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Effect of irrigation on sap flux density variability and water use estimate in cherry (*Prunus avium*) for timber production: Azimuthal profile, radial profile and sapwood estimation

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ABSTRACT

Information on tree water use in plantations for high quality wood is scarce, thus studies are needed to properly estimate the irrigation demand of these plantations. Plant water use estimation with sap flow sensors has been used extensively. However, biases in tree sap flow estimate can arise from variations on radial and azimuthal profiles of sap flux density and also from the sapwood area considered for the up-scaling from sap flux density to sap flux. This work aimed to (1) study the spatial variations of sap flux density in cherry trees in a timber orientated plantation, (2) compare several methods to estimate sapwood depth in cherry trees and (3) to evaluate the effect of drip irrigation on these factors. The results showed that most of the studied trees had decreasing radial sap flux density profiles with depth as expected. However, the three irrigated trees of bigger sizes still showed high sap flux densities in their inner tissues, at contrast with the rest of the trees and especially with the non irrigated ones of similar size with values close to 20% of the sap flux density measured at 1 cm depth from cambium. On the other hand, the different methods tested to estimate sapwood depth gave significantly different results and only the two methods of visual identification in wood cores based on color change and measurements of sap flux densities along the xylem radius may be considered suitable for scaling purposes. Moreover, azimuthal variation pattern was found to be random in all the studied trees, and the ranking between the aspects (north, south, east and west) was not affected by either drip irrigation or sun exposition, and thus measuring sap flux density in any particular aspect has been shown to be suitable to estimate the overall tree sap flux. We conclude that more studies are necessary to properly assess the radial profile of sap flux density, especially when considering the high sap flux density in the inner tissues of the three bigger irrigated trees as compared to the other trees, and also how this pattern seemed to indicate sapwood depths values very contrasted to the ones estimated from color change in wood cores.

1. Introduction

Plantations of Angiosperm trees for high quality timber production (commonly named hardwood) have increased in recent years in Europe as a consequence of two main causes, a permanent demanding market that is not entirely satisfied by the own production, and the EU regulations promoting their establishment due to their important environmental role in CO2 capture (Cambria et al., 2012). The later is especially noticeable when considering that timber from the tree species normally used, such as walnut or cherry, take between 30 and 50 years to get its maximum market value (Cisneros, 2004).

The plantations for high quality timber production are normally developed in areas subject to depopulation, where the normal cultivars are not economically viable. Management of these plantations consisted of several operations such as pruning, thinning, soil tillage, fertilization and irrigation (Cambria and Pierangeli, 2012), and as in any other economical activity, the related cost should be carefully evaluated. Irrigation demand of these plantations is frequently estimated using the FAO procedures with crop factors of fruit plantations, because specific crop factors for timber plantations are still scarce. However, the orchard management of timber plantations is normally quite different than that of fruit plantations

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(leading for instance to different tree architecture and tree density), and this could lead to important biases in the evapotranspiration estimate.

Sap flow sensors based on heat pulse methods have been widely demonstrated as a valuable tool for measuring water use by trees (Burgess et al., 2001; Green et al., 2003). There are, however, several factors to take into account when scaling up to the whole tree, such as the spatial variations of sap flux density within the tree, i.e., the radial and the azimuthal variations (Chang et al., 2014; Kume et al., 2012; Nadezhdina et al., 2002), and a correct estimation of the sapwood depth (Čermák and Nadezhdina, 1998). Furthermore, orchard management techniques such as branch punning and localized irrigation could contribute to add variability (Cabibel and Isberie, 1997; Lu et al., 2000).

Radial variation in sap flux density has been a topic widely studied in several tree species under different conditions (e.g., Nadezhdina et al., 2002; Gebauer et al., 2008; Cohen et al., 2008). The general finding is a decreasing of the sap flux density from the outer to the inner sapwood, though this profile may show different shapes (Alvarado-Barrientos et al., 2013; Gebauer et al., 2008; Kubota et al., 2005) and it could vary with species, tree age and environmental conditions (Čermák and Nadezhdina, 1998). Azimuthal variation of sap flux density, for its part, is understudied as compared to radial variation (Kume et al., 2012), though it may be of higher magnitude (e.g., Shinohara et al., 2013; Lu et al., 2000). In the other hand, the observed results are more contrasting (e.g., Cabibel and Isberie, 1997; Kume et al., 2012; Tsuruta et al., 2010; Shinohara et al., 2013) and consequently general conclusions about tree circumference profile of sap flux density are difficult to be drawn.

Sapwood is the outer part of the xylem conducting sap, which contains living parenchyma cells (Čermák and Nadezhdina, 1998). It can be estimated by several methods, but they normally show contrasted results even for the same species (Cermark and Nadezhdina, 1998; Nadezhdina et al., 2002). As example, Poyatos et al. (2007) found that the sapwood area estimated from radial patterns of sap flux density was 1.5–2 times larger than sapwood area estimates made in the field based on visual inspection of wood cores.

During three years we have been monitoring water use by cherry trees in a timber orientated plantation in a Mediterranean area, under rainfed and irrigated conditions. To this end, sap flow sensors, based on heat pulse with two radial measurements within the sapwood were installed at the east aspect of the studied trees. Sapwood was determined by visual identification of sapwood and heartwood in tree cores.

The aim of this work was to evaluate the accuracy of the approach followed during these three years of experiment (2011–2013) to estimate tree water use with a deeper study in 2014 of the spatial variations of sap flux density (is representative enough measuring sap flux density in two points and only in one aspect of trees?) and, on the other hand, to compare several methods to estimate sapwood depth in cherry trees (was sapwood depth well estimated?). Finally, the effect of drip irrigation on these aspects was also evaluated.

2. Materials and methods

2.1. Study site

The study was carried out at the Torre Marimon site (Caldes de Montbui, Spain) in the IRTA facilities (41° 36′47′ N, 2°10′11′E, 170 m.a.s.l). Climate is Mediterranean, with mean annual (1999–2012) rainfall and potential evapotranspiration of 599.4 ± 33.4 and 846.8 ± 23.3 mm, respectively. Soils are basic and have two contrasting characteristics, sandy-loam soils with about 60% of gravels and loam soils with negligible presence of gravels; these differences are due to an alluvium trend brought by a close river which did not affect to the same extent the study area.

Measurements were conducted during the growing season of 2014 in an 8 year-old cherry tree (*Prunus avium* L.) plantation orientated to timber production with tree spacing of 4×4 m (625 trees ha^{-1}). Trees are pruned every two years at the middle of the growing season. Pruning follows the common practices, where the lower part of crowns is removed, and it approximately accounted for one third of total aboveground biomass.

Meteorological conditions during the experiments were measured in an open area next to the plantation. Mean daily values of potential evapotranspiration and maximum temperature during the summer months (July and August) were 4.6 ± 1.3 mm and 29 ± 2.4 °C respectively, while total rainfall accounted only for 45.4 mm.

2.2. Experiment 1: radial variation in sap flux density and sapwood area estimation methods

Radial variation of sap flux density was studied by mean of two sensors based on the compensation heat pulse method (CHPM, Green et al., 2003) with 4 radial measurements at 0.5, 1.2, 2.1 and 3.2 cm from bark, and the bark of 2 mm depth was not previously removed to install the sensors. The CHPM sensors were programmed to measure each 30 min, and were charged with a battery of 80 mAh and 12 V connected to a CR-1000 logger (Campbell Scientific, USA). Each sensor consisted of three needles 40 mm in length and 1.8 mm in diameter. The needle placed in the centre is the heater that emits the heat pulse during 1 s. Then, the temperature increase is systematically measured during 8 min in the other two needles at 0.5 cm and 1 cm upstream and downstream respectively. Heat pulse velocity is estimated from the time taken to obtain the same temperature upstream and downstream.

The measurements were simultaneously conducted during seven days at 1.3 m height and at the east aspect of the trunk in two close trees with similar diameter but different irrigation treatment (drip irrigated versus non-irrigated trees). Seven days after the two CHPM sensors were moved to other two trees and this was repeated seven times, resulting in a total of 14 trees sampled and a sampling period of 49 days (Table 1). Irrigation treatment consisted of four emitters per tree (16 l h^{-1} $tree^{-1}$) located at 25 and 50 cm at north and south sides from trunk. Daily doses were estimated at the beginning of each week as the 60% of the ET_0 for the previous week, and irrigation was not applied when ET_0 was lower than rainfall. Total irrigation per tree ranged from 8 to 125 l day^{-1} when applied.

Heat pulse velocity was corrected for effects of probe-induced wounding (Barret et al., 1995), following the numerical approximation proposed by Swanson and Whitfield (1981) as a function of wound width. Since no wound width is available from literature for the study specie, we adopted the results of Barret et al. (1995) confirmed by Fernandez et al. (2006) in plum trees (*Prunus domestica* L.) of $1.8 + 2 \times 0.3$ mm. Sap flux density was estimated from corrected heat pulse velocity following Barret et al. (1995).

Once the seven days-period of CHPM measurements finalized in each couple of trees, we proceeded to core the measured trees. Seven different methods were used to determine the limit between sapwood and heartwood: (1) methyl orange or (2) lugol staining, (3) visual differentiation based on colour change (VD_m), (4) dye injection (DI_m), (5) radial variation of wood density (WD_m), (6) wood water content (WC_m) and (7) radial profile of sap flux density.

Methyl orange and lugol methods were prior tested in several cores taken in neighbour trees, as no colour change was observed in any of the samples these methods were not further considered.