Sap flow of a wild cherry tree plantation growing under Mediterranean conditions: assessing the role of environmental conditions on canopy conductance and the effect of branch pruning on water productivity

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Abstract

In recent decades, wild cherry has been one of the species most widely used for reforestation in Europe. Studies aiming to select and improve trees to give them the best growth rates and wood properties have increased in response to growers' demands. However, information relating to key physiological processes such as transpiration or stomatal conductance and to the effect of the common practice of pruning on plant-water relations is scarce. The main objective of this study was to assess the effects of environmental conditions on canopy conductance dynamics. Its secondary objective was to examine the short- and medium-term effects of branch pruning on tree transpiration, growth and derived water productivity. To this end, we measured sap flow in an experimental plantation where trees were subjected to drip irrigation and rain-fed conditions and where variables characterizing climate, soil and tree growth were also monitored. The results demonstrated that the Jarvis-Stewart approach was appropriate for studying the responses of canopy conductance to environmental factors. As well as the role of vapour pressure deficit and net radiation in controlling the daily variations of canopy conductance, the single effects of decreasing soil water content (optimum relative extractable water, REW, higher than 0.4) and increasing air temperature (optimum of 21ºC), as summer conditions approached, were correctly incorporated into the modelling exercise. Soil water content exerted the greatest control on canopy conductance for trees growing under rain-fed conditions, while air temperature did for irrigated trees. Pruning significantly reduced transpiration to about 35% when pre- and post- sub-periods were compared, but also affected annual water productivity regardless of the irrigation treatment. To assess the long-term effects of pruning on water productivity, measurements in both pruned and unpruned trees would be desirable.

Keywords: canopy stomatal conductance, Penman-Monteith equation, noble wood plantations, sap flow, heat pulse, tree circumference

Introduction

Agriculture in Mediterranean areas suffers natural water scarcity and high unpredictability of extreme climatic events, both expected to increase in the future and thus affecting crop production (Fereres and Soriano, 2007). Diversification of land use may allow farmers to adapt better to these new conditions, given that plant species differ in their environmental responses. In Europe, forest plantations for wood production have been widely promoted in recent decades, mainly to confront desertification and rural abandonment (e.g. EU Regulation 2080/92), especially short-rotation plantations of species with rapid growth rates.

In the last two decades, wild cherry (*Prunus avium* L.) has been a species widely used in reforestation programmes that used noble hardwood (Ducci et al., 2013; Montero et al., 2003). Studies aiming to select and improve wild cherry trees in order to give them the best growth rates, forms and wood properties have increased in response to growers' demands (Ducci et al., 2013; Nocetti et al., 2010; Diaz et al., 2007; Curnel et al., 2003; Martinsson, 2001). Wild cherry plantations have also been established in Mediterranean areas, although these areas are outside the natural range of this species and irrigation is normally required to face summer drought (Ducci et al., 2013) and to reduce the rotation length when grown under such conditions (Molina et al., 2016a). Most of the irrigated plantations are nowadays managed in line with selvicultural guidelines, which are mainly concerned with the effects of pruning and thinning interventions on diameter growth (Vilanova et al., 2018; Cisneros et al., 2006). However, in contrast with tree plantations for fruit or nut production, little attention has been paid to the role of environmental conditions and management on tree transpiration in plantations for wood production (e.g.

Lambs et al., 2008; Cabibel and Isbérie, 1997), even though this variable is essential to proper irrigation and to the evaluation of new water management strategies, especially in areas with limiting conditions (Fereres and Soriano, 2007).

Understanding to what extent canopy stomatal conductance (g_c) is dependent on environmental variables is crucial, given its essential role in the regulation of both water losses by transpiration and CO_2 uptake for photosynthesis and, therefore, in plant growth and yield (Granier et al., 2000; Jarvis and McNaughton, 1986). For this reason, g_c is considered a good plant-based indicator for irrigation purposes (Hernandez-Santana et al., 2016). However, its use for management purposes is greatly limited by the difficulty of monitoring it continuously and by the errors associated with the subsequent up-scaling from leaves to tree or canopy surfaces (Ewers and Oren, 2000). In contrast to this approach, the "up-bottom" approach, based on the combination of the Penman-Montheith equation and sap flow measurements, provides a direct estimate of g_c, as the canopy is considered as a big "leaf" (Magnani et al., 1998). The Jarvis-Stewart modelling approach (Stewart, 1988; Jarvis, 1976) is commonly used for studying the combined effects that environmental factors such as vapour pressure deficit or soil water content may have on g_c (del Campo et al., 2019; Kučera et al., 2017; Hernandez-Santana et al., 2016). The multiplicative approach followed in the modelling assumes that environmental factors affecting g_c are not interacting, so every effect is described singly (Granier et al., 2000; Jarvis, 1976). However, as summer approaches in semi-arid conditions, advancing soil water depletion, vapour pressure deficit reduction and air temperature increase may affect g_c in concert, meaning that their separate effects could not be assessed properly. The combined study of sap flow in trees subjected to distinct environmental conditions may help overcome this problem for a particular species. In this respect, comparing trees which are well-watered with trees growing under natural semi-arid conditions may help greatly to isolate, for example, the effect of soil water availability on stomatal regulation.

Branch pruning in forest plantations is a common practice that aims to get a maximum of free tree trunks and so increase timber value (Springmann et al., 2011; Kupka, 2007). While most of the literature on branch pruning focuses on its effects on *Eucalyptus* plantations (e.g. Muñoz et al., 2008; Pinkard et al., 2004; Pinkard and Beadle, 2000), for which it has been suggested that an optimum of pruning 40 to 50% of the total crown increases diameter growth, the results in wild cherry tree plantations indicate the opposite, with negligible or even negative effects of pruning on diameter and height growth (Springmann et al., 2011; Kupka, 2007). On the other hand, branch pruning immediately reduces transpiration by removing part of the trees' leaf area and by reducing the ratio between leaf area and conducting sapwood (Forrester et al., 2012). It may also improve the water status of the retained leaves and increase their stomatal conductance (Pinkard et al., 1998), counterbalancing the reduction in transpiration. The effect that this practice may have on tree water use is still poorly documented for wood plantations, unlike fruit plantations, which means it is not well known how much water productivity or the water transpired per yield (Molden et al., 2010) might be affected.

The study reported here specifically addressed transpiration of wild cherry trees during the two growing periods by measuring sap flow in an experimental plantation where trees were subjected to contrasting soil water content treatments, i.e. drip irrigation *versus* rain-fed conditions. Variables characterizing environmental conditions and tree growth were also monitored. The first growing period was characterized by typical crown temporal evolution for broad-leaf species, while the second growing period saw intense crown pruning of all the trees in the plantation. The main objective of this study was to assess the effects of environmental conditions on canopy conductance dynamics by following the Jarvis-Stewart modelling approach during the first growing period. Secondly, we assessed the short- and medium-term effects of branch pruning on tree transpiration, growth and derived water productivity.

Materials and methods

Study site and experimental design

The site is located near Barcelona, at IRTA's experimental station in Caldes de Montbui (41º36´47´´ N, 2º10´11´´ E) at a height of 170 m asl. The climate is Mediterranean with a mean annual (1991-2010) temperature of 14.4 ± 0.2ºC, reference evapotranspiration of 846.8 ± 23.3 mm and rainfall of 599.4 ± 33.4 mm. Data were obtained from a weather station on the site (Servei Meteorològic de Catalunya, UTM X430803, UTM XY4607309).

The experimental plantation was established in 2006 at a tree density of 625 trees ha^{-1} and with spacing between the trees and between the rows of 4 m (16 m^2 $tree^{-1}$), and used the clone Salamanca 4 (Sa-4) most planted in Mediterranean areas of Spain. The selected site was an alluvial terrace with two zones clearly showing different soil performances and separated by a transition zone with mixed materials from both. The experimental design followed a split-plot structure with three replications arranged in a complete block design (Molina et al., 2016a). The main plot factor was soil management (soil tillage to 30 cm depth *versus* no tillage) and the sub-plot factor was drip irrigation (I, irrigated or NI, non-irrigated). The sub-plots were separated from each other by buffer tree rows and each sub-plot contained four sample trees. Irrigated treatments were drip-irrigated from May to September with 4 emitters (16 l $h^{-1}$$tree^{-1}$) and daily doses were calculated at the beginning of each week as a function of the weekly sums of reference evapotranspiration and rainfall during the previous week. There was no irrigation when evapotranspiration was lower than rainfall (Molina et al., 2016a).

In December 2010, average tree height was 4.7±0.1 m and the mean diameter at breast height was 5.7±0.1 cm. Trees were pruned every two to three years during the growing season, with approximately one third of the total crown volume removed from the lowest part of crowns.

Measurements of meteorology and soil water content

Meteorological conditions were measured at two locations, i.e. 2 m high at a standard weather station located in an open area 50 m away from the plantation and at a tower placed approximately in the centre of the plantation and 2 m above the canopy's height. At the standard weather station, rainfall (ECRN-100, Decagon Devices, Pullman, USA), air temperature and humidity (RH-T sensor, Decagon Devices, Pullman, USA), wind velocity and wind direction (Davis cup anemometer, Decagon Devices, Pullman, USA) and solar radiation (PYR Solar radiation sensor, Decagon Devices, Pullman, USA) were measured every 60 seconds and averaged every 30 minutes (Em-50, Decagon Devices, Pullman, USA). At the tower, net radiation (Q7.1-L REBS Net Radiometer, Campbell Scientific, USA) was measured together with air temperature and humidity, wind velocity and wind direction and solar radiation (with the same sensors described above). The data collected were systematically verified by comparison with data from an official meteorological station (Servei Meteorològic de Catalunya, UTM X430803, UTM Y4607309) located about 500 m from the plantation.

Soil water content (SWC) was measured under the crown projection of sample trees with 3 sensors for each tree. At the mid-point between the southern drip emitter and the tree trunk (I), and at the same position for the non-irrigated trees (NI), 10 cm-long probes (10-HS, Decagon Devices, Pullman, USA) were vertically inserted, with their centres at soil depths of 25, 50 and 100 cm. 60-second measurements were averaged and stored every 30 minutes (Em-5, Decagon Devices, Pullman, USA). To avoid bad contact between the sensors and the soil matrix, gravel was removed before installation. Sensor readings were systematically corrected by taking into account the volumetric percentage of gravel calculated for each measurement point (Molina et al., 2016a).

Time series of SWC for every probe were later converted to relative extractable water by roots (REW, dimensionless), following Granier et al. (2000):

$$REW = (W - W_m) / (W_{FC} - W_m) \quad \text{Eq.(1)}$$

where W is the 30 min-value of soil water content ($cm^3 \cdot cm^{-3}$), W_m is the minimum soil water content during the study period and W_{FC} is the soil water content at field capacity. Finally, mean REW values were obtained for both I and NI trees.

Canopy cover, tree growth dynamics and tree biomass removal by branch pruning

Relative canopy cover (RCC, %) was calculated approximately every twenty days in the early morning by means of sky-oriented photographs taken with an 18 mm-lens Canon EOS 400D digital camera mounted on a tripod 50 cm high and horizontally levelled. Two sky-oriented photographs were taken of each tree at two fixed positions (north and south) 50 cm apart from the tree trunk. The images were analysed with a standard software that calculates RCC based on HUE data for every sample tree by considering all the pixels in green, brown and yellow (Casadesus et al., 2007).

Tree diameter (cm) was measured monthly at breast height (1.4 m) with a diameter tape; and tree height (m) was obtained with a telescopic height pole at the beginning and end of every year.

All the trees in the experimental plantation were pruned in the second year of the study (mid-June 2013): from one to four branches were cut from the lowest part of the tree crowns. Weight of total fresh biomass removed for each tree was calculated in the field, while dry total weight was obtained after calculating the ratios of fresh to dry weight for the leaves and woody materials (1 sub-sample taken from each sample tree) in the laboratory. In addition, allometric relationships were obtained from the diameters of all the branches removed by the pruning.

Sap flow: measurements, potential sources of errors and tree transpiration estimate

Sap flow was measured in all the sub-plots: one tree in each in the 2012 growing season and two trees in each in the 2013 growing season. For this study, we selected the trees growing in the part of the plantation with better soil performance, characterized by a sandy-clay-loam texture, about 10% gravel content and available soil water of 112 mm to a soil depth of 100 cm. Also, given that soil management showed no significant effect on tree growth rates (Molina et al., 2016a), trees from both soil treatments were included. Thus sap flow sensors based on the heat ratio method (HRM) (Burgess et al., 2001), installed in mid-March, measured 4 and 3 trees (2012) and 6 and 5 trees (2013) for I and NI treatments, respectively. The biometric characteristics of the trees measured are given in Table 1.

[TABLE 1 AROUND HERE]

Sap flow sensors (ICT International, Australia) were programmed to measure every 100 seconds and to average the data every 30 minutes. One sensor was installed at each sample tree, 1.3 m high and on the east side of the trunk. The velocity of the heat pulse emitted by the heater needle was measured by thermocouples placed 1.25 and 2.75 cm from the cambium, and 5 cm above and below the heater (Burgess et al., 2001). Thermal diffusivity and wood moisture fraction values were calculated from several tree ring cores, following Kravka et al. (1999). To correct heat pulse velocities when necessary, the alignment of the probes was checked yearly by testing the difference between the measurements and the baseline, which corresponded to the zero sap flow measured during the first leafless week in December. A possible underestimate caused by the probe-induced effects of wounding (Barret et al., 1995) was assessed for each sample tree by comparing the time series of mean daily sap flow values normalized by reference evapotranspiration and REW. This controlled the effects of environmental conditions on trees' dynamics. Clear decreases (approximately 3 days long) were observed in the time series between 15 and 25 days after sensor installation, followed by very similar patterns that did not seem to be further affected by wounding. According to these dynamics and following the recommendations of Wiedemann et al. (2016) for correcting the wound effect in diffuse-porous species, correction factors were calculated for each sample tree by comparing the normalized mean daily sap flow values between the 10-days periods of before and after the described wounding effect appeared. Thus, the time series of sap flow for each tree were multiplied by the obtained correction factors, and the sap flow data which covered the period from sensor installation until the decrease leaded by the wounding effect were not included in further analyses.

As azimuthal and radial variations of sap flux density may lead to major biases in tree transpiration calculations (e.g. Kume et al., 2012), two independent experiments were run during the 2014 growing season in order to establish the application of correction factors to our previous sap flow data when necessary (Molina et al., 2016b). Both experiments used sensors which estimate sap flow based on measurements of heat pulse velocity at different sapwood depths. Briefly, the azimuthal variation was analysed by measuring sap flux density by 4 HRM sensors (as used in this work) located at the four compass points of 6 trees. The radial variation was tested by measuring sap flux density with Compensation Heat Pulse Method (CHPM) sensors (Green et al., 2003) placed 1.0, 1.9 and 3.0 cm from the cambium of 14 trees (east side). On the one hand, the azimuthal variation results showed that the ratio between the sap flux density on the east side and the average from the four sides ranged from 0.73 to 1.46, with no clear systematic pattern observed between trees. Thus, in this study no further correction was made to the readings taken on the east sides. On the other hand, we considered that our HRM sensors with measurements at two sapwood depths were sufficient to characterize the radial profile of sap flux density in our small trees (inner measurement covering a mean 72.4% of total sapwood in 2013, the study year with the highest values), as comparisons between the radial profiles obtained with HRM and CHPM measurements followed similar patterns in most of the sample trees.

Sapwood increment during the growing season was also taken into account because the wild cherry trees were young and they can be considered a fast-growing species at this age (Guan et al., 2012). It was assumed that sapwood depth grew proportionally to tree diameter in the growing season, as in other young fast-growing trees (Guan et al., 2012). To estimate the sapwood area from stem diameters, thickness of sapwood and bark was visually identified in several tree cores during the experiment (Molina et al., 2016b; Nadezhdina et al., 2002). Sapwood area (SW, cm^2) was calculated monthly as a function of diameter at breast height ($SW = 0.93 \times DBH^{1.9028}$, R^2=0.98, n=20). Moreover, based on our field observations and following Beauchamp et al. (2013), as the sensors remained in a fixed location during the growing season, trees grew around the sensors. For each month, the sapwood area was divided into two concentric bands (outer and inner band), delimited by the mid-point between the thermocouple locations (Bleby et al., 2004; Hatton et al., 1990). The sapwood increment during the month was assigned to the outer thermocouples, i.e. the cross-section area of the outer band was equal to the increment band due to the growth of trees around the sensors during the month plus the previous outer band. Tree transpiration ($l \cdot s^{-1}$) was calculated by multiplying the outer band by the sap flux density measured in the outer thermocouples; and the inner band, by the inner sap flux density measured in the inner thermocouples; and then adding both and multiplying this value by numeric factors to obtain the proper units.

Data treatment and analysis

Canopy conductance responses to environmental factors

The responses of canopy conductance (g_c, mm·s^{-1}) to environmental factors were studied for the 2012 growing season, in order to avoid the effect that branch pruning has on canopy cover and thus on transpiration dynamics. The period in which canopy cover showed very similar values (from mid-April to mid-November) was selected. g_c was computed by the inverse form of the FAO-Penman‑Monteith equation (Allen et al., 2006), as follows:

$$g_c = \frac{g_a \cdot \partial \cdot \lambda \cdot Ea}{\Delta \cdot Rn - \lambda \cdot E_a \cdot (\Delta + \partial) + pa \cdot cp \cdot g_a \cdot (es - ea)} \cdot 1000 \qquad \text{Eq.(2)}$$

where g_a is the aerodynamic conductance (mm·s^{-1}), ∂ the psychrometric constant (66.5 Pa K^{-1}), λ the latent heat of vaporisation calculated from air temperature (2.407-2.511 MJ·kg^{-1}), E_a the mean transpiration for I and NI trees normalized by dividing tree transpiration by crow projection (mm·s^{-1}), Δ the slope of the saturated vapour pressure *versus* temperature curve, Rn the available energy (MJ·m^{-2}·s^{-1}; assumed to be equal to net radiation and ignoring the usually small changes in net soil- and within-canopy heat fluxes), pa (kg·m^{-3}) is the density of air, cp the specific heat of air at constant pressure (1.013 MJ·kg^{-1}·K^{-1}), and (es – ea) (Pa) the saturation vapour pressure deficit, VPD. Aerodynamic conductance was calculated from wind speed according to Thom (1975):

$$g_a = \frac{k^2 \cdot u}{\left[\ln\left(\frac{zm - zd}{z0}\right)\right]^2} \cdot 1000 \qquad \text{Eq. (3)}$$

where k is the von Kármán constant (0.40), u ($m \cdot s^{-1}$) wind speed measured at height zm (8 m), zd (m) the zero-plane displacement height (taken as 0.75 h where h is the average canopy height of 6 m), and z0 (m) the surface roughness (0.1 h).

g_c was estimated for daytime hours and when DPV was higher than 600 Pa due to the likely errors associated with sap flow measurements under low DPV values (Ewers and Oren, 2000; Granier et al., 2000). In addition, as only dry-canopy conditions were considered (García-Santos et al., 2009; Harris et al., 2004), the time intervals with measured rainfall and a post-precipitation period of 4 h to allow the canopy to fully dry out were excluded.

The g_c values found with Eq. (1) were all regressed against net radiation (Rn, $MJ \cdot m^{-2} \cdot s^{-1}$), vapour pressure deficit (VPD, kPa), air temperature (T, ºC) and relative extractable soil water content (REW). Different non-linear relationships proposed in the literature were compared (see, for instance, Kučera et al., 2017; Harris et al., 2004) by studying the fit of the regression lines between the measured and the modelled values and the visual inspection of residuals. The relationships (henceforth response functions) were estimated for the upper envelope of data points by the quantile regression technique (quantiles ranging from 95 to 98%) in order to reduce as much as possible the effects that the other interacting environmental factors may have when describing the single relationships (Figure 1). In addition, since a time lag between tree sap flow and canopy transpiration has often been reported as leading to an increase in the scatter of data in the relationships between g_c and environmental variables (Kučera et al., 2017; Granier et al., 2000), the fit for different time lags (from 30 minutes to 2 hours) was studied, with the fit without any time lag being the one that correlated better with all the environmental variables.

[FIGURE 1 AROUND HERE]

The response functions selected were the following:

$$f(Rn) = \frac{Rn}{Rn+a_0} \quad \text{Eq. (4)}$$

$$f(VPD) = a_1-a_2\cdot \ln(DPV) \quad \text{Eq. (5)}$$

$$f(T) = T^2\cdot a_3+T\cdot a_4 \quad \text{Eq. (6)}$$

$$f(REW) = \frac{(a_5+a_6\cdot REW-((a_5+a_6\cdot REW)^2-2.8\cdot a_5\cdot a_6\cdot REW)\wedge 0.5)}{1.4} \quad \text{Eq. (7)}$$

The empirical multiplicative algorithm defined by Stewart (1988) and following Jarvis (1976) was then adopted:

$$g_c = g_0 + g_{max}\cdot f(Rn)\cdot f(VPD)\cdot f(T)\cdot f(REW) \quad \text{Eq. (8)}$$

where g_c is the estimated canopy conductance, g_o is the baseline canopy conductance not modulated by environmental conditions and considered as cuticular conductance (Magnani et al., 1998) and g_{max} is maximum canopy conductance ($mm\cdot s^{-1}$), which is multiplied by the response functions that affect stomatal closing and opening and for which values ranging from 0 (full closure) to 1 (maximum stomatal opening) are assigned.

The optimum models were selected by considering three datasets: data from the I trees (model I), data from the NI trees (model NI) and data from both I and NI trees (general model). The parameters for every tested model were calibrated by minimizing the differences between the predicted and the observed values through the Gauss-Newton algorithm (Annex 1). The different multiplicative model structures were compared through the Akaike information criterion (AIC), which is a model optimality measurement that trades off complexity and the fit of the model (Akaike, 1973), so that the models with the lowest AIC value were selected (Annex 1). The performance of the selected models for the three datasets was evaluated by splitting the 2012 data into two datasets, one for calibrating the parameters (even days) and the other for validating them (uneven days) (Granier et al., 2000; Gash et al., 1989). Model goodness-of-fit was evaluated in terms of mean squared errors of prediction (MSE, $mm \cdot s^{-1}$), normalized root-mean-square deviation (NRMSD, %) and by studying the fit of the regression lines between the observed and the predicted values (Kučera et al., 2017; Petzold et al., 2011).

Assessing the branch pruning effects on tree transpiration, growth and water productivity

Branch pruning effect was assessed in two ways. On the one hand, cumulative tree transpiration from the 7-day sub-periods before and after pruning was statistically compared through paired t-student tests for the I (n=6 trees) and NI (n=5 trees) trees, given the similarity in the environmental conditions (Table 2). On the other hand, total transpired water, wood volume increment and water productivity, as the ratio between the former variables (WP, $m^3 \cdot l^{-1}$) (Molden et al., 2010; Fereres and Soriano, 2007), were calculated for every study year. The wood data for the sample trees were obtained from a previous study carried out within the experimental plantation (Molina et al., 2016a). In this case, the statistical comparisons through paired t-student tests included the trees in which transpiration was measured in both growing seasons (n= 7; Table 1).

[TABLE 2 AROUND HERE]

All statistical analysis, non-linear and quantile regressions were done in R (R Core Team, 2013). Statistical tests and fitted parameters were significant with a significance level of $p<0.05$.

Results

Environmental conditions during the study period

Both growing seasons were characterized by dry summers (June-August) with low rainfall inputs (63 and 43 mm in 2012 and 2013, respectively, or 14 and 7% of annual rainfall) and high values for reference evapotranspiration (mean daily values of 5 and 4 mm day^{-1} in 2012 and 2013, respectively) (Figure 2), although it was higher in 2012 due to the higher magnitude of the environmental drivers (Table 3). The REW dynamics reflected the different water inputs in the I (rainfall + irrigation) and NI (rainfall) trees: 6,417 and 6,903 mm *versus* 414 and 485 mm for the 2012 and 213 growing seasons, respectively. Furthermore, the NI trees showed strong soil water depletion in both growing seasons, although this started later in 2013 because of a higher rainfall recharge in early spring (121 *versus* 63 mm in April 2012 and 2013). In contrast, REW in the I trees was most of time close to 1 (close to field capacity) and consequently higher than 0.4 as the threshold from which tree transpiration is expected to be affected (Granier et al., 2000), except for a period of about 20 days between April and May 2012 when irrigation system failed.

[FIGURE 2 AROUND HERE]

[TABLE 3 AROUND HERE]

Modelling the canopy conductance responses to environmental factors

The temporal dynamics of relative canopy cover and tree transpiration for the 2012 growing season are shown in Figure 3.

According to the deciduous character of wild cherry tree, the sprouting of the leaves made canopy development to start at the beginning of April, reaching its maximum values in June (68.7±9.6 *versus* 50.8±15.3% for I and NI, respectively). Leaves remained in crowns until the end of November.

Transpiration at the beginning of the growing season clearly followed the pattern in canopy cover and was quite similar in the two treatments, although it showed steadily diverging decreases for both I and NI trees as summer conditions approached. The differences in timing and magnitude for the transpiration responses between the I and NI trees indicated that the regulation of stomatal conductance was not affected in the same way by the environmental conditions (Figure 4). For both treatments, and with the magnitude depending on the day considered, canopy conductance was maximum at early hours; after peaking, it decreased to a lower value that was maintained during the central hours; then it peaked again before decreasing until the end of the hours of light (Figure 4).

[FIGURE 3 AROUND HERE]

[FIGURE 4 AROUND HERE]

The canopy conductance modelling started with the analysis of all the possible combinations among the response functions (Annex 1). Table 4 shows the optimum models when considering one, two or three response functions, since the models did not converge when all the environmental variables were included. As indicated by both the reduction in the AIC values and the statistics quantifying the model's goodness-of-fit (Table 4), the steady introduction of the response functions improved the model performance for the I and NI datasets (model I and model NI), while the general model achieved the best results when taking into account two response functions instead of three. The environmental variables considered varied depending on the model: while the response function introduced for soil moisture improved both model fit and quality for model I and the general model, it was the response function for air temperature that did so in the case of I trees (Annex 1). The comparisons between the observed and the modelled values showed poor results when including all the data (general model), but acceptable results for the I and NI datasets (model I and model NI), although the latter had a slightly better model performance, as indicated by an adjusted R^2 of 0.81 (Figure 5) and a NRSMD value of 6.21% (Table 4). It should also be noted that both model I and model NI, but especially the latter, underestimated canopy conductance for high observed values (Figure 5).

[FIGURE 5 AROUND HERE]

[TABLE 4 AROUND HERE]

Branch pruning effects on transpiration, growth and water productivity

Mean total dry weight removed by pruning was 7.20 ± 2.38 kg·tree^{-1}, while relative canopy cover reduction showed a mean value of 52.7 ± 9.7%. As expected, biomass removal correlated significantly with relative canopy cover reduction; and the allometric relationships between branch diameter and total fresh weights showed very good fits (Annexes 2 and 3). Pruning also affected tree transpiration in the short term, with significantly higher cumulative values for both I (p=0.042) and NI (p=0.048) trees in the pre-pruning period, translated into mean decreases of 30.9 ± 20.7 and 38.4 ± 26.8%, respectively.

To assess the effect of branch pruning in the medium term, wood increment, total transpired water and water productivity in 2012 and 2013 were compared. Paired t-students' tests showed that tree transpiration, though higher in 2012, did not differ between 2012 and 2013 in either I or NI trees. However, wood increment was significantly higher in 2013 despite the reduction of crown biomass by pruning (Figure 6), while water productivity also showed significantly higher values in 2013 for both I and NI trees (Figure 6). It is, therefore, important to highlight the influence of the timing of pruning when evaluating water productivity. In the period before the 2013 pruning, most of the diameter growth had already been achieved, with 74 and 96% of the total diameter increment for I and NI trees, respectively (Figure 7). In contrast, in the same period of 2012, characterized by worse soil water content conditions, diameter growth accounted for 62 and 58% of the total diameter increment for I and NI trees, respectively.

[FIGURE 6 AROUND HERE]

[FIGURE 7 AROUND HERE]

Discussion

Wild cherry transpiration and canopy conductance under drip irrigation and rain-fed conditions

Our cherry trees (7 years old in 2012) gave mean transpiration values of 3.1 and 6.2 litres day^{-1} in the 2012 growing season (Figure 3, right), when growing under rain-fed conditions (NI) or drip irrigation (I), respectively. These values are in the low range when compared with other cherry plantations growing in Mediterranean areas, which was probably caused by the reduced ratios between leaf area and conducting sapwood in our trees because of the intensive pruning in the initial years of the plantation. Juhász et al. (2013) found cumulative values ranging from 10.9 to 23.6 litres day^{-1} for trees of a similar age and tree density to ours, but selected and managed for fruit production. Cabibel and Isbérie (1997) compared transpiration during one summer month in 12 year-old trees growing under irrigation *versus* rain-fed conditions and obtained 101 *versus* 15 litres day^{-1}, respectively. Chifflot (2003) observed mean tree water consumption of about 5 litres day^{-1} in 17 year-old wild cherry trees growing under irrigation conditions. Finally, Lambs et al. (2008) found mean tree water consumption of 9.5 litres day^{-1} in 7-year old wild cherry trees growing under rain-fed conditions.

In line with the tree transpiration observed, canopy conductance (maximum values no higher than 0.02 mm· s^{-1}; Figure 4) was also much lower than in other broad-leaf species, since there is no available information for cultivated wild cherry trees for direct comparisons. As examples, Magnani et al. (1998) obtained a mean value of 5 mm·s^{-1} in a mature beech forest, while del Campo et al. (2019) obtained maximum values close to 2 mm·s^{-1} in a disperse oak coppice forest growing under water-limited conditions.

Daily courses of canopy conductance in I and NI trees were quite similar, although the magnitude and the cumulative effect of the environmental variables differed, as discussed below. Normally, canopy conductance was large early in the morning under conditions of sufficient solar radiation and low vapour pressure deficit (Figure 4). This then decreased steadily during the day before a second maximum of canopy conductance was sometimes observed late in the afternoon (Kučera et al., 2017; Magnani et al., 1998).

Canopy conductance response to environmental conditions

The aerodynamic coupling between plant and atmosphere is considered a prior requirement to a proper assessment of canopy conductance responses to environmental variables (Zhang et al., 2016; Magnani et al., 1998; McNaughton and Jarvis, 1983). In the air surrounding leaves, a quasi-laminar flow of heat and vapour (boundary-layer resistance) is likely to appear, which results in the turbulent flow (turbulent resistance) driven by air eddies not being directly linked to the physiological behaviour of leaves and decreasing aerodynamic conductance. To evaluate this, the classical approach of McNaughton and Jarvis (1983) is normally followed (e.g. del Campo et al., 2019; Zhang et al., 2016), where a decoupling coefficient Ω is calculated. Broad-leaf forests are recognized as those ecosystems that are more prone to be decoupled due to both large leaf size and higher stomatal than aerodynamic conductance (Magnani et al., 1998; Jarvis and

McNaughton, 1986). This aspect is, however, only partially true for tree plantations growing under low tree density conditions and low values of LAI, in which the leaf boundary layer may have a negligible effect on aerodynamic conductance (del Campo et al., 2019; Zhang et al., 2016; Nicolás et al., 2008). In our case, calculated Ω values were no higher than 0.01 at any time (data not shown), indicating a very high coupling between tree crowns and atmosphere under our experimental conditions (Magnani et al., 1998).

After calculation of g_c values by means of the inverted form of the Penman-Monteith equation, the second step in the modelling exercise was to study the various relationships between g_c and the environmental variables measured under optimal conditions (upper envelope through quantile regression at 95-98%). g_c followed the generally expected patterns; all the selected relationships had already been satisfactorily used for other species and environmental conditions: the Michaelis-Menten quadratic form for net radiation (Thornley and Johson, 1990), the negative relationship with ln D (Oren et al., 1999) and the polynomial relationships with air temperature (Gash et al., 1989) and with REW (Granier et al., 2000). From these fits, information for better management of wild cherry tree plantations for timber production can be drawn. Optimum responses of canopy conductance to temperature were in the range of 15 to 25ºC, with the optimum temperature value being close to 21ºC. In addition, the effect of REW on canopy conductance was almost linear until reaching a value close to 0.4, after which a plateau was observed. While the observed pattern of g_c with REW is commonly described elsewhere (Granier et al., 2000), the effect of temperature was more similar to effects reported for species growing under non-limiting conditions, such as poplar in Germany (Petzold et al., 2011) or cypress and cedar in mountain areas of Japan (Saito et al., 2017). In this sense, the clone considered in the present study (Salamanca-4) comes from a region of Spain where climate is continental and rainfall does not act as a limiting factor. The clear steep decrease in g_c from the optimum temperature to higher values indicates that transpiration was highly controlled by stomatal regulation once summer conditions approached, when days with maximum temperatures between 30 and 45ºC showed relative canopy conductance of about 10% in both I and NI trees.

The general model taking into account both I and NI data did not show satisfactory results, since the different responses of canopy conductance between the I and NI trees to environmental factors such as REW lead to poor fits. In contrast, the modelling of the I and NI datasets independently showed model performances comparable to other studies that followed a similar modelling procedure (Kučera et al., 2017; Granier et al., 2000; Magnani et al., 1998). While the daily variations in g_c were highly controlled by the dynamics of net radiation and DPV, the progressive response of g_c to summer conditions differed between the models considered. In the case of the general model, as the response functions for DPV and net radiation were followed by that for REW, it can be stated that REW exerted greater control on stomatal regulation in our clones of wild cherry trees than air temperature did. This, however, was not the case for the I trees, for which REW also probably affected g_c dynamics (especially at the beginning of the growing period), but to a lesser extent than air temperature did. This aspect, together with the clear negative impact of REW leading to a decreased g_c pattern in the NI trees, highlight the key roles of both interacting environmental factors in controlling the progressive physiological adjustments of *Prunus avium* to semi-arid conditions. Furthermore, the cumulative diameter increments in the July-November period of 2012, like those with more pronounced differences between the treatments, showed very similar values (42.8 *versus* 38.4 for I and NI), thus indicating that the single control on growth of air temperature (whether controlling g_c, photosynthetic activity or both) can be comparable to the effects of REW and air temperature acting in concert.

The effect of branch pruning on transpiration, growth and water productivity

In our study, branches were removed to a predetermined height at the beginning of the summer period, as a better wound occlusion was expected at that time (Springmann et al., 2011). It is clear that branch pruning directly reduces the leaf area available for photosynthesis and transpiration. Intuitively, one would expect pruning to reduce the growth of trees, at least in the short term. However, the photosynthetic activity of remaining leaves may be enhanced by pruning, leading to a compensatory growth effect (Pinkard et al., 1998). This has been seen especially in *Eucalyptus* plantations, for which it has been suggested that an optimum total crown reduction of about 50% increases diameter growth in the medium term (e.g. Muñoz et al., 2008; Pinkard et al., 2004; Pinkard and Beadle, 2000). In contrast, negligible or even negative effects have been described in wild cherry plantations (Springmann et al., 2011; Kupka, 2007). Springmann et al. (2011) found significant lower stem diameter growth in the years after pruning, when comparing conventionally pruned and control trees. In our case, despite the lack of unpruned trees in the experiment, the results may also help improve the management of noble wood plantations by taking into account not only growth aspects but also water use considerations. Comparison between the pre- and post-pruning periods under similar environmental conditions showed that a mean canopy reduction of about 53% (52.4 *versus* 53.1% for I and NI trees) was translated into tree transpiration decreases of 31 to 38%. This non-linear relationship between biomass removal and water consumption contrasts with the significant linear relationships between pruning intensity or leaf area removed and tree transpiration observed by Bayala et al. (2002) and Kou-Tan Li et al. (2003), which is probably explained by the differing stomatal responses to the micro-meteorological conditions between the remaining upper leaves and those removed by pruning from the base of crowns. Nicolás et al. (2008) pointed out that shaded leaves of lemon trees transpired less than exposed ones and that stomatal conductance was less important in controlling transpiration due to bigger decoupling between g_c of the shaded leaves and the atmosphere. Therefore, the removing of upper leaves with better light conditions in our trees would probably cause transpiration to reduce the crown in a more linear way.

Apart from the short-term effects, water productivity in 2012 and 2013 was significantly enhanced by tree pruning due to both reduced transpiration and increased wood volume production, regardless of the irrigation treatment. Most tree diameter growth was achieved before pruning in 2013 for both the I and NI trees, while this was not the case for the same time period in 2012. As shown here, as summer conditions approach, the responses of canopy conductance to vapour pressure deficit and air temperature gradually move away from the optimum ones, which points to the crucial role of soil water content at this time of year for obtaining optimum growth rates. Therefore, to maximize water productivity, irrigation must be controlled accurately and branches need to be pruned properly.

Conclusions

This study demonstrates the suitability of the Jarvis-Steward approach for a proper assessment of the effects of environmental factors on the regulation of canopy conductance in wild cherry trees growing under Mediterranean conditions and two contrasting water availability regimes. Apart from the role of vapour pressure deficit and net radiation in controlling the daily variations of canopy conductance, the single effects of decreasing soil water content and increasing air temperature, as summer conditions approach, were properly described and incorporated into the modelling exercise. As expected, soil water content exerted the highest control on canopy conductance for trees growing under rain-fed conditions, while air temperature was the most limiting factor for irrigated trees. In addition, branch pruning significantly reduced transpiration to about 35% when the pre- and post-sub-periods were compared, and affected water productivity regardless of the irrigation treatment. An investigation into the long-term effects of pruning on water productivity in both pruned and unpruned trees would be desirable for a further assessment of conventional pruning in tree plantations to produce noble wood.

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Figure captions

Figure 1. Examples of the non-linear regressions between relative canopy conductance and the environmental variables of net radiation and REW

Figure 2. Time series of (a) reference evapotranspiration (ET_0) and rainfall, and (b) relative extractable soil water (REW) in the 2012 and 2013 growing seasons. I: drip-irrigated trees, NI: non-irrigated trees. Daily cumulative values are shown for ET_0 and rainfall, while 30-min means are given for REW. REW values higher than 1 are equalled to 1 to make the comparison between the I and NI trees easier

Figure 3. Time series of relative canopy cover (means and standard deviations, %) and transpiration (means of daily cumulative values, litres·day^{-1}; standard deviations are not shown for clarity) for the I and NI trees during the 2012 growing season

Figure 4. Daily courses of canopy conductance (g_c, mm·s^{-1}) in four sample days from the 2012 growing period

Figure 5. Modelled *versus* observed values of canopy conductance in the validation dataset (uneven days of the 2012 growing season) for the I and NI trees. A certain level of colour transparency is applied in order to highlight point density. The 1:1 lines and the equations for the linear regression fits are also shown

Figure 6. Wood volume increment (dm^3), cumulative transpired water (l) and water productivity ($dm^3 \cdot l^{-1}$) for the 2012 and 2013 growing years. Different letters indicate significant differences between years within each treatment in the Student’s t-tests (p-value<0.05)

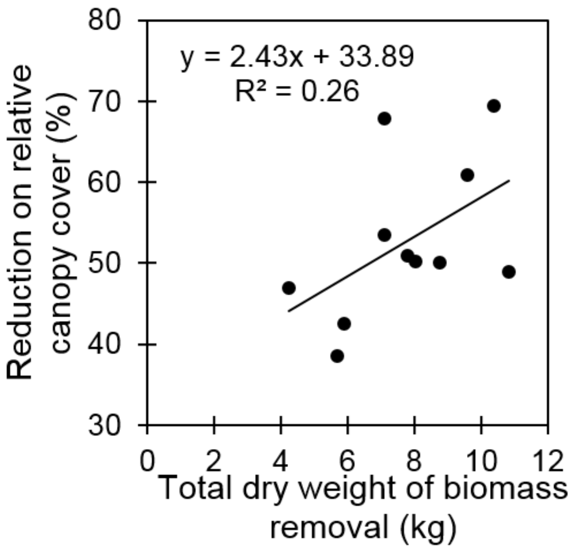
Figure 7. Time series (means and standard deviations) of tree diameters (cm) in the I and NI trees for the 2012 and 2013 growing seasons. The arrow indicates the moment of branch pruning

Annex 1. Calibrated parameters, Akaike information criterion values (AIC) and the changes in the AIC values (ΔAIC) with respect to the optimum model for all the models tested considering the three datasets. – means no convergence in the model tested. Rn: net radiation; VPD: vapour pressure deficit; T: air temperature; REW: relative extractable water. Units for the environmental variables are detailed in the Materials and methods section

Data	**Model**	**a_0**	**a_1**	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**	**AIC**	**ΔAIC**
	g_o+g_{max}*f(Rn)	0.0010742							-1223.6	4164.3
	g_o+g_{max} *f(VPD)		1.747	0.20					-4125.1	1262.8
	g_o+g_{max} *f(T)				0.0012	0.042			-3772.4	1615.5
	g_o+g_{max} *f(REW)						0.365	2.88	-4279.0	1108.9
	g_o+g_{max} *f(Rn)*f(VPD)	0.0000302	2.409	0.28					-4940.2	447.7
	g_o+g_{max} *f(Rn)*f(T)	-0.0000005			-0.0012	0.042			-3878.1	1509.8
	g_o+g_{max} *f(Rn)*f(REW)	0.0000048					0.378	3.01	-4382.4	1005.5
	g_o+g_{max} *f(VPD)*f(T)		-	-	-	-			-	-
	g_o+g_{max} *f(VPD)*f(REW)		2.040	0.23			1.110	4.00	-5387.9	0.0
	g_o+g_{max} *f(T)*f(REW)				-0.0001	0.001	0.100	1.00	2111.1	7498.9
	g_o+g_{max} *f(Rn)*f(VPD)*f(T)	0.0000302			-0.0023	0.098			-4940.6	447.3
	g_o+g_{max} *f(Rn)*f(VPD)*f(REW)	0.0000302	2.409	0.28			1.082	1.09	-2177.5	3210.3
	g_o+g_{max} *f(VPD)*f(T)*f(REW)		-	-	-	-	-	-		-
All dataset	g_o+g_{max} *f(Rn)*f(VPD)*f(T)*f(REW)	-	-	-	-	-	-	-	-	-
	g_o+g_{max}*f(Rn)	0.0006884							-421.8	3566.5
	g_o+g_{max} *f(VPD)		2.058	0.23					-2870.4	1117.9
	g_o+g_{max} *f(T)				-0.0013	0.050			-2417.4	1570.9
	g_o+g_{max} *f(REW)						-	-	-	-
	g_o+g_{max} *f(Rn)*f(VPD)	0.0000232	2.750	0.32					-3951.6	36.6
	g_o+g_{max} *f(Rn)*f(T)	-0.0000005			-0.0014	0.051			-2530.9	1457.4
	g_o+g_{max} *f(Rn)*f(REW)	-					-	-	-	-

	g_o+g_{max} *f(VPD)*f(T)		-	-	-	-			-	-
	g_o+g_{max} *f(VPD)*f(REW)		0.900	0.11			9.100	7.00	43.0	4031.3
	g_o+g_{max} *f(T)*f(REW)				-0.0001	0.001	0.100	1.00	1748.4	5736.7
	g_o+g_{max} *f(Rn)*f(VPD)*f(T)	0.0000232	2.750	0.32	-0.0018	0.087			-3988.3	0.0
	g_o+g_{max} *f(Rn)*f(VPD)*f(REW)	-	-	-		-	-		-	-
	g_o+g_{max} *f(VPD)*f(T)*f(REW)		-	-	-	-	-	-	-	-
I dataset	g_o+g_{max} *f(Rn)*f(VPD)*f(T)*f(REW)	-	-	-	-	-	-	-	-	-
	g_o+g_{max}*f(Rn)	0.0017720							-1566.1	3068.4
	g_o+g_{max} *f(VPD)		1.437	0.17					-2964.4	1670.2
	g_o+g_{max} *f(T)				-0.0010	0.033			-2872.6	1762.0
	g_o+g_{max} *f(REW)						0.360	2.10	-3605.5	1029.1
	g_o+g_{max} *f(Rn)*f(VPD)	0.0000540	2.171	0.26					-3439.9	1194.7
	g_o+g_{max} *f(Rn)*f(T)	-0.0000019			-0.0005	0.021			-2144.0	2490.6
	g_o+g_{max} *f(Rn)*f(REW)	0.0000033					0.369	2.15	-3640.9	993.7
	g_o+g_{max} *f(VPD)*f(T)		-	-	-	-			-	-
	g_o+g_{max} *f(VPD)*f(REW)		0.200	0.01			9.100	7.00	-1399.1	3235.5
	g_o+g_{max} *f(T)*f(REW)				-0.0001	0.001	0.100	1.00	-72.0	4562.6
	g_o+g_{max} *f(Rn)*f(VPD)*f(T)	0.0000540	2.171	0.26	-0.0032	0.120			-3558.214	1076.4
	g_o+g_{max} *f(Rn)*f(VPD)*f(REW)	0.0000540	2.171	0.25			1.082	13.49	-4634.594	0.0
	g_o+g_{max} *f(VPD)*f(T)*f(REW)		-	-	-	-	-	-	-	-
NI dataset	g_o+g_{max} *f(Rn)*f(VPD)*f(T)*f(REW)	-	-	-	-	-	-	-	-	-

Annex 2. Relationship between canopy cover reduction (%) and total dry weight of biomass removed (kg) by the branch pruning carried out between of 14th and 15th of June 2013. Canopy cover reduction was estimated between the 3rd and the 20th of June



Annex 3. Plots and the fitted equations for obtaining a) total biomass fresh weight (kg) and b) length branch (cm) as a function of branch diameter (cm). Mean ± SD specific leaf area (SLA) was 15.06±4.02 $m^2 \cdot kg^{-1}$

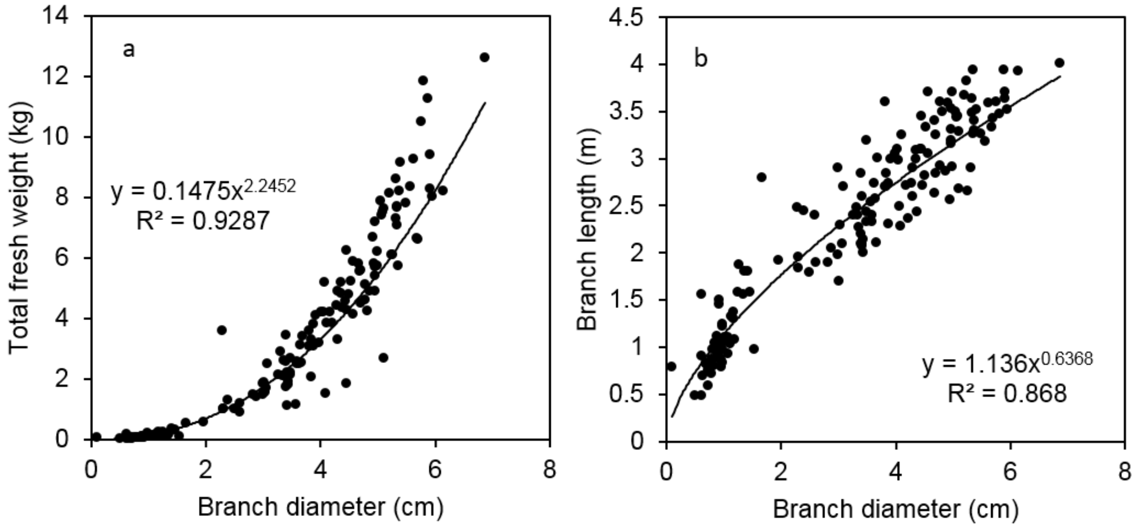


Table 1. Tree biometric characteristics (maximum values in growing seasons) of the NI and I trees selected for sap flow measurements. DBH: diameter at breast height, H: height and SW: sapwood area.

			2012			2013		
Measurement period	Irrigation treatment	Sample tree	DBH (cm)	H (m)	SW (cm^2)	DBH (cm)	H (m)	SW (cm^2)
2012-2013	I	1	9.5	7.1	67.4	11.3	7.6	93.8
2012-2013	I	2	9.6	6.6	68.8	11.1	7.2	90.7
2012-2013	I	3	10.2	6.7	77.2	11.7	7.4	100.2
2012-2013	I	4	8.8	5.8	58.3	10.4	6.6	80.1
2012-2013	NI	5	7.8	6.4	46.3	8.8	7.1	58.3
2012-2013	NI	6	9.3	6.9	64.8	10.5	7.1	81.6
2012-2013	NI	7	9	5.9	60.8	9.9	6.3	72.9
2013	I	8	8.6	7.1	55.8	11.7	7.7	100.2
2013	I	9	8.2	6.3	51.0	10.1	7.1	75.8
2013	NI	10	8.1	6.4	49.8	9.9	7.1	72.9
2013	NI	11	8	6.7	48.6	10.2	7.3	77.2

Table 2. Statistics for the 7-days sub-periods before and after the pruning for reference evapotranspiration (Eto), air temperature (T) and relative extractable water for the I (REW I) and NI trees (REW NI)

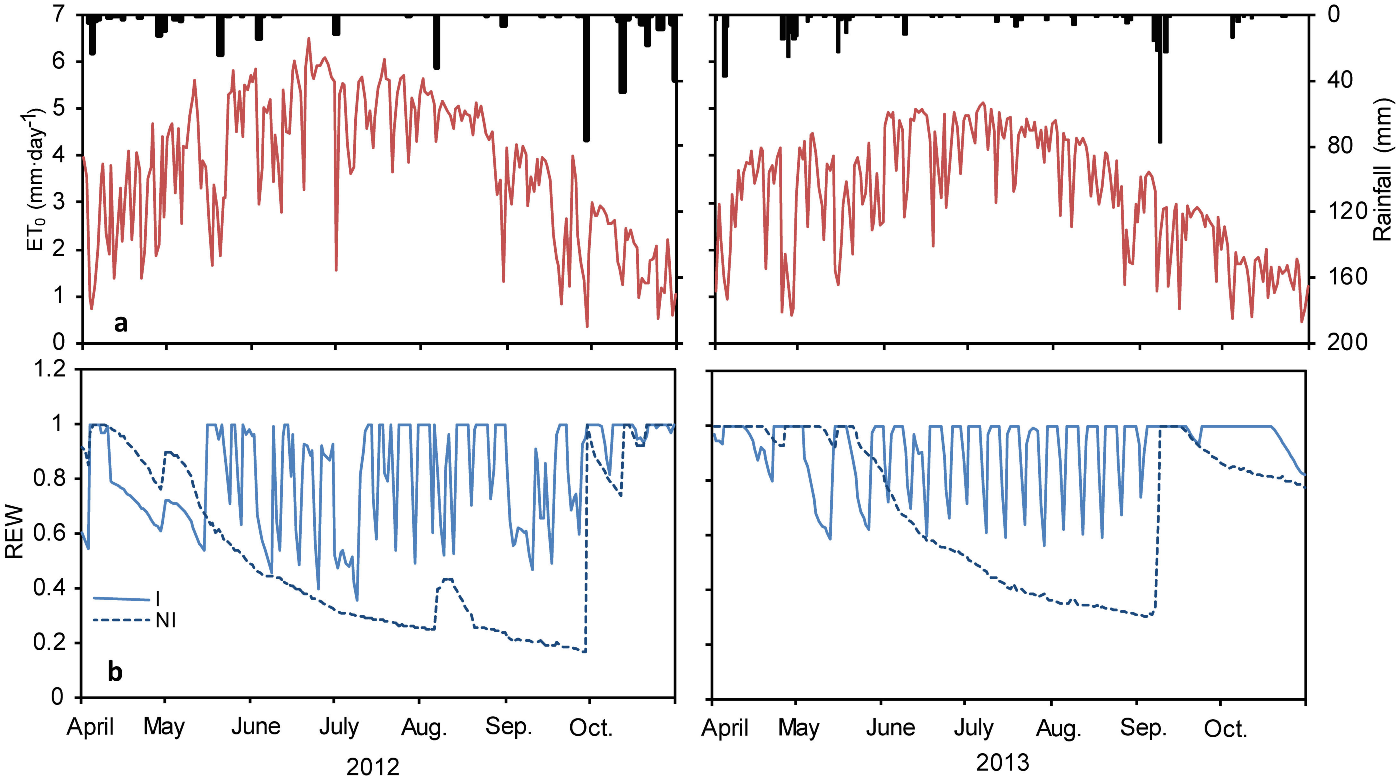
Sub-period	Value	Eto (mm)	T (ºC)	REW I	REW NI
	Mean	4.10	17.58	0.93	0.52
	SD	0.87	1.29	0.10	0.03
	Maximum	4.91	19.45	1.00	0.57
Pre-pruning	Minimum	2.68	15.60	0.77	0.49
	Mean	3.56	20.19	0.92	0.43
	SD	0.97	1.14	0.11	0.02
	Maximum	4.89	21.79	1.00	0.45
Post-pruning	Minimum	2.06	18.80	0.74	0.40

Table 3. Statistics for some variables describing the environmental conditions during the growing periods. Values for net radiation are calculated taking into account light conditions. SD is standard deviation.

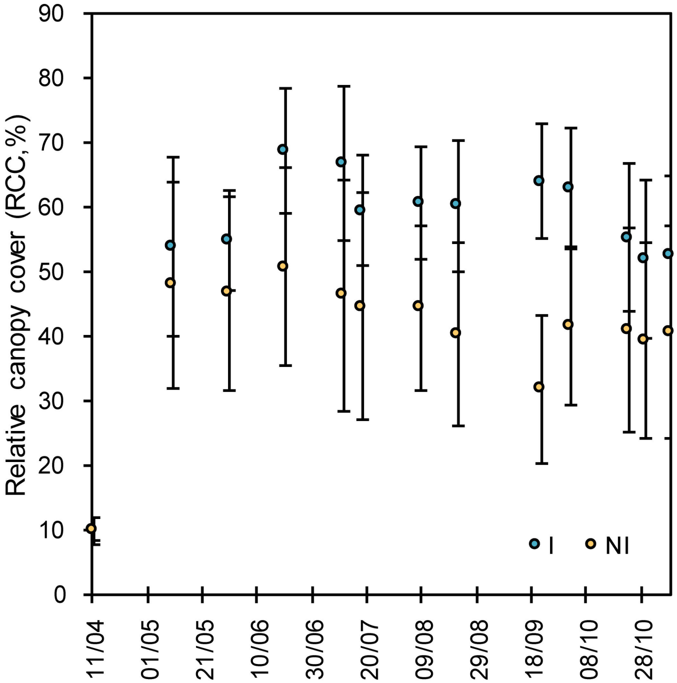
Year	Variable	Units	Mean	Maximum	Minimum	SD
	Net radiation	$MJ \cdot m^{-2} \cdot h^{-1}$	0.0002	0.0008	0.0000	0.0002
	Wind velocity	$m \cdot s^{-1}$	0.57	4.73	0.00	0.64
	Air temperature	ºC	20.26	39.69	-1.19	6.85
	Vapor pressure deficit	Pa	923.79	5377.16	21.67	907.79
	Soil water content_I	$cm^3 \cdot cm^{-3}$	0.16	0.24	0.11	0.03
	Soil water content_NI	$cm^3 \cdot cm^{-3}$	0.11	0.21	0.07	0.03
	REW_I		0.93	2.52	0.36	0.50
2012	REW_NI		0.36	1.56	0.17	0.39
	Net radiation	$MJ \cdot m^{-2} \cdot h^{-1}$	0.0001	0.0008	0.0000	0.0002
	Wind velocity	$m \cdot s^{-1}$	0.37	5.63	0.00	0.49
	Air temperature	ºC	19.27	36.41	2.65	6.60
	Vapor pressure deficit	Pa	776.94	4798.11	29.03	817.45
	Soil water content_I	$cm^3 \cdot cm^{-3}$	0.20	0.28	0.16	0.02
	Soil water content_NI	$cm^3 \cdot cm^{-3}$	0.17	0.26	0.13	0.03
	REW_I		0.91	1.84	0.56	0.12
2013	REW_NI		0.71	1.55	0.31	0.24

Table 4. Calibrated parameters and statistics for the evaluation of model goodness-of-fit when considering one, two or three response functions. The values for the parameters g_o and g_{max}, estimated for every tested model, are not shown for clarity. NRSMD stands for normalized root-mean-square deviation (%).

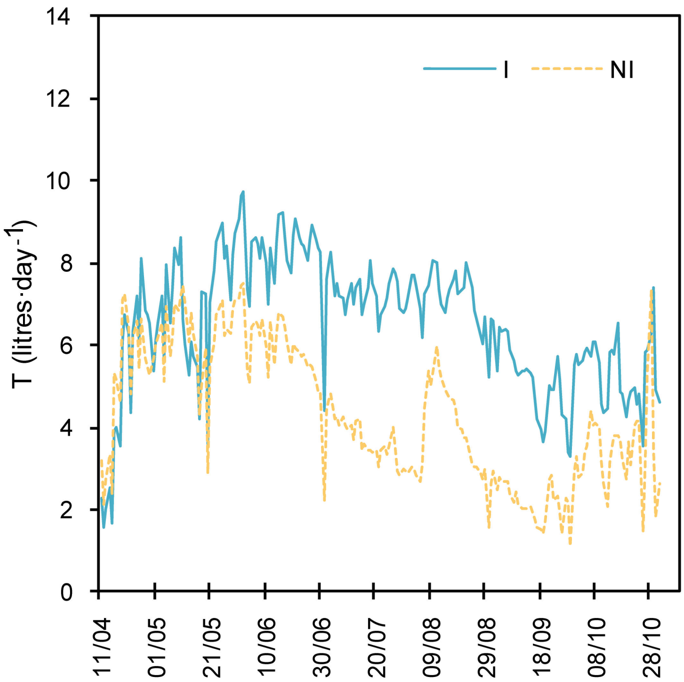
Data	**Model**	**a_0**	**a_1**	**a_2**	**a_3**	**a_4**	**a_5**	**a_6**	**Intercept**	**Slope**	**Adj. R^2**	**NRMSD (%)**
	g_o+g_{max}*f(REW)						0.365	2.88	0.00330	0.378	0.395	12.66
	g_o+g_{max} *f(VPD)*f(REW)		2.040	0.23			0.365	4.00	0.00220	0.586	0.586	10.44
General Model	g_o+g_{max} *f(Rn)*f(VPD)*f(REW)	0.0000302	2.409	0.28			1.082	1.09	0.00250	0.528	0.528	11.16
	g_o+g_{max} *f(T)				-0.0013	0.050			0.00440	0.365	0.365	11.75
	g_o+g_{max} *f(Rn)*f(VPD)	0.0000232	2.750	0.32					0.00200	0.714	0.714	7.84
Model I	g_o+g_{max} *f(Rn)*f(VPD)*f(T)	0.0000232	2.750	0.32	-0.0018	0.087			0.00190	0.732	0.732	7.59
	g_o+g_{max} *f(REW)						0.360	2.10	0.00150	0.591	0.592	9.13
	g_o+g_{max} *f(Rn)*f(REW)	0.0000033					0.369	2.15	0.00150	0.596	0.598	9.06
Model NI	g_o+g_{max} *f(Rn)*f(VPD)*f(REW)	0.0000540	2.171	0.25			1.082	13.49	0.00070	0.812	0.810	6.21



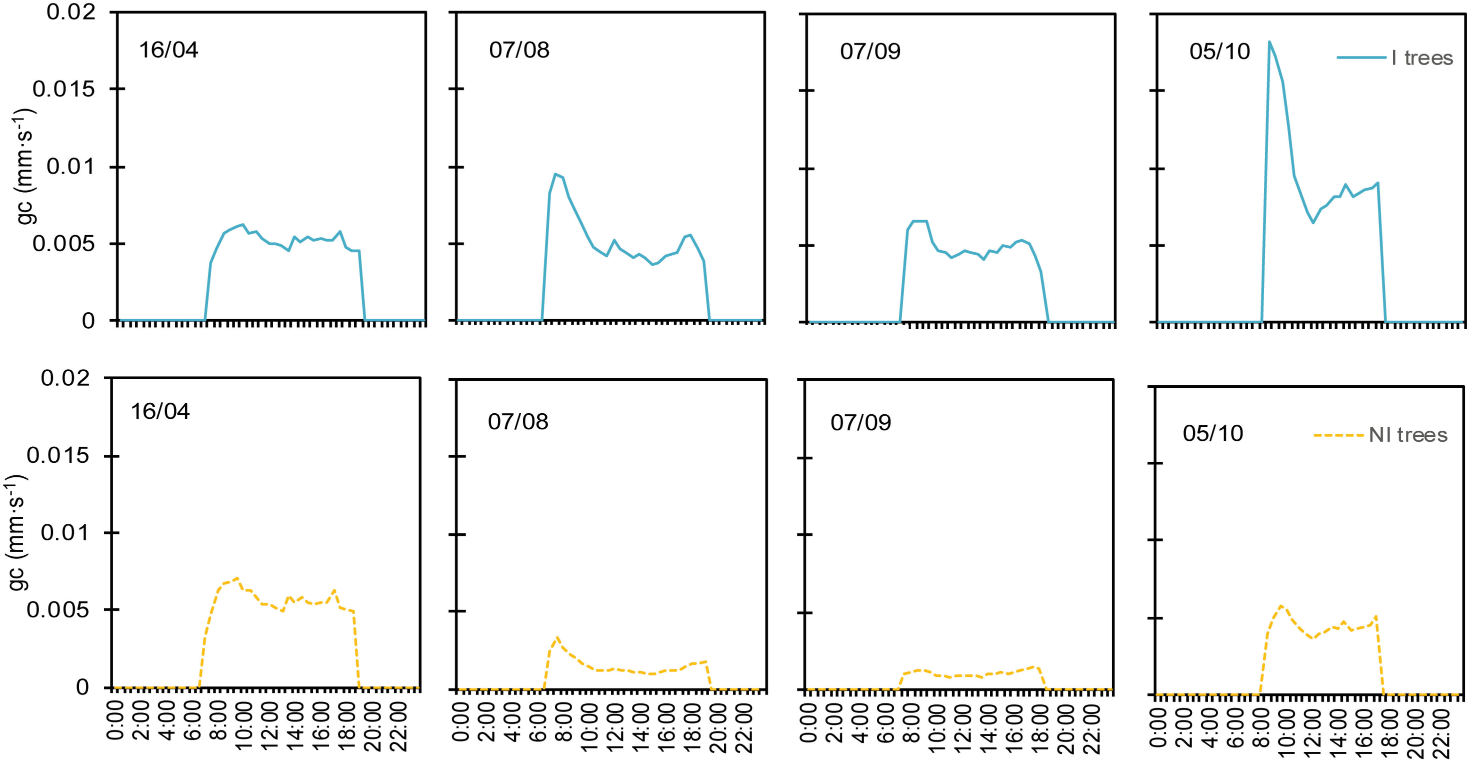
ET0 (mm·day-1)
Rainfall (mm)
a
b
REW
I
NI
April
May
June
July
Aug.
Sep.
Oct.
2012
2013



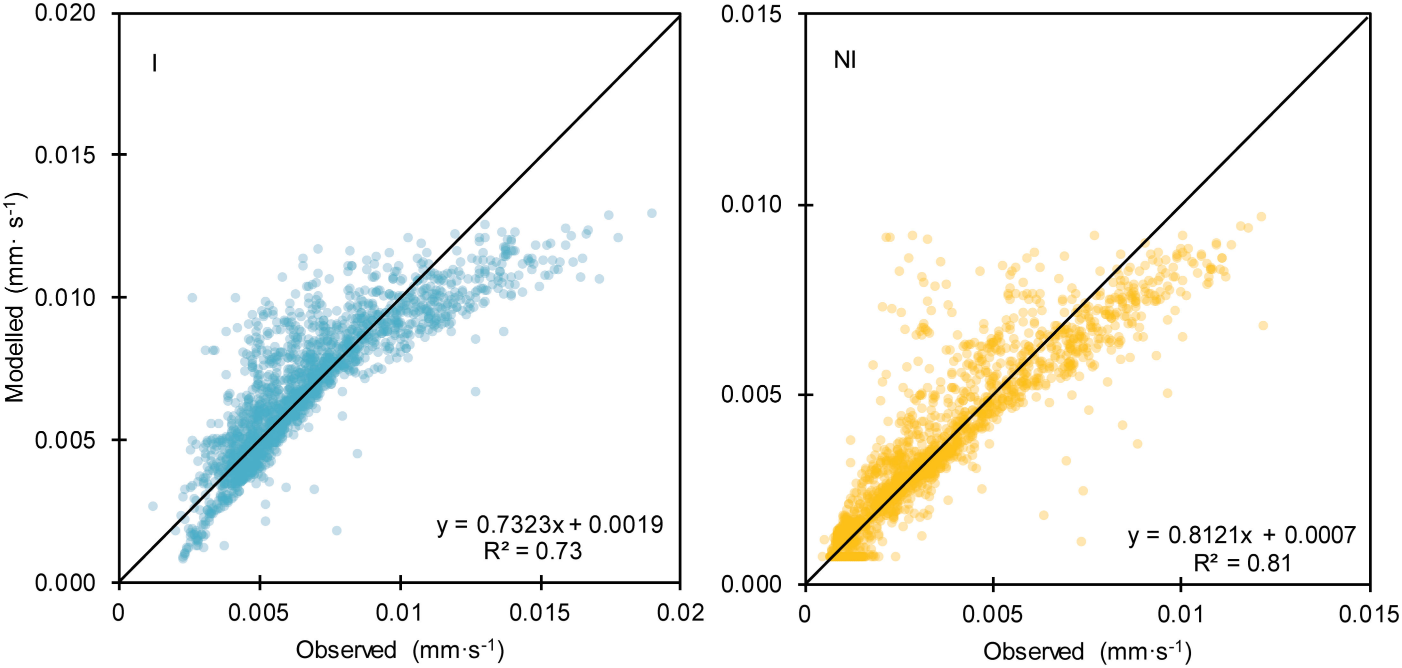
Relative canopy cover (RCC,%)
90
80
70
60
50
40
30
20
10
0
I
NI
11/04
01/05
21/05
10/06
30/06
20/07
09/08
29/08
18/09
08/10
28/10

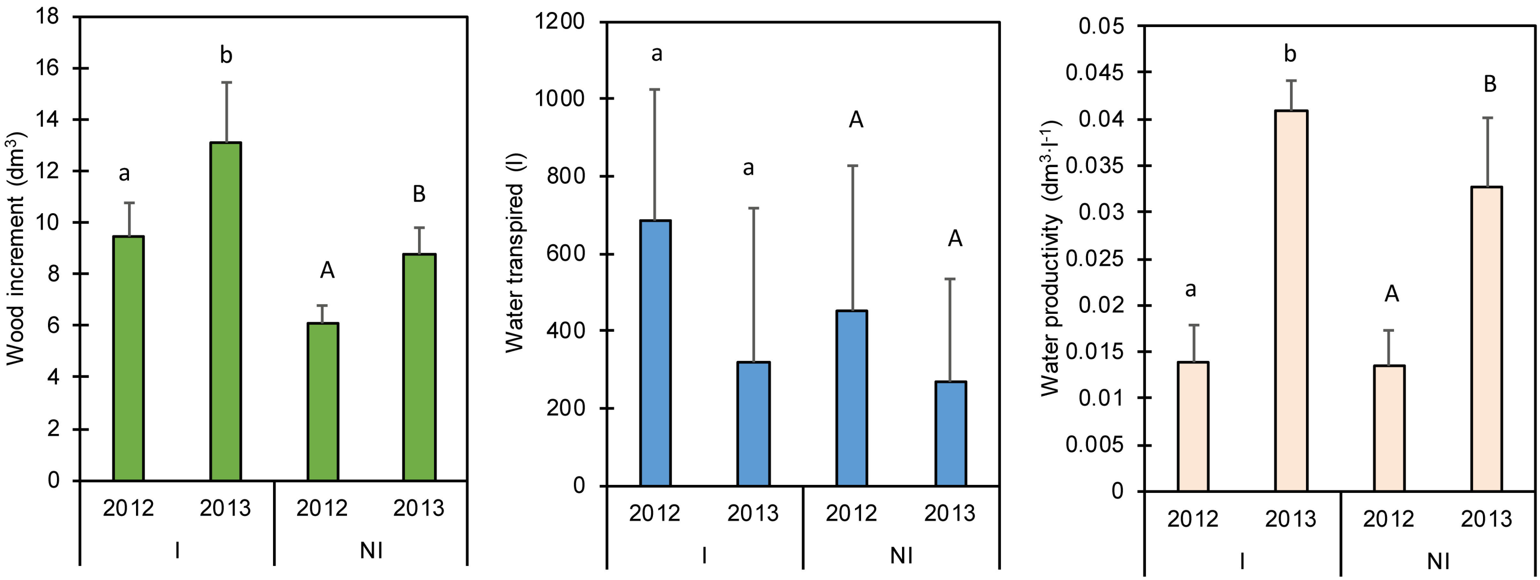


T (litres·day-1)
14
12
10
8
6
4
2
0
I
NI
11/04
01/05
21/05
10/06
30/06
20/07
09/08
29/08
18/09
08/10
28/10

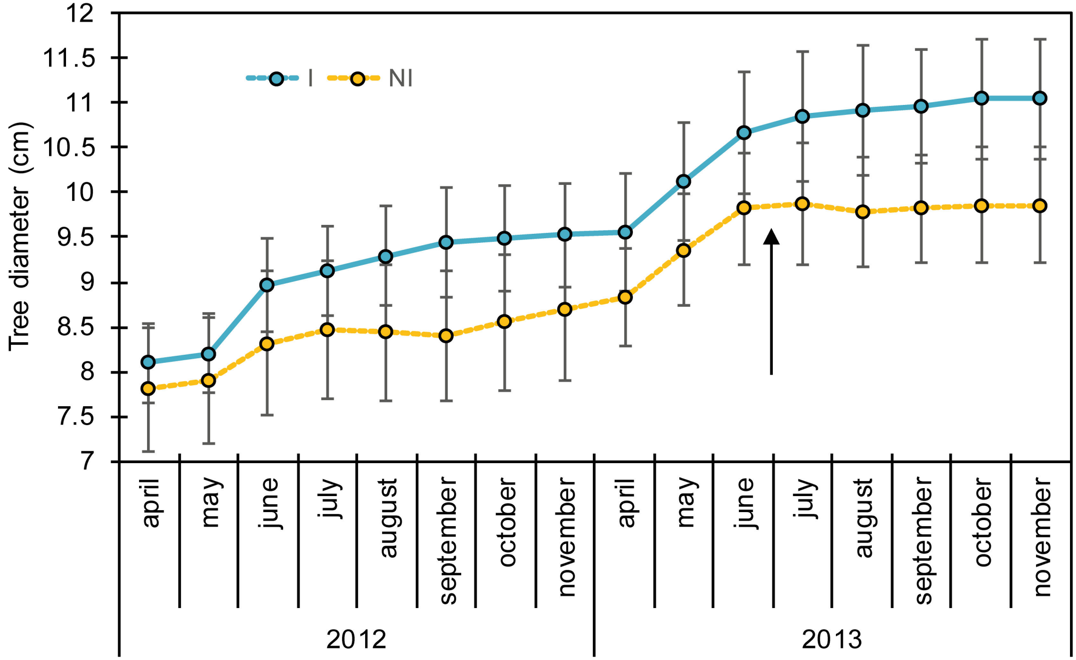


0.02
0.015
0.01
0.005
0
gc (mm·s-1)
16/04
07/08
07/09
05/10
I trees
NI trees
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00


0.020
0.015
0.010
0.005
0.000
Modelled (mm· s-1)
I
y = 0.7323x + 0.0019
R² = 0.73
0
0.005
0.01
0.015
0.02
Observed (mm·s-1)
0.015
0.010
0.005
0.000
NI
y = 0.8121x + 0.0007
R² = 0.81
0
0.005
0.01
0.015
Observed (mm·s-1)



Wood increment (dm3)
18
16
14
12
10
8
6
4
2
0
a
b
A
B
2012
2013
2012
2013
I
NI
Water transpired (l)
1200
1000
800
600
400
200
0
a
a
A
A
2012
2013
2012
2013
I
NI
Water productivity (dm3·l-1)
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
a
b
A
B
2012
2013
2012
2013
I
NI



I
NI
Tree diameter (cm)
12
11.5
11
10.5
10
9.5
9
8.5
8
7.5
7
april
may
june
july
august
september
october
november
april
may
june
july
august
september
october
november
2012
2013