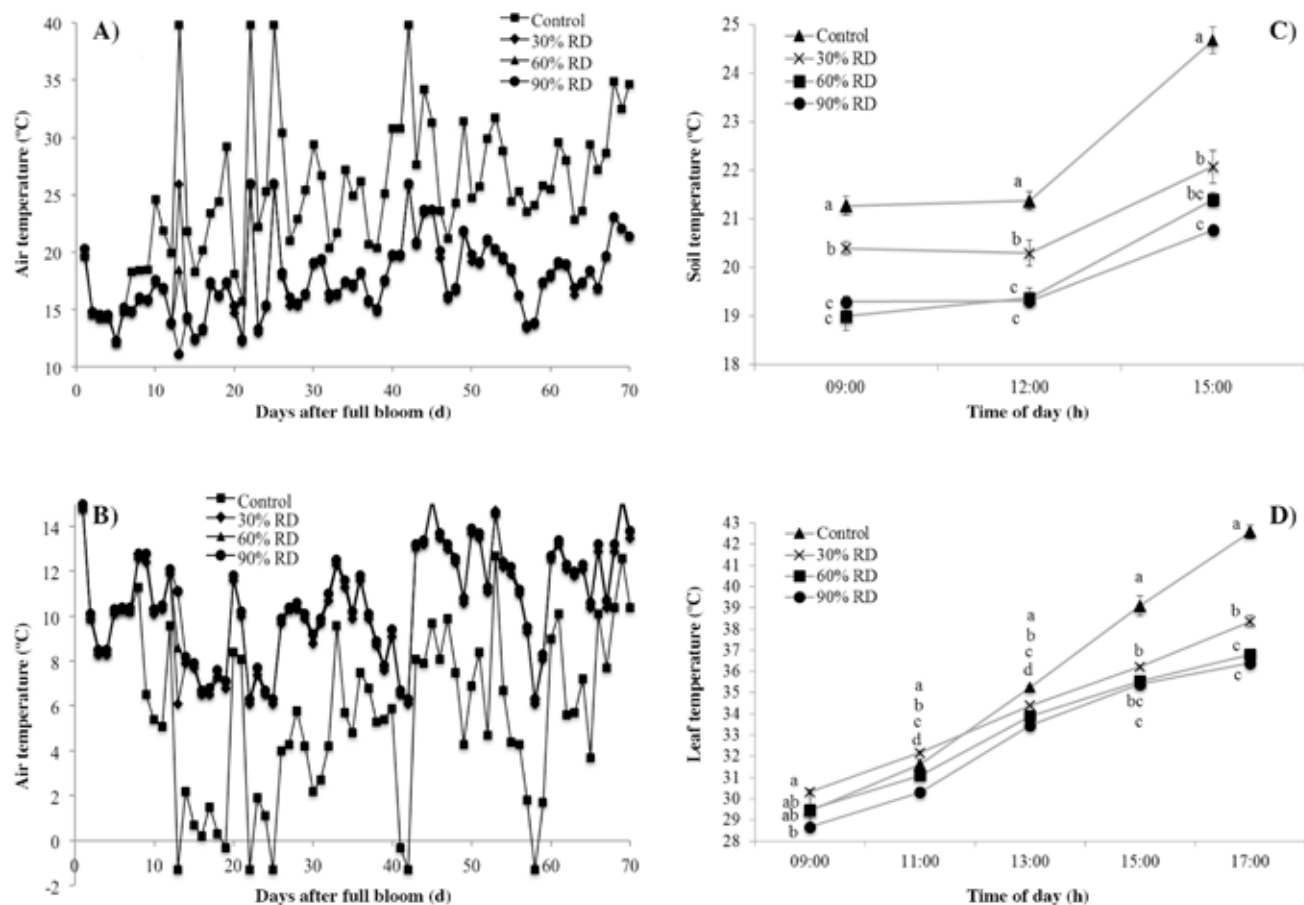
The effect of the treatments was estimated by a one-way ANOVA and Tukey's test ( $P \leq 0.05$ ). The statistical analysis of data was performed with the general SAS model (SAS Institute, 1989).

## RESULTS AND DISCUSSION

### Environmental parameters and plant temperature

Figure 1A shows the maximum  $T_a$  recorded during the period of development of the fruit under different radiation intensities;  $T_a$  was higher in T1 at 7.6 °C ( $P < 0.05$ ) compared to the different RD treatments, which had nonsignificant differences between RD treatments ( $P > 0.05$ ). The maximum  $T_a$  mean was 25.2, 17.7, 17.7, and 17.7 °C for the control, 30%, 60%, and 90% RD treatments, respectively. The maximum  $T_a$  recorded in the present study concur with findings described by various authors (Zhang et al., 2004; Lobos et al., 2013). They point out that this decrease in maximum  $T_a$  in the different shade treatments, observed in the present study (Figure 1A), would delay crop development because the crop development optimal temperature decreases and which fluctuates between 21 and 28 °C (Kirk and Isaacs, 2012; Retamales and Hancock, 2012).

**Figure 1.** Diurnal responses for different radiation intensities on maximum air temperature<sup>†</sup> (A), minimum air temperature<sup>†</sup> (B), soil temperature (C), and leaf temperature (D).



For each time of day, different lower-case letters indicate significant differences for different shade intensities according to Tukey's test ( $P < 0.05$ ). For C and D, vertical bars refer to  $\pm$  standard deviation of the mean ( $n = 32$ ).

RD: Radiation decrease.

<sup>†</sup>Curves of T2, T3 and T4, are on top of each other.

On the other hand, Figure 1B displays minimum  $T_a$  values recorded at different times of day under different radiation intensities and highlights that the mean minimum  $T_a$  in the different RD treatments was 4.6 °C higher than the control ( $P < 0.05$ ). Mean minimum  $T_a$  values recorded throughout crop development, 0 to 70 DAF were 5.8, 10.4, 10.5, and 10.7 °C for the control, 30%, 60%, and 90% RD treatments, respectively. These results concur with those pointed out by Li et al. (2014) in a study conducted under the same conditions. Ten events of  $T_a \leq 0$  °C were observed in the control (Figure 1B) during fruit set and fruit development; this would affect fruit yield because of the death of recently set fruit and developing fruit as pointed out by Retamal-Salgado et al. (2015). This technique with the characteristics of the present study would be an effective tool to protect the plant against temperatures  $\leq 0$  °C. At the same time, the increase in minimum temperatures would promote fertilization and fruit set because, according to Aras et al. (1996) and Cooper and Schaffer (1985), the initial working temperature of pollinating agents, such as *Aphis mellifera* and *Bombus* spp., is greater than 10 and 5 °C, respectively. This factor is relevant because Brevis et al. (2006) and Kirk and Isaacs (2012) point out that the period of flower receptivity is approximately 4 to 5 d. Javorek et al. (2002) and Kirk and Isaacs (2012) mention that this greater activity of pollinating agents would increase fruit fertilization, increase fruit size, and crop yield. Just as for maximum  $T_a$ , soil temperature was higher ( $P < 0.05$ ) throughout the day in the control (Figure 1C) compared to the different RD treatments in which mean soil temperature was 22.4, 20.9, 19.9, and 19.8 °C for the control, 30%, 60%, and 90% RD treatments, respectively. However, temperatures recorded at the different times of day (Figure 1C) in the 30% and 90% RD treatments would be within the optimal temperature for root development between 18 and 21 °C (Spiers, 1995; Retamales and Hancock, 2012). Concurrently, Spiers (1995) indicates that a negative correlation exists between soil temperature increase from 16 to 38 °C; soil temperatures observed in the control treatment (Figure 1C,  $T > 24$  °C) would decrease root development to some degree. On the other hand, Figure 1D shows the variations in  $T_L$  at different radiation intensities at different times of day with  $T_L$  means ranked as 90% RD > 60% RD > 30% RD > control. At the first times of day,  $T_L$  values were similar and from midday onward,  $T_L$  in the control was higher ( $P > 0.05$ ) than all the RD treatments. By the end of the day, temperatures were greater than 40 °C (Figure 1D). These larger  $T_L$  in the control, would be given by greater  $T_a$  as seen in Figure 1A, which would not only be affecting the flight threshold of the pollinating agents ( $T > 27$  °C), but they would be greater than the optimal crop development temperature ( $T > 28$  °C) (Chen et al., 2012; Kirk and Isaacs, 2012). This would negatively affect the fruit expansion rate in the last development stage, 40 to 70 DAF, Figure 1D) (Retamal-Salgado et al., 2015). Figure 2D illustrates that intercepted PPFd in the control was significantly higher than 30%, 60%, and 90% RD treatments at different times

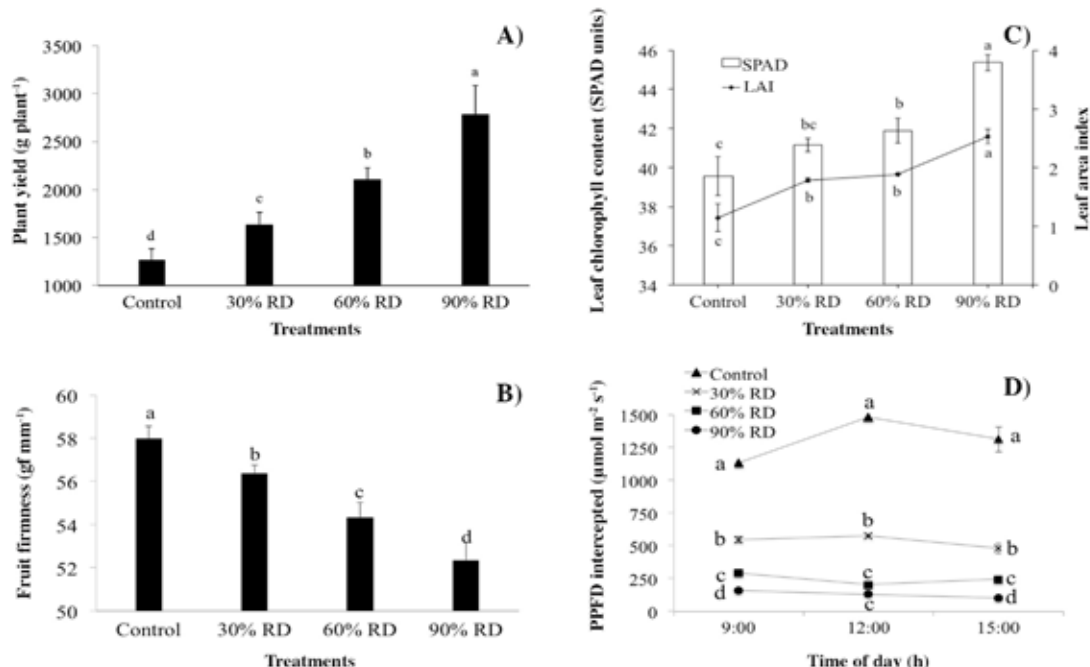
of day with values of 47.7%, 79.1%, and 88.7% for the 30%, 60%, and 90% RD treatments, respectively. These levels of intercepted PPFd reduction would be greater than levels indicated by Retamal-Salgado et al. (2015), who also pointed out that an approximate decrease of 30% in radiation values would not affect plant yield. Other authors mention that this decrease in intercepted PPFd could reach values of 60% without any negative effects on yield and photosynthetic processes (Kim et al., 2011; Lobos et al., 2012); these studies were conducted in *Vaccinium corymbosum* L., which could have a higher light saturation point than *V. virgatum* Aiton.

### Chlorophyll fluorescence and stomatal conductance

Figure 3A illustrates the different variations in PSII maximum quantum yield ( $F_v/F_m$ ) at different times of day and different radiation intensities. There are nonsignificant differences ( $P > 0.05$ ) among treatments at the first times of day (09:00 and 11:00 h) and values fluctuated between 0.76 and 0.79. However, between 13:00 and 17:00 h, the 30%, 60%, and 90% RD treatments exhibited higher values than the control ( $P < 0.05$ ). Results for the different RD treatments established that there was no damage caused by photoinhibition because  $F_v/F_m$  values increased during the day (Figure 2A) until reaching near-optimal values close to the optimal value of 0.8 (Lobos et al., 2012; Retamal-Salgado et al., 2015). On the contrary, the lowest recorded value in the control was 0.78 at 13:00 h; this value decreased during the course of the afternoon and reached 0.75. This confirms some degree of photoinhibition in plants exposed to full sunlight conditions during growth (Figure 2A) (Medina et al., 2002; Lobos et al., 2013). It is important to consider that results for increases in  $T_L$  in the control beginning at 11:00 h (Figure 1D) could be stimulating the increase in the degree of photoinhibition (Figure 2A) (Chen et al., 2012). This is because the high radiation and high temperature combination, also recorded in the present study, would affect photosynthetic efficiency (Chen et al., 2012). The observed  $g_s$  at the first time of day (09:00 h) did not exhibit any differences among treatments (Figure 2B). However,  $g_s$  decreased in the control during the day (11:00 to 15:00 h) (Figure 2B) along with an increase in the degree of photoinhibition ( $F_v/F_m$ ) (Figure 2A),  $T_s$  (Figure 1A), and intercepted PPFd (Figure 2D). This concurs with other authors who point out that a positive correlation exists between the increase in PAR and  $g_s$  up to light saturation levels ( $700 \mu\text{mol m}^{-2} \text{s}^{-1}$ ), which subsequently decreases, as observed in the present study (Kim et al., 2011; Retamal-Salgado et al., 2015). Although  $g_s$  decreased in all the RD treatments after 15:00 h with nonsignificant differences (Figure 3B), it was always within normal levels (Lobos et al., 2012). Zhang et al. (2004) specify that plants cultivated under the shade photosynthesize twice as much as plants grown under full sunlight conditions, which leads to the corresponding changes in  $g_s$  because of greater stomatal opening; this would explain the high  $g_s$  values despite RD (Figure 1C) and  $T_L$  compared to the control treatment

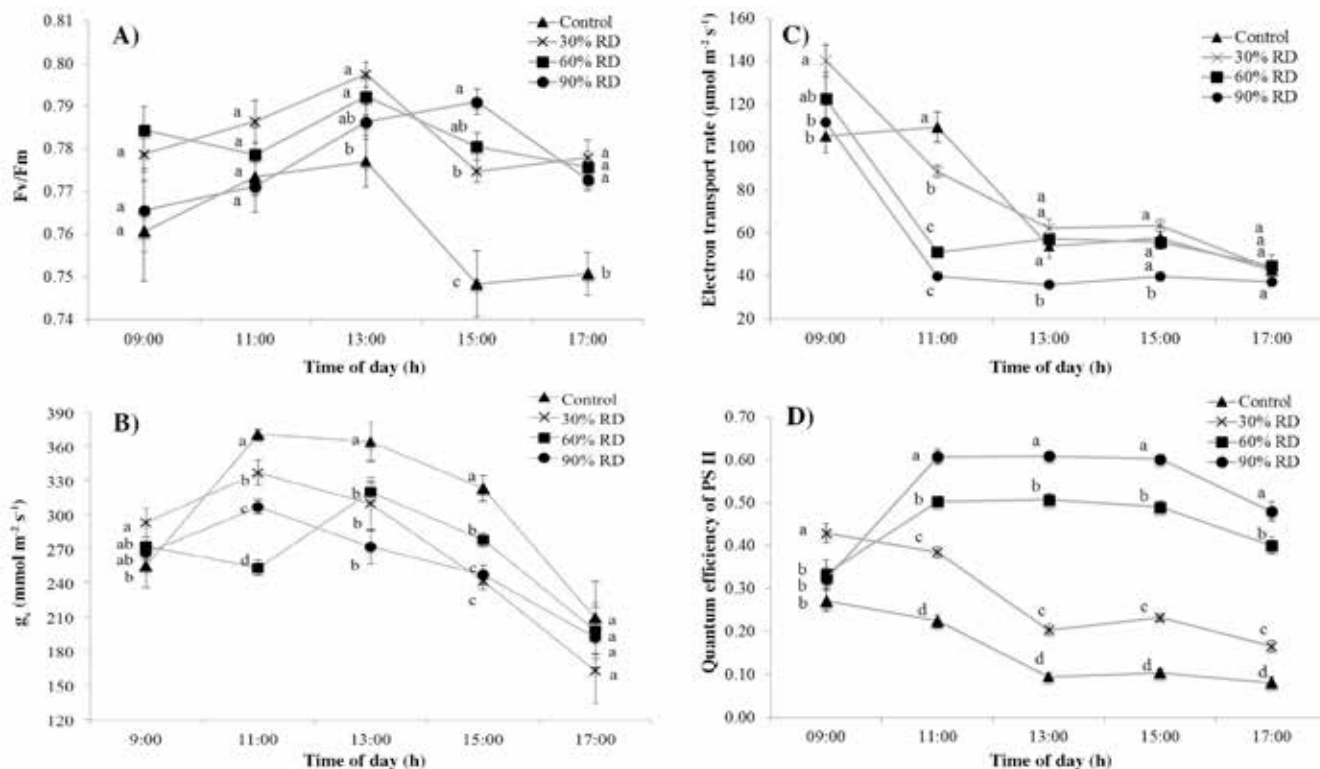


Figure 2. Diurnal responses for different radiation intensities on plant yield (A), fruit firmness (B), leaf chlorophyll content and leaf area index (C), and intercepted photosynthetic photon flux density (PPFD) (D).



RD: Radiation decrease; LAI: leaf area index.

Figure 3. Diurnal responses for different radiation intensities on photosystem II maximum quantum yield ( $F_v/F_m$ ) (A), leaf stomatal conductance ( $g_s$ ) (B), electron transport rate (C), and photosystem II (PSII) quantum efficiency (D).



For each time of day, different lower-case letters indicate significant differences for different shade intensities according to Tukey's test ( $P < 0.05$ ). Vertical bars refer to  $\pm$  standard deviation of the mean ( $n = 32$ ). RD: Radiation decrease.

(Figure 1D). These results concur with those determined by Jifon and Syvertsen (2003), who observed a negative correlation in  $g_s$  when  $T_L$  increased; these values concur with those found in the present study for the control treatment from 15:00 h onward (Figure 1D).

According to Figure 2D,  $\Phi_{PSII}$  decreases during the day in the control and 30% RD treatments; however, the rates of decrease for  $\Phi_{PSII}$  were higher in the control, which this concurs with the  $F_v/F_m$  results (Figure 3A) and a higher observed degree of photoinhibition in the control than in the other treatments (Figure 3A). At the same time,  $\Phi_{PSII}$  was higher ( $P < 0.05$ ) in the 90% RD treatment from 11:00 h onward ( $P < 0.05$ ) compared to the other treatments. This is confirmed by the negative correlation ( $R^2 = 0.72$ ) observed in the present study between PPF and  $\Phi_{PSII}$  (Figure 4A). Various authors (Kim et al., 2011; Retamal-Salgado, 2015) explain that this is because the direct radiation levels in the different shade treatments are below the light saturation point of  $700 \mu\text{mol m}^{-2} \text{s}^{-1}$ . These results concur with those mentioned by Kim et al. (2011), who found that  $\Phi_{PSII}$  values fluctuated between 0.2 and 0.7 for different radiation intensities (Figure 3D) and under similar conditions (Figure 2D). This would indicate that netting is an effective tool against stress generated by excessive radiation and temperature, as observed in the different RD treatments (Figures 3A, 3D, and 2D). The mean  $\Phi_{PSII}$  value in the 90% RD treatment was the highest of all treatments (0.52,  $P < 0.05$ ); at the same time, the control, 30%, and 60% RD treatments were significantly different when compared and had mean values of 0.16, 0.28, and 0.45, respectively (Figure 3D). The lower value found in the control ( $\Phi_{PSII} < 0.02$ , Figure 3D) would indicate a higher degree of photoinhibition and decrease in the PSII ( $\Phi_{PSII}$ ) quantum efficiency (Losciale et al., 2011; Cordon et al., 2016). These results concur with those specified by Iriel et al. (2015), who conclude that  $\Phi_{PSII}$  is a parameter more sensitive to a stress situation than  $F_v/F_m$ . This coincides with the results displayed in Figures 4A and 4B that show a high correlation between  $\Phi_{PSII}$  and the increase in radiation and temperature.

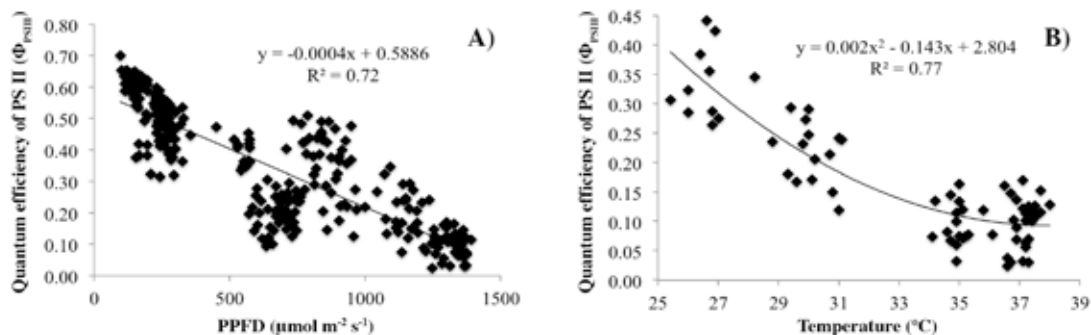
Figure 3C shows that ETR decreases during the day in all treatments and the highest ETR values occur in the 30% shade treatment with a mean value during the day of  $80 \mu\text{mol m}^{-2} \text{s}^{-1}$  (Figure 3C). Nonsignificant

differences ( $P > 0.05$ ) exist between the control, 30% and 60% RD treatments at 13:00, 15:00, and 17:00 h (Figure 3C) probably because blueberry plant plasticity adapts to different levels of RD (Lobos et al., 2013). The 90% RD treatment obtained the lowest value ( $P < 0.05$ ) among all treatments from 11:00 h onward; this is probably because of the adaptation to low radiations levels (Cordon et al., 2016). The results of the present study concur with those obtained by Losciale et al. (2011), who observed that PSII activity increases as it is exposed to lower photon flux levels.

### Productive parameters and leaf indices

Figure 3A illustrates a trend when production increases as radiation decreases. The highest production per plant was  $2786 \text{ g plant}^{-1}$  for the 90% RD treatment (Figure 2A) with a mean yield value for the 60% RD, 30% RD, and control treatments of 2109, 1640, and  $1268 \text{ g plant}^{-1}$ , respectively, ( $P < 0.05$ , Figure 2A). Figure 3D illustrates that this increase in production is benefited by the increase in PSII quantum efficiency and associated with a decrease in the degree of photoinhibition (Figure 3A) (Retamal-Salgado et al., 2015). The latter is also benefited by the results obtained for the highest LAI and chlorophyll index observed in the present study, which were significantly higher in all the RD treatments compared to the control. Maximum LAI and chlorophyll index values were found in the 90% RD treatment with 2.53 and 45.4, respectively, ( $P < 0.05$ ). The 30% and 60% RD treatments exhibited higher values than the control ( $P > 0.05$ ) for both parameters (Figure 2C). These higher chlorophyll and LAI indices concur with results obtained by Muñoz-Vega et al. (2016) and Lobos et al. (2012), respectively; the latter author points out that blueberries produced under different RD levels increase total chlorophyll content and leaf area (Kim et al., 2011; Lobos et al., 2012) as a response to acclimation due to the decrease in radiation. It is important to consider, that the higher yield of fruit under shade (Figure 2A), it could presumably be favored by an increase in the net assimilation rate of  $\text{CO}_2$ , given by the high levels of stomatal conductance observed in this study in treatments under netting (Figure 3B), associated with increased leaf area and the higher chlorophyll content (Figure 2C), as

**Figure 4. Diurnal responses of photosystem II quantum yield ( $\Phi_{PSII}$ ) to intercepted photosynthetic photon flux density (PPFD) (A) and environmental temperature (B).**



noted by Medina et al. (2002). Who also points out that in plants in full sun, there would be a reduction in net CO<sub>2</sub> assimilation, as a consequence of a water deficit imposed by an excess of transpiration, therefore, This possible water deficit in shady plants is not experienced, due to a lower temperature of leaves and air, and to a possible increase of water availability of the soil, as Jifon and Syvertsen (2003) indicate that the use of netting reduces water loss by direct evaporation of soil, to the decreasing radiation, and soil temperature and air, as observed in this study (Figures 1A, 1C, and 2D). Generating a greater efficiency in the use of water, which could be ratified by higher fruit yields in shade treatments than in control treatment, to equal water supplies added to all treatments (Medina et al., 2002).

Finally, Figure 2B reveals the variations in fruit firmness at different radiation intensities at different times of day. It is highlighted that fruit firmness was significantly higher in the control treatment than in the 30%, 60% and 90% RD treatments with values of 58.0, 56.4, 54.3, and 52.5, respectively; the latter three treatments did not show any differences ( $P > 0.05$ ).

## CONCLUSIONS

The use of netting decreases soil temperature between 1 and 3 °C and increases minimum temperatures air between 1 and 6 °C, which promoted plant development and decreased frost damage in the flowering and fruit development stages. Netting decreases the degree of photoinhibition and increases photosystem II photochemical efficiency throughout the day with the 90% and 60% radiation decrease treatments exhibiting higher efficiency. Current direct radiation levels greater than 1000  $\mu\text{mol m}^{-2} \text{s}^{-1}$  in the *Vaccinium virgatum* crop inhibit productivity. The reduction of radiation over 60%, decreased leaf stomatal conductance during the day, and increased leaf chlorophyll index, and leaf area index, without adverse effects on fruit yield, corroborating that *V. virgatum* is an understory species. The radiation decrease technique promotes the increase in fruit yield because of the increase in photosynthetic efficiency and decrease in extreme environmental conditions. However, fruit firmness decreases when the level of shade increases, which could be economically important for producers when fruit quality decreases.

## ACKNOWLEDGEMENTS

This study was financed by Facultad de Ingeniería y Negocios, Universidad Adventista de Chile.

## REFERENCES

- Al-Helal, I.M., and Abdel-Ghany, A.M. 2010. Responses of plastic shading nets to global and diffuse PAR transfer: Optical properties and evolution. *Wageningen Journal of Life Science* 57:125-132.
- Aras, P., Oliveira, D., and Savoie, L. 1996. Effect of a honey bee (Hymenoptera: Apidae) gradient on the pollination and yield of lowbush blueberry. *Journal of Economic Entomology* 89(5):1080-1083.
- Bassett, C., Wisniewski, M., Artlip, T., and Norelli, J. 2006. Global analysis of genes regulated by low temperature and photoperiod in peach bark. *Journal of the American Society for Horticultural Science* 131(4):551-563.
- Bastías, R.M., and Corelli-Grappadelli, L. 2012a. Light quality management in fruit orchards: physiological and technological aspects. *Chilean Journal of Agricultural Research* 72(4):574-581.
- Bastías, R.M., Manfrini, L., and Corelli-Grappadelli, L. 2012b. Exploring the potential use of photo-selective nets for fruit growth regulation in apple. *Chilean Journal of Agricultural Research* 72:224-231.
- Brevis, P.A., NeSmith, D.S., Wetzstein, H.Y., and Hausman, D.B. 2006. Flower age affects fruit set and stigmatic receptivity in rabbiteye blueberry. *HortScience* 41:1537-1540.
- Cooper, P.D., and Schaffer, W.M. 1985. Temperature regulation of honey bees (*Apis mellifera*) foraging in the Sonoran Desert. *Journal Experimental Biology* 114:1-15.
- Cordon, G., Lagorio, M.G., and Paruelo, J.M. 2016. Chlorophyll fluorescence, photochemical reflective index and normalized difference vegetative index during plant senescence. *Journal Plant Physiology* 199:100-110.
- Corelli-Grappadelli, L. 2003. Light relations. p. 195-216. In Ferree, D.C., and Warrington, I.J. (eds.) *Apples: Botany, production and uses*. CAB International, Wallingford, UK.
- Corelli-Grappadelli, L., and Lakso, A.N. 2007. Is maximizing orchard light interception always the best choice? *Acta Horticulturae* 732:507-518.
- Cowan, J.S., Miles, C.A., Andrews, P.K., and Inglis, D.A. 2014. Biodegradable mulch performed comparably to polyethylene in high tunnel tomato (*Solanum lycopersicum* L.) production. *Journal of the Science Food and Agriculture* 94:1854-1864.
- Chen, W., Cen, W., Chen, L., Di, L., Li, Y., and Guo, W. 2012. Differential sensitivity of four highbush blueberry (*Vaccinium corymbosum* L.) cultivars to heat stress. *Pakistan Journal of Botany* 44(3):853-860.
- Cunha, A.R., Ieoschua, K., Sousa, A.P., y Martinez, R.A. 2015. Índice SPAD en el crecimiento y desarrollo de plantas de *Lisianthus* en función de diferentes dosis de nitrógeno en ambiente protegido. *IDESIA* 33(2):97-105.
- Demchak, K. 2009. Small fruit production in high tunnels. *HortTechnology* 19(1):44-49.
- Iriel, A., Dundas, G., Fernández Cirelli, A., and Lagorio, M.G. 2015. Effect of arsenic on reflectance spectra and chlorophyll fluorescence of aquatic plants. *Chemosphere* 119:697-703.
- Javorek, S.K., Mackenzie, K.E., and Vander Kloet, S.P. 2002. Comparative pollination effectiveness among bees (Hymenoptera: Apoidea) on lowbush blueberry (*Ericaceae: Vaccinium angustifolium*). *Annals of the Entomological Society of America* 95(3):345-351.
- Jifon, J.L., and Syvertsen, J.P. 2003. Moderate shade can increase net gas exchange and reduce photo inhibition in citrus leaves. *Tree Physiology* 23:119-127.
- Kim, S.J., Yu, D.J., Kim, T., and Lee, H.J. 2011. Growth and photosynthetic characteristics of blueberry (*Vaccinium corymbosum* cv. Bluecrop) under various shade levels. *Scientia Horticulturae* 129:486-492.

- Kirk, A.K., and Isaacs, R. 2012. Predicting flower phenology and viability of highbush blueberry. *HortScience* 47(9):1291-1296.
- Kooten, O., and Snel, J.H. 1990. The use of chlorophyll fluorescence nomenclature in plant stress physiology. *Photosynthesis Research* 25:147-150.
- Li, T., Heuvelink, E., Dueck, T.A., Janse, J., Gort, G., and Marcelis, L.F.M. 2014. Enhancement of crop photosynthesis by diffuse light: quantifying the contributing factors. *Annals of Botany* 114:1-12.
- Lobos, G.A., Retamales, J.B., Hancock, J.F., Flore, J.A., Cobo, N., and del Pozo, A. 2012. Spectral irradiance, gas exchange characteristics and leaf traits of *Vaccinium corymbosum* L. 'Elliott' grown under photo-selective nets. *Environmental Experimental Botany* 75:142-149.
- Lobos, G.A., Retamales, J.B., Hancock, J.F., Flore, J.A., Romero-Bravo, S., and del Pozo, A. 2013. Productivity and fruit quality of *Vaccinium corymbosum* cv. Elliott under photo-selective shading nets. *Scientia Horticulturae* 153:143-149.
- Losciale, P., Hendrickson, L., Corelli-Grappadelli, L., and Chow, W.S. 2011. Quenching partitioning through light-modulated chlorophyll fluorescence: A quantitative analysis to assess the fate of the absorbed light in the field. *Environmental and Experimental Botany* 73:73-79.
- Maxwell, K., and Johnson, G.N. 2000. Chlorophyll fluorescence: A practical guide. *Journal of Experimental Botany* 51:659-668.
- Medina, C.L., Souza, R.P., Machado, E.C., Rivero, R.V., and Silva, J.A.B. 2002. Photosynthetic response of citrus grown under reflective aluminized polypropylene shading nets. *Scientia Horticulturae* 96:115-125.
- Muñoz-Vega, P., Paillán, H., Serri, H., Donnay, D., Sanhueza, C., Merino, E., et al. 2016. Effects of organic fertilizers on the vegetative, nutritional, and productive parameters of blueberries 'Corona', 'Legacy', and 'Liberty'. *Chilean Journal of Agricultural Research* 76(2):201-212.
- Retamal-Salgado, J., Bastías, R.M., Wilckens, R., and Paulino, L. 2015. Influence of microclimatic conditions under high tunnels on the physiological and productive responses in blueberry cv. O'Neal. *Chilean Journal of Agricultural Research* 75(3):291-297.
- Retamales, J.B., and Hancock, J.F. 2012. *Blueberries*. CABI Publishing, Cambridge, Massachusetts, USA.
- Sandri, M.A., Andriolo, J.L., Witter, M., and Dal Ross, T. 2003. Effect of shading on tomato plant grower under greenhouse. *Horticultura Brasileira* 21:642-645.
- SAS Institute. 1989. Usage and reference. Version 6. 501 p. SAS. Institute, Cary, North Carolina, USA.
- Sonnentag, O., Talbot, J., Chen, J.M., and Roulet, N.T. 2007. Using direct and indirect measurements of leaf area index to characterize the shrub canopy in an ombrotrophic peatland. *Agricultural and Forest Meteorology* 144:200-212.
- Spiers, J.M. 1995. Substrate temperature influence root and shoot growth of southern highbush and rabbiteye blueberries. *HortScience* 30(5):1029-1030.
- Stolpe, N.B. 2006. Descripción de los principales suelos de la VIII Región de Chile. Universidad de Concepción, Chillán, Chile.
- Zhang, J.Z., Shi, L., Shi, A.P., and Zhang, Q.X. 2004. Photosynthetic responses of four *Hosta* cultivars to shade treatments. *Photosynthetica* 42(2):213-218.