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INFLUENCIA DEL MATERIAL DE COBERTURA EN LAS RESPUESTAS DE ISODRICIDAD Y TOLERANCIA A LA SEQUÍA DE PLANTAS JÓVENES DE ARÁNDANOS

Tesis para optar al grado de Magister en Ciencias Agronómicas con Mención en Producción y Protección Vegetal

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RESUMEN

El cultivo protegido puede mejorar las relaciones hídricas de las plantas en los huertos de arándanos con poca disponibilidad de agua. Se realizaron dos ensayos en huertos jóvenes de arándanos (*Vaccinium corymbosum* L.), cv. Blue Ribbon y cv. Top Shelf, en Linares y Traiguén, por dos temporadas consecutivas (2018-2019 y 2019-2020). Se instalaron cuatro tratamientos de cobertura (control, malla, rafia y plástico) desde la brotación hasta la senescencia de la hoja. Bajo riego deficitario, las plantas cubiertas exhibieron un mayor estado hídrico de la planta ($\Delta\Psi_{\text{tallo}}$ ± 0.13 MPa), conductancia estomática (Δg_s ± 45 mmol $m^{-2}s^{-1}$) y eficiencia del fotosistema II ($\Delta F_v/F_m$ ± 0.2) en comparación con los valores observados en plantas descubiertas. Sin embargo, el estado hídrico de la planta fue similar para todos los tratamientos de cobertura bajo riego convencional. El mayor estrés hídrico en plantas con riego deficitario descubiertas se atribuyó a una mayor transmisión de radiación solar en lugar de cambios en la demanda evaporativa (VPD). La conductancia estomática en plantas con estrés hídrico moderado (Ψ_{tallo} <-1.0 MPa) fue 40% mayor en condiciones cubiertas. El cultivo protegido puede retrasar la aparición de estrés hídrico en los huertos de arándanos jóvenes. Dado que las plantas de arándanos son altamente sensibles a la sequía, esta práctica puede ser muy relevante en el escenario actual de cambio climático.

SUMMARY

Protected cultivation can improve plant water relations in blueberry orchards under low water availability. Two trials were carried out in young blueberry orchards (*Vaccinium corymbosum* L.), cv. Blue Ribbon and cv. Top Shelf, in Linares and Traiguén, for two consecutive seasons (2018-2019 and 2019-2020). Four cover treatments were installed (uncovered, netting, woven-covered, and plastic-covered) from budburst to leaf senescence. Under deficit irrigation, covered plants exhibited higher plant water status ($\Delta\Psi_{stem}$ ± 0.13 MPa), stomatal conductance (Δg_s ± 45 mmol $m^{-2}s^{-1}$) and photosystem II efficiency ($\Delta F_v/F_m$ ± 0.2) compared to values observed in uncovered plants. However, plant water status was similar for all the cover treatments under conventional irrigation. The higher water stress in uncovered deficit-irrigated plants was attributed to higher transmission of solar radiation rather than changes in the evaporative demand (VPD). Stomatal conductance in moderately water-stressed plants (Ψ_{stem} <-1.0 MPa) was 40% higher under covered conditions. Protected cultivation may delay the occurrence of water stress in young blueberry orchards. Given the fact that blueberry plants are highly sensitive to drought, this practice can be very relevant under the current climate change scenario.

CAPÍTULO 1

INTRODUCCIÓN GENERAL

El arándano alto (*Vaccinium corymbosum* L.) es un cultivo frutal arbustivo que presenta una alta sensibilidad a la falta de agua debido a un sistema radical poco denso, carente de pelos radical, y muy superficial, con raíces que se concentran en los primeros 40 cm de profundidad (Bryla y Strik, 2007). Estas características contribuyen a que el arándano alto presente una limitada exploración del suelo y, por ende, una baja capacidad de escape al estrés hídrico. Sin embargo, estudios realizados en las variedades Duke, Bluecrop, y Elliot han reportado que el arándano alto exhibe una disminución exponencial de la conductancia estomática bajo un estrés hídrico leve (potenciales hídricos del tallo al mediodía entre -0,8 a -0,6 MPa) (Bryla y Strik, 2004). Esto significa que, a pesar de la baja capacidad de acceso a agua de reserva en los suelos, el arándano alto presenta un control estomático muy sensible a la falta de agua, lo cual reduce la tasa de deshidratación de las plantas y la vulnerabilidad a sufrir cavitación. Esto es particularmente importante en esta especie frutal, pues en arándano alto se han detectado importantes disminuciones en la conductividad hidráulica del xilema con potenciales hídricos del tallo más altos que en otros cultivos frutales (entre -1.2 y -1.0 MPa) (Améglio et al., 2000). Aunque el cierre estomático es un mecanismo eficiente de tolerancia a la falta de agua, la persistencia de una condición de estrés hídrico moderado-severo durante más de 21 días puede reducir en más de un 30 % la fotosíntesis de las plantas (Rho et al., 2012). Un aspecto interesante, es que la mayor parte de los estudios que han evaluado el impacto del estrés hídrico sobre los arándanos se han realizado en plantas adultas, sin considerar que las plantas jóvenes son mucho más sensibles a la ocurrencia de un estrés por falta o exceso de agua. En este contexto, la condición hídrica de un huerto de arándanos recién establecidos es de vital importancia, pues una menor severidad de estrés hídrico, por sequía o anegamiento, en las plantas jóvenes pueden extender el tiempo necesario para alcanzar el su potencial productivo (Bryla et al., 2011).

Actualmente, la producción de arándanos en zonas de clima mediterráneo se ha visto fuertemente amenazada por el cambio climático, el cual ha generado un aumento de la evapotranspiración y una reducción progresiva de las precipitaciones, comprometiendo la disponibilidad de agua de riego para este cultivo. Por ejemplo, en la Región del Maule, la zona productora de arándanos más importante de Chile, se ha registrado un aumento de la ETc y un disminución de las precipitaciones de 10% y 45% en los últimos 10 años, respectivamente (INIA, 2020). Consecuentemente, es posible que varios huertos de arándanos de la región del Maule, y otras zonas productivas con condiciones climáticas similares, no cuenten con agua suficiente para satisfacer por completo la demanda hídrica estacional y evitar la ocurrencia de un estrés hídrico severo.

Junto con la presencia de importantes limitantes hídricas, el cultivo del arándano en la zona centro-sur de Chile debe soportar el efecto de niveles extremos alta de radiación UV (280 - 400 nm), la cual puede superar hasta 0,3 Wm^{-2} (Dirección General de Aeronáutica Civil, 2020). En este contexto, es sabido que el desarrollo de las actividades humanas durante el último siglo ha generado un incremento importante de los niveles de radiación UV en latitudes medias del Hemisferio Sur (Madronich, 1994, Vernet et al., 2009). En general, la presencia de altos niveles de radiación UV, principalmente la UV-B (280 - 320 nm), debido al agotamiento continuo de la capa de ozono (Kakani, 2003) o de los cambios en la transmisividad de esta tipo de radiación originados en la atmósfera asociados al cambio climático (Bais et al., 2015), la cual puede dañar el aparato fotosintético de las plantas, especialmente en condiciones hídricas restringidas (Carrasco-Ríos, 2009). Una radiación UV-B de 0,19 Wm^{-2} puede reducir la tasa fotosintética neta de las hojas del arándano entre un 35% y 50% (Inostroza-Blancheteau et al., 2016), lo cual es debido al daño que ejerce la radiación sobre al fotosistema II (PSII) (Boesgaard et al.,2012).

El uso de cultivos protegidos en frutales es una práctica que ha ido ganando popularidad durante los últimos años debido a la necesidad de proteger a los huertos de las adversidades climáticas (Carlen y Krliger, 2009; Lamont, 2009; Zhao et al., 2014) y a la obtención de otros beneficios, tales como el manejo de las tasas de maduración de la fruta y la fecha cosecha (Demchak, 2009). En arándanos (*Vaccinium corymbosum*) cultivados bajo túneles de polietileno se observó mostraron que aumenta un aumento de la precocidad y el rendimiento de las plantas cubiertas, lo cual se asoció debido al impacto de las coberturas sobre el microclima y la tasa de fotosíntesis neta una mayor difusividad de la radiación fotosintéticamente activa (Retamal-Salgado et al., 2015). La modificación de las condiciones ambientales de radiación solar, temperatura, y humedad relativa (Lamont, 2005) en huertos bajo cultivos protegidos puede traer consigno no solo cambios fotoquímicos que mejoren la asimilación de CO_2 en especies frutales (Salazar-Canales et al., 2021), sino también cambios en la demanda evaporativa que reduzcan la pérdida de agua por transpiración (Li et al., 2014) o retrasen la ocurrencia de estrés hídrico severo (Calderón-Orellana et al., 2021). Por ejemplo, en plantas del género Citrus, el empleo de mallas sombra mostró reducciones en las tasas transpiratorias de las hojas cercanas al 25% (Cohen et al., 1997). Por el contrario, en manzanos cubiertos con mallas 50% sombra roja se observó un aumento en el flujo xilemático y en el uso del agua con relación a plantas sin cobertura (Boini et al., 2019). El uso de mallas puede inducir aumentos en la elongación de brotes y cambios anatómicos en las hojas con efecto en su funcionalidad, dependiendo de la cantidad y calidad de la luz transmitida bajo las mallas incremento de la dominancia apical y reducción del grosor de la hoja (Bastías et al., 2012; Bastías et al., 2021) o en la densidad estomática de los frutales (Salazar-Canales et al., 2021), lo cual puede alterar la evapotranspiración de los cultivos, a pesar de que los cambios microclimáticos asociados al empleo de los cultivos protegidos tiendan a reducir la demanda evaporativa atmosférica. Estos resultados indican que el rol de los cultivos protegidos sobre las relaciones hídricas de los huertos frutales es más complejo que el de una herramienta para reducir la demanda hídrica.

Durante los últimos años, la industria del arándano chilena ha comenzado un proceso de tecnificación, el cual ha incluido un fuerte recambio varietal y el uso de cultivos protegidos (Comité de Arándanos de Chile-ASOEX, 2021). Debido a la falta de información científica sobre el impacto de los cultivos protegidos sobre las relaciones hídricas en plantas jóvenes de arándanos se realizó un estudio cuyo objetivo fue estudiar el efecto de distintas coberturas sobre las relaciones hídricas de plantas jóvenes de dos nuevos cultivares de arándano bajo clima templado.

HIPOTESIS

El uso de coberturas mejora la tolerancia al estrés hídrico en nuevas variedades de arándanos.

OBJETIVO GENERAL

Estudiar el efecto del uso de coberturas sobre las relaciones hídricas en nuevas variedades de arándanos en dos localidades contrastantes.

OBJETIVOS ESPECÍFICOS

- Evaluar el efecto del uso de las cubiertas sobre el estado hídrico de plantas jóvenes de arándanos.

- Caracterizar la relación entre el contenido del agua en el suelo y el potencial hídrico del brote en nuevas variedades de arándano bajo sistema de cultivos protegidos.
- Caracterizar la relación entre el potencial hídrico del brote y la conductancia estomática en nuevas variedades de arándano bajo sistema de cultivos protegidos.
- Caracterizar la relación del déficit de presión de vapor con el potencial hídrico del brote y la conductancia estomática de las hojas en nuevas variedades de arándano bajo sistema de cultivos protegidos.
- Evaluar el impacto del estrés hídrico sobre variables que determinan la actividad fotosintética de las hojas en nuevas variedades de arándano bajo cubiertas.

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CAPÍTULO 2

Influence of the covering material on the isohydricity and drought tolerance responses of young blueberry plants

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Keywords: *Vaccinium corymbosum*; stem water potential; protected cultivation, stomatal conductance; solar radiation.

REVISTA: AGRICULTURAL WATER MANAGEMENT

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Abstract

Protected cultivation can improve plant water relations in blueberry orchards under increasing water scarcity in Mediterranean regions. Two trials were carried out in young blueberry orchards (*Vaccinium corymbosum* L.), cv. Blue Ribbon and cv. Top Shelf, in south-central Chile (Linares and Traiguén), for two consecutive seasons (2018-2019 and 2019-2020). Four covering treatments were installed (uncovered control, netting, woven, and plastic) from budburst to leaf senescence. While woven and plastic-covered plants showed no relationship between Ψstem and g_s, clearly indicating an anisohydric behavior, uncovered and netting-covered plants exhibited a quadratic relationship between both variables. Under deficit irrigation, higher plant water status ($\Delta\Psi_{stem}$ ± 0.2 MPa), stomatal conductance (Δg_s ± 50 mmol $m^{-2}s^{-1}$) and photosystem II efficiency ($\Delta F_v/F_m$ ± 0.2) was found in covered plants. The higher water stress in uncovered deficit-irrigated plants was attributed to higher transmission of global solar radiation rather than changes in the evaporative demand (VPD). Stomatal conductance in moderately water-stressed plants (Ψ_{stem} <-1.0 MPa) was 40% higher under covered conditions. Protected cultivation may delay the occurrence of water stress in young blueberry orchards. Since blueberry plants are highly sensitive to drought, this practice can be particularly relevant under ever-increasing and more severe droughts forecasted by climate change models.

Keywords: *Vaccinium corymbosum*; stem water potential; protected cultivation, stomatal conductance; solar radiation.

1. Introduction

Highbush blueberry (*Vaccinium corymbosum* L.) is widely regarded as a sensitive fruit crop to water deficits, as the depth of the root system is restricted to upper soil layers (0-0.4 m), and roots produce no root hairs (Bryla and Strik, 2007). Hence, blueberry plants show a limited capacity to escape water stress under non-irrigated conditions. However, leaves from highbush blueberries start displaying an exponential reduction in stomatal conductance when midday stem water potentials are lower than -0.2 MPa (Bryla and Strik, 2006). Rapid stomatal closure in response to water stress can reduce transpiration and vulnerability to cavitation. The ability to quickly respond to water stress may be crucial for blueberry plants, as a 50% reduction in xylem hydraulic conductivity has been reported between -1.2 and -1.0 MPa (Améglio *et al*., 2000). Although stomatal closure is an efficient mechanism to limit water loss, moderate water stress (SWP between -1.0 and -0.8 MPa) for more than 21 days can reduce plant photosynthesis by more than 30% (Rho *et al*., 2012).

In general, irrigation studies in blueberry have evaluated the impact of water stress on adult orchards, despite young plants may be more sensitive to biotic or abiotic stress. For instance, low levels of water stress or the occurrence of waterlogging conditions can reduce plant growth and the yield potential of a recently established orchard (Bryla *et al*., 2011).

The cultivation of blueberries in areas with a Mediterranean climate has been strongly affected by climate change, as the increase in evapotranspiration and the progressive decrease in precipitation have reduced water availability for agriculture. For instance, in the Maule Region (Chile's most relevant blueberry production area), a 10% increase in ETc and a 45% decrease in annual rainfall have been registered during the last ten years (INIA, 2020). Consequently, several blueberry orchards in the Maule Region, and other productive areas with similar climatic conditions, are likely to face severe levels of water stress between budburst and leaf senescence.

In south-central Chile, blueberry is not only affected by water deficit but also by high UV radiation (280-400 nm), which can exceed 0.3 W m^{-2} (General Directorate of Civil Aeronautics, 2020). Human-derived emissions of chloride and bromide bearing organic gases during the last century have resulted in the depletion of stratospheric ozone (Kakani, 2003), increasing the transmissivity of UV radiation, particularly of UV-B (280-320 nm) (Bais et al., 2015) in the mid-latitudes of the Southern Hemisphere (Madronich 1994, Vernet *et al*., 2009). The exposure of plants to high levels of UV radiation can irreversibly damage the photosynthetic apparatus of plants, especially under water stress conditions (Carrasco-Ríos, 2009). In fact, 0.19 W m^{-2} of UV-B radiation has been reported to reduce the net photosynthetic rate of blueberry leaves between 35% and 50% (Inostroza-Blancheteau *et al*., 2016), which reflects the profound impact of UV radiation on the photosystem II (PSII) (Boesgaard *et al.*, 2012).

The use of protected cultivation in fruit crops is a cultural practice that has been gaining popularity in recent years. There are many objectives of using protected cultivation in commercial orchards, such as protecting fruit from climatic adversities (Carlen and Krliger, 2009; Lamont, 2009; Zhao et al., 2014) or accelerating fruit ripening (Demchak, 2009). For example, the use of shade netting can reduce skin sunburn by 26% and 44% in apples (Umanzor et al., 2017; Raffo et al., 2015) and cherries, respectively. A study on highbush blueberry (*Vaccinium corymbosum* L.) reported earlier production and higher yield in plants covered with a polyethylene film, which was associated with the effect of the covering on microclimate and the net photosynthesis rate (Retamal-Salgado *et al*., 2015). The modification of environmental conditions (i.e., solar radiation, temperature, and relative humidity) in fruit orchards covered with films (Lamont, 2005) can yield not only photochemical changes that improve the assimilation of CO_2 in fruit crops (Salazar-Canales et al., 2021), but also induce changes in the atmospheric evaporative demand. Therefore, the use of covering has been associated with a reduction in water loss through transpiration (Li et al., 2014) or a delay in the occurrence of severe water stress (Calderón-Orellana et al., 2021a). In Citrus, the transpiration rate was reduced by 25% in plants covered with shade netting (Cohen *et al*. 1997). Conversely, the use of a 50% red shade netting increased xylem water flow and water demand in apple trees (Boini *et al*., 2019). Furthermore, the use of netting can stimulate the elongation of shoots and change leaf anatomy, which may modify leaf functionality, depending on the quantity and quality of transmitted light (Bastías et al., 2012; Bastías et al., 2021). In hazelnut (*Corylus avellana* L.), netting-covered plants showed an increase of stomatal density in leaves (Salazar *et al*., 2021), while, in kiwifruit (*Actinidia deliciosa* Chev.), plastic-covered vines exhibited a 20% increase in stomatal conductance (Calderón-Orellana et al., 2021b). These results clearly indicate that the role of protected cultivation in plant water relations of fruit crops goes beyond reducing water demand.

In recent years, the Chilean blueberry industry has started to plant new cultivars and use various types of coverings in orchards established under contrasting weather conditions (Committee of Blueberries of Chile-ASOEX, 2021). Yet, there is a lack of scientific research on the impact of protected cultivation on plant water relations of recently-established blueberry orchards. The objective of this study was to determine the effect of various types of coverings on plant water relations of two new blueberry cultivars in recently-planted orchards under two temperate climate types.

2. Materials and methods

2.1. Study sites

The study was conducted under drip irrigation for two consecutive seasons (2018-2019 and 2019-2020) in two orchards of highbush blueberry (*Vaccinium corymbosum*). The first orchard was established in 2018 with cv. Top Shelf and cv. Blue Ribbon in Linares, Maule Region, Chile (35º 81’ 04.97’ ’S; 71º 32’ 27.36” W), with a spacing of 1 m between plants and 3 m between rows. The soil corresponds to the Linares series and belongs to the mixed, thick-loam thermal family of the Typic Xerorthents (Entisol), with dominant loam surface texture (CIREN, 1999). The other orchard (Traiguen orchard) was established in 2017 with the cv. Top Shelf in Traiguén, Araucanía Region, Chile (38º 33’ 82.37” S; 71º 54’ 02.45” W), with a spacing of 1 m between plants and 3.2 m between rows. The soil is mapped as Chufquén series and belongs to the mixed, loamy-fine mesic family of the Fluventic Humic Dystrudepts (Inceptisol), with dominant silty loam surface texture (CIREN, 2002). Climatic conditions in both study sites (Linares and Traiguén) correspond to Temperate Mediterranean and Humid Temperate climates, respectively (INE, 2017).

2.2. Experimental design.

The study was conducted in a completely randomized block design with four replicates and repeated measurements over two years. A deficit irrigation treatment was arranged in a split-split-plot design during the 2019-2020 season in the Linares orchard. The main plot was the cover treatment, the first subplot was the cultivar, and the second subplot was the irrigation treatment.

In the Traiguén orchard, all plants were irrigated similarly to avoid the occurrence of water stress during the whole growing season (midday stem water potential above -0.5 MPa). Four cover treatments (Control: uncovered plants; Netting: covered plants with a 20% black shade net; Woven: covered plants with a high-density polyethylene film; and Plastic: covered plants with a low-density polyethylene film) were applied from bud break to the onset of dormancy in each orchard (Figure 1). The covers were placed at 3 m above the ground, with a width of 2.5 m and an angle of 28º to the ground. The nets were mounted on a structure made of impregnated pine blocks or concrete and spaced 12 m apart in both orchards (Figure 2).

The uncovered plants remained under open-field conditions throughout the whole season. Covering treatments were installed for 240 continuous days in 2019 in Linares and both seasons in Traiguén (from September 1 to May 1). Covering treatments were installed over the main plot of twelve plants in both orchards, at 0.70 m above each of the three consecutive rows for each block-treatment combination (10 pl row^{-1}).

In the Linares orchard, two irrigation treatments were randomly applied to a subplot of six plants within each main plot one week after veraison (50% of berries turned from green to red), aiming to obtain significant differences in plant water status near harvest time, when water availability in both locations often reaches the minimum value of the season (midday stem water potential below -0.8 MPa). Control (WET) plants were irrigated to satisfy at least 100% ETc throughout the whole season, trying to maintain an average midday stem water potential (Ψ_s) above -0.8 MPa. In the regulated deficit irrigation (RDI) treatment, water was cut off from January 16 for 14 continuous days in both covered and uncovered plants. Irrigation was resumed in all plants when deficit-irrigated subplots reached an average midday stem water potential (Ψ_s) of -1.2 MPa.

2.3. Environmental conditions and water requirements

Atmospheric evaporative demand was evaluated as the vapor pressure deficit

(VPD) under each cover using meteorological stations (PCE-FWS 20, PCE Instruments, Spain). The air temperature and relative humidity (°C) were measured with a sampling frequency of 15 minutes from August 10 to March 30 in the 2018-2019 season and from August 10 to March 30 in the 2019-2020 season. The VPD was calculated according to the following formula (Monteith and Unsworth, 2013):

$$VPD = \frac{(100-HR)}{100} \cdot 0.6108 \cdot e^{(17.27 . (Ta/Ta+237.3))} \quad (1)$$

where RH is relative humidity, and Ta is air temperature.

Photosynthetic photon flux density (PPFD) was measured weekly above and below plants using a ceptometer (LP-80, Decagon Instruments, Washington, USA) from November 11 to February 3 and from October 15 to January 21 in Linares and Traiguén, respectively. In 2019, data collection was carried out at midday, every 14 days, with a sampling frequency of one measurement above the plant canopy and four measurements below the plant canopy. Above-canopy PPFD was measured 1.5 m above the soil level, while below-canopy PPFD was measured at the center of the row, right below the plant canes at 0, 0.15, and 0.3 m from the crown, and the edge of the ridge at 0.45 m from the crown. The ceptometer used the PPFD data to calculate the leaf area index (LAI), previously entering the coordinates of each orchard to estimate the azimuth for that geographic area.

Reference evapotranspiration (ETo) and rainfall data were obtained from the Santa Amada weather station (Agroclima Weather Network) (35°76’03 “S

71°57’46 “W) for the Linares orchard, and from the Caballería (38°45’72 “S 72°74’02 “W) and La Providencia (38°28’92 “S 72°61’19 “W) weather stations (Agroclima Weather Network) for the Traiguen orchard. The weather stations were located about 10 km from the study sites.

Irrigation requirements were estimated based on the evapotranspiration for blueberry plants:

$$ETc = ETo \times Fc \times K_c$$

$$FC = F_1 \cdot Pc + F_2$$

$$Pc = \frac{\pi \cdot D\hat{}2}{4 \cdot Eeh \cdot Esh}$$

where ETo is the reference evapotranspiration, K_c is the crop coefficient. FC is the estimate of a dimensionless crop cover factor ($0<FC<1$) associated with Pc, which corresponds to the shading fraction of a plant at midday ($0.1<Pc<0.7$); F1 and F2 are crop-associated cover factors; Ds is the diameter of the vegetation shadow at midday (m) determined from measurements of the plant’s shadow projection on the ground; Eeh and Esh correspond the spacing between rows (m) and between plants (m), respectively. The crop coefficients (k_c) for young blueberry plants used in this study from bud-break to harvest were obtained from Holzapfel and Arumi (2010).

Volumetric soil water content was measured in a single block in conventionally irrigated plants, with no irrigation deficit, using capacitance sensors (GS-1, Decagon Devices, Washington, USA) connected to a datalogger recording measurements every 15 minutes and installed in the soil profile at a depth of 10 and 20 cm from the center of the plant. Measurements were taken from September 4 to March 13 of 2019. Water flow meters (Dishnon, Arad Ltd, Dalia, Israel) were installed at the beginning of each irrigation line in each main plot to estimate irrigated water supply from October 15 to February 3 in the 2019-2020 season.

2.4. Plant water status and physiological responses

The water status of blueberry plants was determined by measuring stem water potential (SWP) at midday (from 12:30 to 3:30 pm) using a pressure chamber (PMS 60, PMS Instruments, Washington, USA). However, as blueberry plants have small leaf petioles, complete shoots were sampled from the lower third of the canopy to visualize the meniscus during pressurization. A shoot was selected and covered for 45 min with an opaque and airtight bag, according to the methodology described by McCutchan and Shackel (1992). During the 2018-2019 season, SWP was measured only once, seven days after harvest (February 5, 2019), to avoid reducing leaf area in very young plants. In the 2019-2020 season, SWP was measured every 14 days from fruit set to *veraison* and every seven days from *veraison* to harvest in one shoot per plant in each treatment.

Stomatal conductance (g_s) was measured on three leaves per plant, using a steady-state porometer (SC-1, Decagon Instruments, Washington, USA). Photosystem II (PSII) efficiency was evaluated at the beginning and end of the season using a chlorophyll fluorimeter (Pocket PEA, Hansatech Instruments, England) and determined based on a variable (F_v/F_m), where Fv= [Fm-Fo], Fm= maximum fluorescence performance (Maxwell and Johnson, 2000), by previously adapting the leaves to dark conditions for 20 minutes (Balboa, 2019) and using tongs with a measurement area of 4 mm in diameter. Both evaluations were carried out in the upper third of the canopy in mature, healthy leaves, exposed to the sun, without chlorosis or evident damage, using the same plant in which Ψ_s was determined.

2.6. Statistical analysis

The data were subjected to an analysis of variance (ANOVA) after testing for normality distribution of errors (Shapiro-Wilks), homogeneity of variances (Levene), and additivity of effects (Tukey). Additionally, we evaluated the relationship between environmental and physiological variables through linear and quadratic regression analysis. Differences between means were determined using the LSD test at a significance level of 95% ($P \leq 0.05$). All statistical analyzes were performed using SAS-Studio software (SAS Institute, NC, USA).

3. Results

3.1. Environmental conditions and water requirements

The use of covers resulted in a significant reduction in both global solar radiation (300-1100 nm) and photosynthetically active photon flux intensity (PPFD) (400-700 nm). Global solar radiation is reduced by 10% under plastic and 20% under mesh and woven covers compared to the control treatment, with December and

January being the months of maximum radiation (Figure 3). Meanwhile, PPFD decreases by approximately 25%, 38%, and 46% under the mesh, woven, and plastic covers, respectively (Figure 4) compared to the control treatment with PPFD close to 2000 µmol $m^{-2}s^{-1}$ in both locations.

Similar climatic conditions were observed between treatments. The air vapor pressure deficit (VPD) was higher in Linares, averaging between 1.5 and 4.0 kPa among treatments (Figure 5A), while in Traiguén, VPD ranged from 1.0 to 1.6 kPa (Figure 5B). The cover treatments did not display relevant differences from the control treatment. During the 2019-2020 season and at the time of maximum demand under the control treatment, the maximum temperatures during harvest reached 40 °C and 34 °C with a relative humidity close to 15% and 30% for Linares and Traiguén, respectively. These conditions generated excessive transpiration because a high VPD, close to 3 kPa (Lorenzo et al., 1998), produces a rise in water stress. The latter effect was more prominent in the Linares orchard, where the DPV values were close to 6 kPa.

The use of plastic covers displayed a consistently elevated volumetric soil water content than the control treatment being on average 31.1% and 52.3% higher during the season in Linares and Traiguén, respectively. In both locations, the volumetric water content of the soil in the open air remained lower during the second season, with values close to 0.2 m^3m^{-3}. In Linares, plastic sustained higher soil moisture with an average of 0.29 m^3m^{-3}, followed by woven with 0.26 m^3m^{-3} and 0.25 m^3m^{-3} under mesh (Table 1). Consequently, in Traiguén, the same behavior was observed, where under plastic, higher soil moisture of 0.35 m^3m^{-3} than for mesh 0.34 m^3m^{-3} and woven 0.23 m^3m^{-3} were observed (Table 1). On the other hand, volumetric content of soil water in cv. Top Shelf was ~ 10% higher than in cv. Blue Ribbon during the season, except under woven, where cv. Blue Ribbon display higher values (Table 1).

As expected, the contrasting climatic conditions between localities were reflected in the water demand. The accumulated ETc in Linares reached close to 380 and 340 mm for the hp Top Shelf and cv. Blue Ribbon, respectively, during the 2019-2020 season (data not revealed). In Traiguén, the accumulated ETc was 260 mm during the second season (data not revealed).

3.2. Plant water relations

Since measuring SWP with a pressure chamber is a destructive technique, water stress readings on two-year-old blueberry plants were only carried out once during the first growing season to minimize the reduction of the foliar area in the recently established plants.

In the first season, all irrigation treatments showed similar SWP values between -0.55 and -0.7 MPa and between -0.63 and -0.67 (Table 2) in Linares and Traiguén, respectively. In the second season, the control plants consistently exhibited the lowest SWP at midday from veraison to postharvest in Linares (~-0.7 MPa). On the contrary, in Traiguén, no consistent differences in SWP were observed between treatments. Water stress increased as the season progressed due to the augmented water demand due to the elevated temperature and the differences in plant phenological state. Hence, the most evident differences in the treatments were detected during postharvest, when the severity of the plant's water stress was maximum and reached an average SWP of -0.93 MPa in Linares.

Concordantly, stomatal conductance (gs) considerably decreased as the season progressed and water demand increased. In the first season, the gs under the mesh and woven cover were ~500 mmol $m^{-2}s^{-1}$, differing by ~100 mmol $m^{-2}s^{-1}$ from the control and ~250 mmol $m^{-2}s^{-1}$ from the plastic in the Linares orchard (Table 3). Regarding Traiguén, the highest gs were observed under covers between a range of 269.6 and 310.2 mmol $m^{-2}s^{-1}$, differing from the control by >100 mmol $m^{-2}s^{-1}$ (Table 3). For the second season, no consistent differences were observed in gs. The gs in the town of Linares drops considerably, but it remains similar throughout the season in Traiguén. There were significant differences between the cover treatments in postharvest because of increased water demand, where uncovered plants had a considerably lower gs (~30%).

Regarding the hydric state between varieties, it remained similar in the first and second seasons, except at postharvest, in which the cv. Top Shelf responds better to conditions of high water demand, reaching a SWP of -0.8 MPa and a gs of 225.1 mmol $m^{-2}s^{-1}$ (Table 2 and 3). The cv. Top Shelf has 30% higher gs compared to cv. Blue Ribbon under an optimal water state; however, the stomata of the cv. Top Shelf seemed to be more sensitive under water stress because its gs was drastically reduced when SWP decreased.

The induced water deficit condition greatly affected the hydric status between treatments. Two weeks after the suspension of the water supply, the plants under plastic covers have a higher hydric state than the control. The mesh treatment reached higher values in the SWP of -0.84 MPa, which differed significantly from the control treatment and the other covers by -0.16 and -0.08 MPa, respectively (Figure 6A). Regarding gs, the plastic treatment reached 204.55 mmol $m^{-2}s^{-1}$, higher than the control treatment by ± 70 mmol $m^{-2}s^{-1}$ and other covers by ± 20 mmol $m^{-2}s^{-1}$ (Figure 6B).

Consequently, gs and SWP were highly correlated, observing an inflection point close to -0.8 MPa for all treatments (Figure 7). Uncovered plants displayed a rapid reaction past this point, where gs dropped dramatically to 100 mmol $m^{-2}s^{-1}$. However, covered plants maintained a gs, even at SWP lower than -0.8 MPa (Figure 7A). gs was much more sensitive to changes in the Ψs in the cv. Top Shelf than cv. Blue Ribbon; however, under conditions of moderate to severe water stress (Ψs between -1.0 to -0.8 MPa), both have a gs ~ 160 mmol $m^{-2}s^{-1}$ (Figure 7B)

For both Linares and Traiguén, the maximum photochemical efficiency of photosystem II, estimated as F_v/F_m, did not show differences between treatments under conventional irrigation, maintaining values close to 0.8 (Figure 8A). However, under a water deficit, discovered plants differed from the other treatments, decreasing significantly to F_v/F_m values similar to 0.6 (Figure 8B). These PSII efficiency values resulted from a high incident PPFD radiation in conjunction with a ~ 30% decrease in gs under a condition of moderate-severe water stress.

In Linares, the DPV was strongly correlated with the SWP results. Under outdoor and mesh conditions a better relationship between SWP and DPV was obtained (R2 = 0.61, p-value <0.01) (Figure 9). However, the relationship seemed to decrease or be nonexistent under plastic and woven treatments (data not shown).

4. Discussion

The results obtained in this research provided consistent evidence that the use of cover crops can mitigate the negative effects of climate change on water status and photoinhibition in young blueberry plants. However, the impact of cover crops on the water stress level of blueberry plants, measured as SWP, was only of physiological significance under moderate-high severity (<-0.8 MPa) (Bryla and Strik, 2007). When unirrigated plants were under covers, they exhibited SWP values ~0.2 MPa higher than uncovered plants. The maintenance of improved water status in non-irrigated plants under cover crops is important in young orchards, as it can mitigate the drop in cellular turgor and, therefore, the reduction of vegetative growth under water stress. The improved water status of non-irrigated plants under cover crops was due to a reduction in crop evapotranspiration, which was evident when analyzing differences in soil volumetric water content between treatments. In the present study, the plants under cover exhibited on average a volumetric soil water content 31.1% and 52.3% higher than those uncovered in the Linares and Traigúen orchards, respectively. Preliminary studies have shown decreases similar decreases in evapotranspiration in protected citrus orchards (Cohen et al., 1997, Nicolás et al., 2008), grapes (Rana et al., 2004), and apple trees (Iglesias and Alegre, 2006; Shahak et al., 2004).

The lower soil desiccation in plants under cover was associated with a considerable reduction in the amount of incident solar radiation and not in the atmospheric evaporative demand, measured as VPDair, or in the area of soil covered by the crop. In the Linares and Traiguén orchards, global solar radiation and PPFD decreased between 10 - 20% and 25% - 46% under the different covers, respectively. While the differences between treatments for VPDair were minimal in both orchards (± 0.1 kPa). Although fruit plants under cover usually show higher vegetative growth rates than uncovered plants (Novello et al., 2000; Bastías et al., 2012; Salazar et al., 2021), in the present study no differences in LAI between treatments were observed to explain changes in evapotranspiration.

Surprisingly, the effect of cover treatments on leaf stomatal conductance was not the same for plants under conventional irrigation and deficit irrigation, even though the covers maintained a better soil water status. In conventionally irrigated plants, no changes were observed in leaf stomatal conductance, which was maintained in all treatments between 150 and 300 mmol m-2s-1 in Linares and between 250 and 400 mmol $m^{-2}s^{-1}$ in Traiguén. These results differ from those reported in other fruit crops, where well-watered netted plants exhibited a higher stomatal density than uncovered plants (Bastías et al., 2012; Salazar et al., 2021). On the other side, in water-stressed plants, uncovered plants exhibited a decrease in stomatal conductance close to 30%, which would have been generated as a consequence of a higher ABA synthesis in drier soils (Zhang and Davies, 1990). Previous studies have reported a very close relationship between water stress and stomatal conductance in outdoor blueberry plants, where a slight drop in plant water status (0.2 MPa) could induce a greater than 40% reduction in leaf stomatal conductance (Ameglio et al., 2000; Bryla and Strik, 2004).

In this study, the relationship between SWP and gs was not similar in all cover treatments. While uncovered and netted plants showed a nearly 30% drop in gs when SWP reached -0.9 MPa, plants under woven and plastic coverings showed practically no variation in gs at the same water stress severity. In kiwifruit, Calderón-Orellana et al. (2021b) found that the use of a low-density transparent plastic cover maintained relatively stable stomatal conductance in plants under high water stress severity (-1.3 MPa), while uncovered plants exhibited a 20% reduction in stomatal conductance. These results suggest that the use of waterproof covers such as raffia and plastic could induce anisohydric behavior not only in blueberry plants, but also in other fruit trees. Although the reason for the induction of anisohydric behavior in blueberries under plastic and woven is not known, it has been seen that some plants (e.g., Acacia aptaneura) can maintain high values of stomatal conductance at very low water potentials (-1.8 MPa), which has been associated with maintenance of guard cell turgor via osmotic adjustment (Nolan et al., 2017). This mechanism could explain the anisohydric behavior of blueberry plants under certain canopies.

Studies on blueberries grown in open fields have reported significant levels of xylem cavitation at SWP values of -1.2 MPa (Améglio et al., 2000), showing that blueberries are a species very sensitive to water deficit. Therefore, an effective stomatal closure in response to water stress is a mechanism used to limit foliage dehydration. Although plants under woven and plastic with anisohydric behavior may have a higher risk to suffer cavitation of xylem vessels, in this study, all cover treatments under water stress presented a higher PSII efficiency, registering an average value of F_v/F_m of 0.8. These results are in agreement with previous studies in blueberry (Retamal-Salgado et al., 2017), kiwifruit (Calderón-Orellana et al., 2021), and european hazelnut (Salazar et al., 2021), among others, which have associated higher PSII efficiency in plants under cover due to reduced photoinhibition by excess incident light. Values of F_v/F_m lower than 0.8 are associated with damage to PSII (Maxwell & Johnson, 2000), indicating greater photoinhibition in plants uncovered under water deficit.

From an ecophysiological perspective, these results indicate that the combined use of mulching and deficit irrigation would increase intrinsic water use efficiency in young blueberry plants due to a combination of several factors, such as lower photoinhibition, maintenance of high stomatal conductance, and thus high CO2 diffusion rate to chloroplasts, and lower soil desiccation. Similar results have been reported in apple trees covered with 50% red shade netting (Bioni et al., 2019) and in kiwifruit under plastic (Calderón-Orellana et al., 2021). The fact that plants under plastic and woven cover exhibit higher photosynthetic efficiency and stomatal conductance in a water stress situation could facilitate the generation of osmotically active solutes that sustain the osmotic adjustment of guard cells.

Under conventional irrigation, plants of both cultivars showed a similar water status during most of the season, maintaining a SWP representative of optimal water conditions (between -0.7 and -0.6 MPa). The lack of significant differences in SWP between cultivars of well-watered plants contrasted with a 30% higher stomatal conductance in cv. Top Shelf. However, when plants entered moderate-severe water stress (<-1.0 MPa), cv. Top Shelf reached slightly lower water stress severity (0.1 MPa) than cv. Blue Ribbon, but similar stomatal conductance values. A denser and deeper root system, which is characteristic of cv. Top Shelf, could delay the occurrence of severe water stress, given that in the present study no differences were observed in the volumetric water content of the surface soil (between 10 and 20 cm depth) between both cultivars. The analysis of the relationship between SWP and gs shows that cv Blue Ribbon initiates stomatal closure at -0.7 MPa, while cv Top Shelf does it at -0.9 MPa. These results indicate that cv. Blue Ribbon is more sensitive to water stress than cv. Top Shelf because its stomatal closure occurs at a higher SWP value, reducing the possibility of occurrence of severe water stress and consequent xylem cavitation. Given that diverse species have acquired plasticity in leaf characteristics to respond to environmental conditions, studies in northern highbush blueberries have reported differences in stomatal densities associated with cultivars, where, cv. Brigita presented a higher stomatal density compared to cv. Duke for two consecutive seasons under equal conditions (Sotelo, 2018). These results could explain the permanent differences in stomatal conductance between both cultivars under a conventional irrigation condition and oriented to avoid water stress. Despite the differences in stomatal conductance, both cultivars maintained similar PSII efficiency, independent of water stress severity. This would indicate that, despite cultivar differences in stomatal response to water stress, the CO_2 diffusion rate would not have undergone major changes that altered the photosynthetic efficiency of blueberry leaves. This suggests that the water stress values reached in the present study could have induced a greater reduction in transpiration than in photosynthesis, and therefore could be used as reference values in a controlled deficit irrigation program in blueberries. Linear regression between water potential (SWP) and vapor pressure deficit (VPD), presents a negative correlation between both parameters, showing that well-watered plants exhibited midday SWP values between -0.8 and -0.5 MPa that have indicated moderate-severe water stress in previous blueberry studies (Bryla and Strik, 2004). SWP reaches a minimum point of -0.8 MPa at a DPV of

3.5 kPa. These results highlight the importance of considering atmospheric water demand in determining irrigation needs using the pressure chamber.

The strong correlation between SWP and VPD is attributed to the fact that by increasing VPDair, the plant dehydrates more quickly, generating a greater condition of water stress compared to these climatic requirements. However, under covers, this relationship was decreased because when protecting the plant with an impermeable material, the properties of the wind were altered. In addition, the measurement height of the meteorological stations added to a high frequency, does not allow to record important changes in the properties of the wind. Wind speed is an important factor in gs because it modifies the boundary layer in the leaves and it changes dramatically with height, decreasing by 90% from the top to the crown to the interior of the canopy (Jones 1983), Also, the friction force near the ground surface increases air turbulence.

5. Conclusions

The results of this study show that the use of different cover crops can alter the water relations of young blueberry plants due to a reduction in solar radiation, and not to significant changes in atmospheric water demand. In this context, the major benefits of the use of the installed covers from budbreak to senescence were the delay in the occurrence of moderate-severe water stress, a decrease in plant water requirements, and reduced leaf photoinhibition. These changes translate into higher irrigation water use efficiency, which becomes particularly important in Mediterranean climate zones, where lower water availability contrasts with higher water demand by fruit crops. Although all covers provided physiologically relevant protection against water stress (±0.2 MPa) in non-irrigated plants, the mechanisms of plant tolerance to water stress were not the same for all treatments. While plants under a woven and plastic cover exhibited anisohydric behavior, plants under netting and without cover exhibited isohydric behavior. This means that, when faced with a decrease in irrigation water availability in young blueberry orchards, netting offers better water use efficiency, but with a lower risk of xylem vessel cavitation than the other covers, which is due to stomata closure in response to an increase in the severity of water stress. Additionally, the differences observed between cultivars indicate that Top Shelf cv. has a better mechanism to tolerate high water demand and water stress conditions. Its high stomatal sensitivity coupled with a denser and deeper root system, which characterizes Top Shelf, reduces the possibility of occurrence of severe water stress and consequent cavitation of the xylem. These results confirm that the use of cover crops to cope with water scarcity is not only restricted to a tool for reducing water requirements, but also to the activation of complex mechanisms for regulating the balance between transpiration and photosynthesis that can improve the efficiency of irrigation water use.

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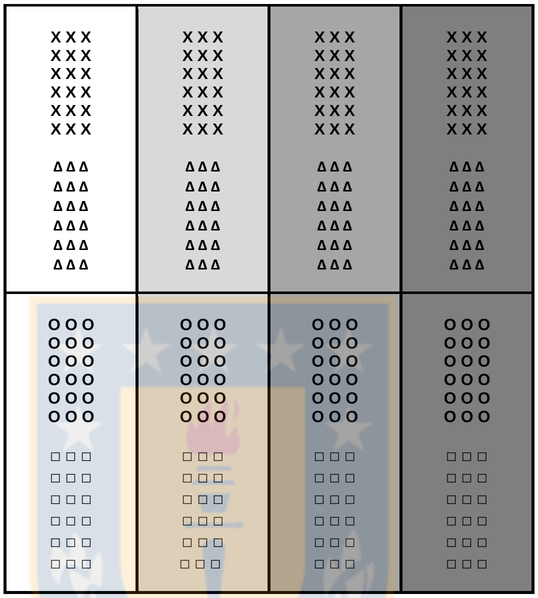
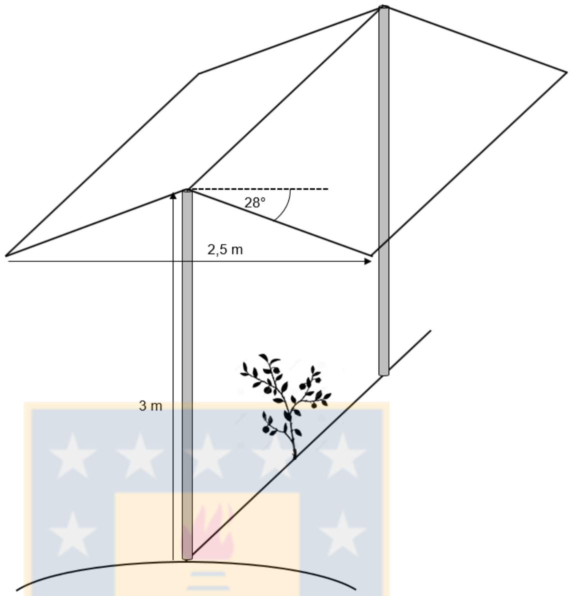
Figure 1. Experimental design applied in two young blueberry orchards, cv. Top shelf (x and Δ) and cv. Blue Ribbon (O and □) under four coverage treatments (Control: uncovered; Netting: monofilament netting; Woven: high-density polyethylene canopy, and Plastic: low-density polyethylene canopy) subjected to well-irrigated (x and O) and deficit irrigation (Δ and □**)** conditions in Linares and Traiguén in the 2018-2019 and 2019-2020 season.



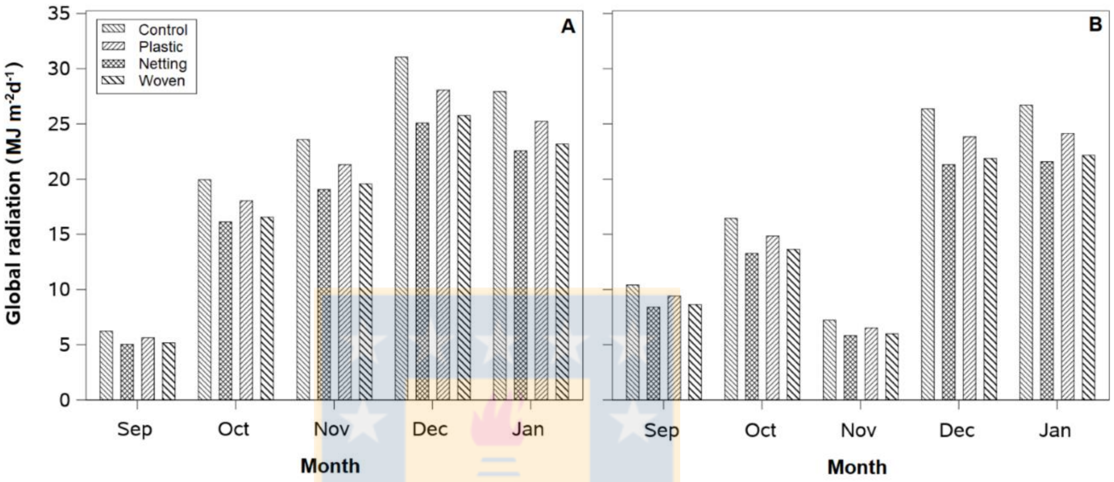
Fuente: Elaboración propia

Figure 2. Structure design for the establishment of the coverings in the experimental sites for two young northern highbush blueberry orchards**.**



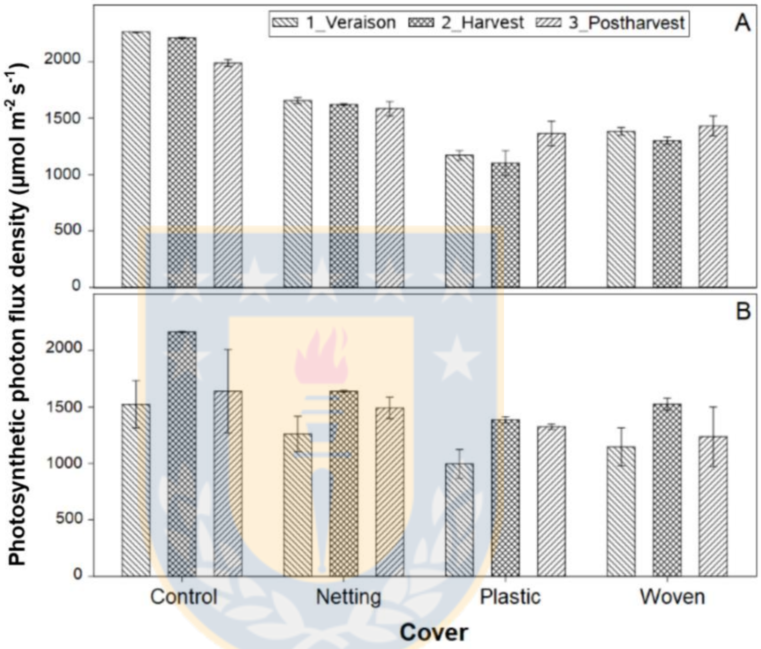
Fuente: Elaboración propia

Figure 3. Monthly average of global solar radiation in young northern highbush blueberry plants (cv. Blue Ribbon and cv. Top Shelf) under four coverage treatments (Control: uncovered; Netting: monofilament netting; Woven: high-density polyethylene canopy, and Plastic: low-density polyethylene canopy) in (A) Linares and (B) Traiguén in the 2018 and 2019 seasons.



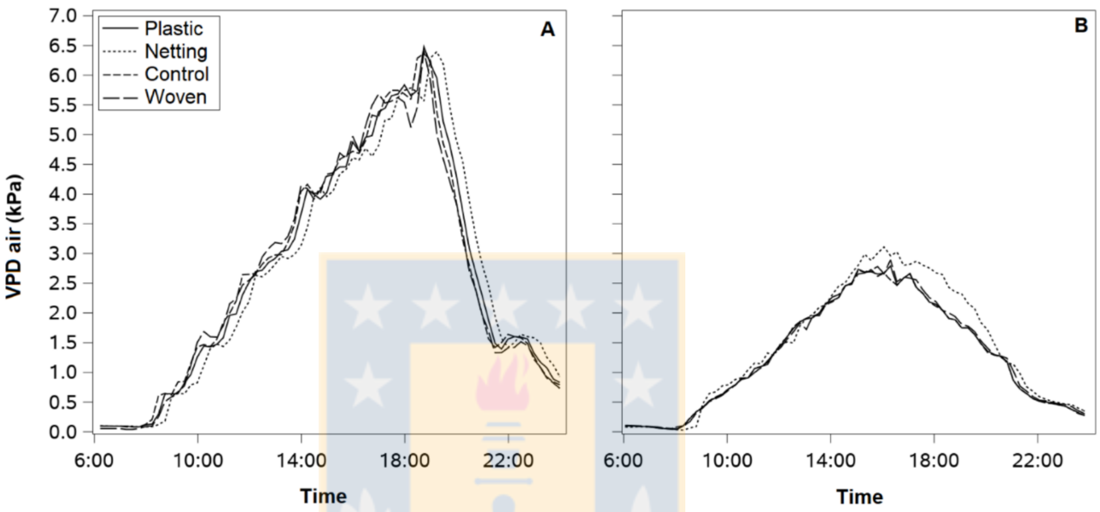
Fuente: Elaboración propia

Figure 4. Average values of photosynthetic photon flux density (PPFD) in young northern highbush blueberry plants (cv. Blue Ribbon and cv. Top Shelf) measured at three phenological stages (veraison, harvest, and postharvest) under four coverage treatments (Control: uncovered; Netting: monofilament netting; Woven: high-density polyethylene canopy, and Plastic: low-density polyethylene canopy) in (A) Linares and (B) Traiguén in the 2019 season.



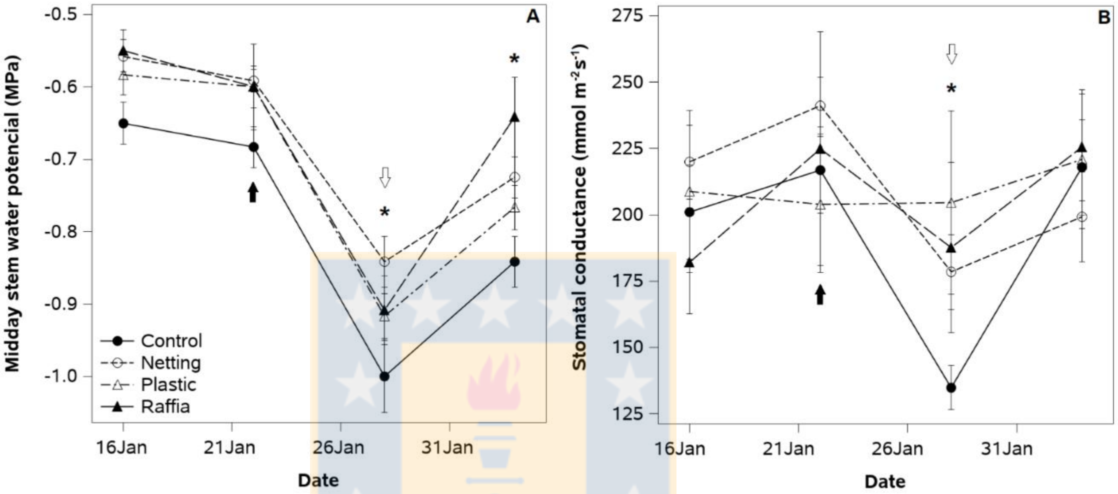
Fuente: Elaboración propia

Figure 5. Diurnal values of air Vapor Pressure Deficit (VPD) in young northern highbush blueberry plants (cv. Blue Ribbon and cv. Top Shelf) under four coverage treatments (Control: uncovered; Netting: monofilament netting; Woven: high-density polyethylene canopy, and Plastic: low-density polyethylene canopy) in (A) Linares and (B) Traiguén at the end of harvest in 2019 (January 18 and January 30 in Linares and Traiguén, respectively).



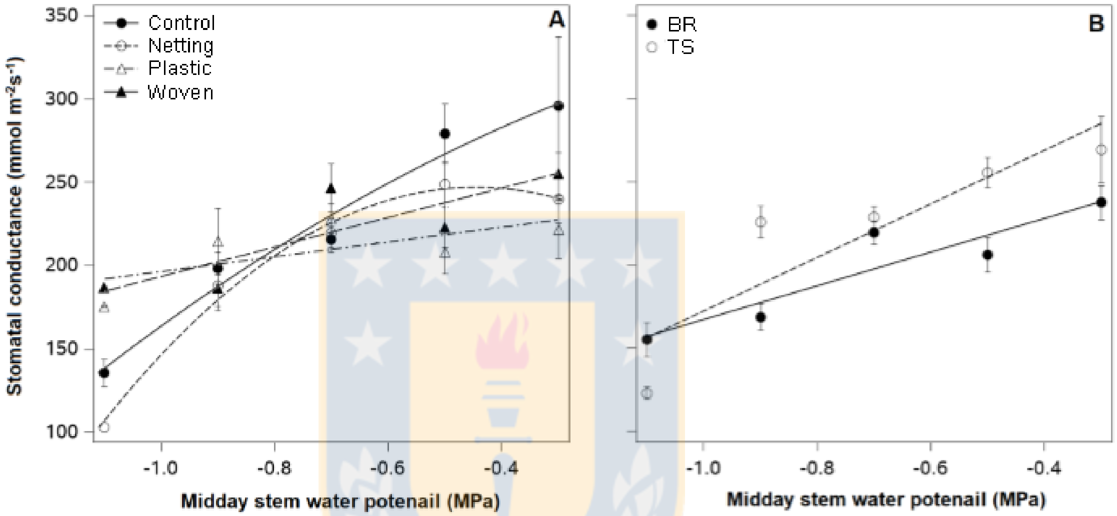
Fuente: Elaboración propia

Figure 6. Average values of (A) midday leaf water potential and (B) stomatal conductance in young northern highbush blueberry plants (cv. Blue Ribbon and cv. Top Shelf) subjected to deficit irrigation under four cover treatments (Control: uncovered; Netting: monofilament netting; Woven: high-density polyethylene canopy, and Plastic: low-density polyethylene canopy) in the 2019-2020 season. Asterisks indicate significant differences (P≤ 0.05, n=4). Black and white arrows indicate irrigation cutoff and resuming, respectively. Error bars represent ±1 se.



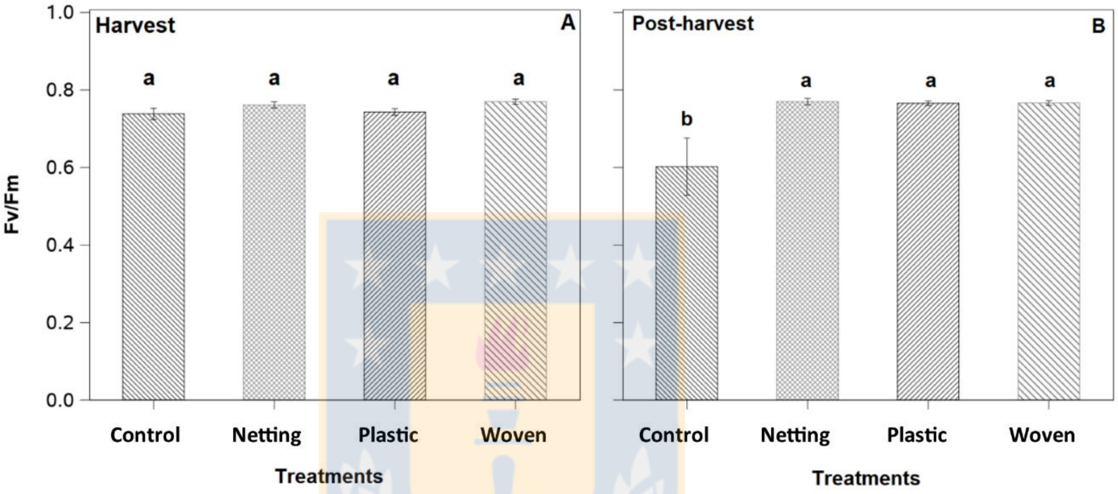
Fuente: Elaboración propia

Figure 7. Regression lines for the relationship of midday leaf water potential and stomatal conductance in young northern highbush blueberry plants under (A) four cover treatments (Control: uncovered; Netting: monofilament netting; Woven: high-density polyethylene canopy, and Plastic: low-density polyethylene canopy) and (B) the two cultivars (BR: cv. Blue Ribbon and TS: cv. Top Shelf) subjected to deficit irrigation in the 2019-2020 season. Asterisks indicate significant differences (P≤ 0.05, n=4). Black and white arrows indicate irrigation cutoff and resuming, respectively. Error bars represent ±1 se.



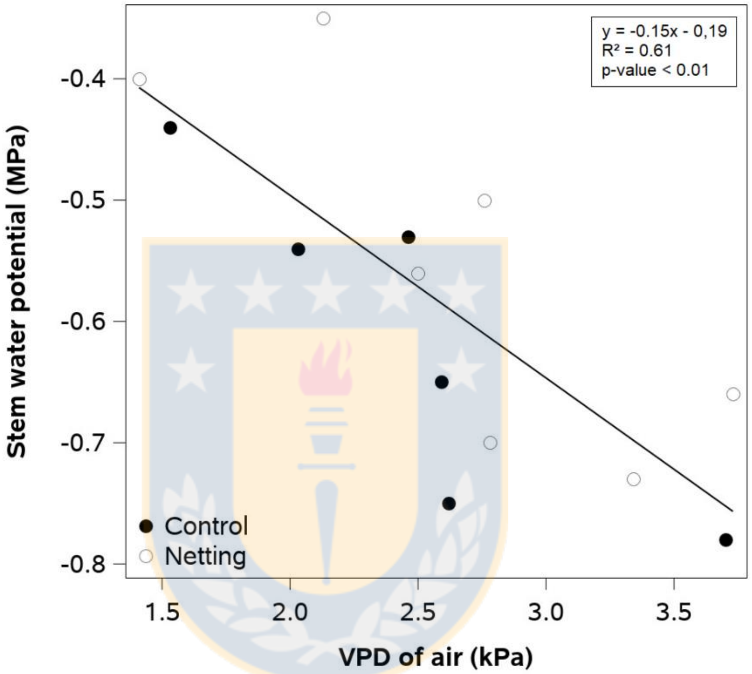
Fuente: Elaboración propia

Figure 8. Fv/Fm in two cultivars (cv. Blue Ribbon and cv. Top Shelf) of young northern highbush blueberry plants under four cover treatments (Control: uncovered; Netting: monofilament netting in Linares; Woven: high-density polyethylene canopy, and Plastic: low-density polyethylene canopy) (A) well-irrigated and (B) deficit irrigation conditions in the 2019-2020 season. Each bar represents the average of 6 plants three weeks after applying deficit irrigation (P≤ 0.05; n = 6). Error bars represent ± 1 sec.



Fuente: Elaboración propia

Figure 9. Linear regression for the relationship of the air vapor pressure deficit (VPDair) and the water potential of the stem at noon (12: 00-16: 00 h) in two cultivars (cv. Blue Ribbon and cv. Top Shelf) from young northern blueberries. Plants under control (uncovered) and mesh (monofilament) in well-irrigated conditions in the 2019-2020 season. Each symbol represents the daily average of 6 plants measured between November 8 and January 28. (P≤ 0.05, n = 6). Error bars represent ± 1 sec.



Fuente: Elaboración propia

Table 1. Average values of soil water content at four phenological stages in young northern highbush blueberry plants (cv. Blue Ribbon and cv. Top Shelf) under four cover treatments (Control: uncovered; Netting: monofilament netting; Woven: high-density polyethylene canopy, and Plastic: low-density polyethylene canopy) in two seasons 2018-2019 and 2019-2020.

Treatments	Veraison		50% harvest		Post-harvest	
	Soil water content (m^3 m^{-3})					
	-10 cm	-20 cm	-10 cm	-20 cm	-10 cm	-20 cm
Linares						
Covering						
Control	0,16	0,22	0,14	0,22	0,18	0,23
Netting	0,24	0,30	0,22	0,28	0,21	0,28
Woven	0,24	0,31	0,23	0,29	0,29	0,30
Plastic	0,28	0,27	0,27	0,27	0,30	0,29
Cultivar						
Blue Ribbon	0,22	0,25	0,21	0,24	0,22	0,26
Top Shelf	0,24	0,20	0,22	0,28	0,24	0,30
***Traiguén (**cv. Top Shelf)*						
Covering						
Control	0,15	0,22	0,15	0,19	0,14	0,16
Netting	0,29	0,36	0,26	0,31	0,29	0,35
Woven	0,22	0,34	0,18	0,36	0,08	0,27
Plastic	0,29	0,41	0,30	0,42	0,28	0,40

Fuente: Elaboración propia

Table 2. Average values of midday leaf water potential at four phenological stages in young northern highbush blueberry plants (cv. Blue Ribbon and cv. Top Shelf) under four cover treatments (Control: uncovered; Netting: monofilament netting; Woven: high-density polyethylene canopy, and Plastic: low-density polyethylene canopy) in two seasons 2018-2019 and 2019-2020.

Treatments	Post-Harvest	Veraison	50% harvest	Post-harvest
	2018-2019	2019-2020		
	Midday stem water potential (MPa)			
Linares				
Covering				
Control	-0.61	-0.70 b	-0.78 b	-0.93 b
Netting	-0.55	-0.65 ab	-0.65 ab	-0.79 a
Woven	-0.56	-0.54 a	-0.78 b	-0.83 a
Plastic	-0.70	-0.69 ab	-0.58 a	-0.78 a
Cultivar				
Blue Ribbon	-0.59	-0.70	-0.68	-0.87 b
Top Shelf	-0.62	-0.60	-0.73	-0.80 a
Interaction				
Cultivar x Covering	ns	ns	ns	ns
Traiguén (*cv. Top Shelf)*				
Covering				
Control	-0.67	-0.55 b	-0.58 b	-0.48 ab
Netting	-0.63	-0.45 a	-0.47 ab	-0.47 a
Woven	-0.66	-0.53 b	-0.50 ab	-0.47 a
Plastic	-0.63	-0.38 a	-0.42 a	-0.55 b

Different letters indicate significant differences among rows (LSD; P≤ 0.05). ns indicates non-significant differences.

Fuente: Elaboración propia

Table 3. Average values of stomatal conductance at four phenological stages in young northern highbush blueberry plants (cv. Blue Ribbon and cv. Top Shelf) under four cover treatments (Control: uncovered; Netting: monofilament netting; Woven: high-density polyethylene canopy, and Plastic: low-density polyethylene canopy) in two seasons 2018-2019 and 2019-2020.

	Post-Harvest	Veraison	50% harvest	Post-harvest
Treatments	2018-2019	2019-2020		
	Stomatal conductance (mmol $m^{-2}s^{-1}$)			
Linares				
Covering				
Control	407,77 ab	196,60	141,77	162,29 b
Netting	506,00 a	166,83	152,03	224,19 a
Woven	512,63 a	207,48	135,67	205,91 ab
Plastic	276,98 b	161,25	135,12	225,10 a
Cultivar				
Blue Ribbon	441,15	164.54 b	123,18	183,64 b
Top Shelf	410,98	201,54 a	159,12	225,10 a
Interaction				
Cultivar x Covering	ns	ns	ns	ns
Traiguén (*cv. Top Shelf*)				
Covering				
Control	165.4	327.1	344.8 ab	246,6
Netting	310.2	361.0	374.5 a	253,1
Woven	269.6	262.7	299.9 b	253,1
Plastic	282.8	254.8	314.1 ab	239,3

Different letters indicate significant differences among rows (LSD; P≤ 0.05). ns indicates non-significant differences.

Fuente: Elaboración propia

CAPÍTULO 3

CONCLUSIONES GENERALES

Este estudio genera evidencia consistente de que las coberturas retrasan la ocurrencia de un estrés hídrico moderado-severo en comparación con condiciones al aire libre y con restricción de riego. Reduce los requerimientos hídricos, disminuye la fotoinhibición, por lo tanto, mejora la eficiencia del uso de agua de riego. En condiciones de alta demanda evaporativa, todas las coberturas muestran una menor reducción de la conductancia estomática en respuesta a un estrés hídrico moderado-severo. Port otro lado, el cv. Top Shelf posee un mejor mecanismo para tolerar una alta demanda hídrica y una condición de estrés hídrico, debido a su alta sensibilidad estomática sumado a un sistema radical más denso y profundo que el cv. Blue Ribbon.

Las plantas bajo cobertura exhibieron en promedio un contenido volumétrico de agua en el suelo mayor, manteniendo un estado hídrico superior que el de aquellas descubiertas.

Cabe destacar que, el uso de rafia y plástico genera un comportamiento anisohícrico en las plantas, mientras que malla y al aire libre, mantienen un comportamiento isohídrico.

El VPDair se correlaciona negativamente con el SWP, siendo significativa solo bajo condiciones al aire libre y bajo malla.

Si bien las plantas bajo riego convencional, la función del PSII se encuentra óptimo en todos los tratamientos. No obstante, plantas descubiertas la eficiencia del PSII se ve disminuida bajo un déficit hídrico.