

Research Paper

Mechanistic modelling of daily hydraulic resistance and capacitance in pear to support irrigation decisions

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ABSTRACT

Translating continuous plant sensor signals into actionable irrigation rules remains a practical bottleneck in fruit tree orchards. Integrating sensor outputs with a compact water flow and storage model offers a clear pathway toward simpler, physiology-based control. We assessed this model in a rainfed 'Conference' pear orchard to test its ability to reproduce diurnal stem water potential (Ψ_{stem}) and yield daily stem hydraulic resistance (R_{stem}) and capacitance (C_{stem}) values. Two mature trees were monitored in 2024 (DOY 238–266). Using sap flow rate and soil water potential measurements as model inputs, simulated Ψ_{stem} closely matched microtensiometer data ($R^2 = 0.95$), indicating excellent model reliability. Model-calibrated R_{stem} was invariant across the observed Ψ_{stem} range and stable over time, with mean $\pm$ SD values of 0.308 ± 0.037 and 0.683 ± 0.052 MPa h kg⁻¹ for Tree 1 and 2, respectively. The temporal dynamics of both R_{stem} and C_{stem} were similar across trees, with C_{stem} declining as Ψ_{stem} became more negative. Model-calibrated R_{stem} corresponded well with the van den Honert concept under steady-state conditions but diverged on more dynamic days, with daily standard deviations being markedly smaller for the model, indicating greater robustness to transient conditions. This study provides proof of concept that daily R_{stem} dynamics can support future irrigation decision-making, while emphasizing the need for tree-specific baselines across phenological stages and interpretation in conjunction with Ψ_{stem} .

1. Introduction

Water scarcity is a critical factor in fruit production, particularly in regions where drought conditions make irrigation essential to sustain both yield and fruit quality (Ali et al., 2024; Espinoza-Meza et al., 2023; Marsal et al., 2002). This growing pressure on freshwater resources demands irrigation strategies that maximize water-use efficiency and minimize waste. At the same time, imposing mild water deficits at specific phenological stages (e.g., through regulated deficit irrigation, RDI) can enhance fruit quality traits, such as sugar concentration and firmness (Lopez et al., 2012; Naor, 2006; Pérez-Pastor et al., 2016; Vallverdu et al., 2012). Both the need to reduce water consumption and the potential benefits of controlled stress application underscore the importance of accurate, well-timed irrigation strategies that respond to plant water status.

Pear is a key pome fruit crop in the European Union (EU), where

production is dominated by common pear (*Pyrus communis* L.). In 2024, EU production reached 1.9 million tons, with Italy (24%), the Netherlands (17%) and Belgium (15%) among the leading producers (Eurostat, 2025). In water-limited regions, particularly in Mediterranean Europe, drip irrigation is the main system to improve water-use efficiency (Dombrowski et al., 2024; Milano et al., 2013; Ramos et al., 2023). In more temperate regions, increasing drought frequency and irregular rainfall have also increased interest in supplemental irrigation (Deckers et al., 2011).

Conventional irrigation schedules based on weather, evapotranspiration or soil moisture are widely used and easy to automate (Jones, 2004). Yet, because these approaches rely on proxies, they fail to capture short-term physiological fluctuations in water demand and can consequently mistime irrigation, especially when mild, intentional stress is intended (Asefa and Tadesse, 2024; Fernández, 2017; Jones, 2004). Plant-based methods address these limitations by treating the tree as a

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biological indicator, using measurements such as stem water potential (Ψ_{stem}), sap flow rate (F_{stem}), and stem diameter dynamics to track water status directly (Bwambale et al., 2022; Fernández, 2017; Jones, 2004). Ψ_{stem} is widely implemented with threshold-based rules (Blanco and Kalcsits, 2021; García-Tejera et al., 2021) and typically measured with a pressure chamber (Scholander et al., 1965), but discontinuity and labor demands motivate continuous sensing with psychrometers or microtensiometers (Blanco and Kalcsits, 2021; Carella et al., 2024). However, although Ψ_{stem} is a robust, direct indicator of plant water status, using it as the sole irrigation trigger is problematic, because it conflates environmental forcing with hydraulic architecture, thereby obscuring the distinction between short-term fluctuations and structural plant responses (García-Tejera et al., 2021; Jones, 2007; McCutchan and Shackel, 1992).

To move beyond proxy-based or single-signal triggers toward physiology-based control, mechanistic water flow and storage models provide a bridge from continuous plant measurements to decision-ready variables by enforcing mass balance and causal links among Ψ_{soil} , F_{stem} and Ψ_{stem} (De Pauw et al., 2008; Steppe et al., 2006, 2008). At the whole-plant scale, these models build on the classical soil-plant-atmosphere continuum formulation of van den Honert (1948), which in steady state (i.e., when storage fluxes are negligible) links transpiration-driven flow to water potential gradients via a hydraulic resistance (R_{stem}). When hydraulic parameters, such as R_{stem} and hydraulic capacitance (C_{stem}), are made explicit, the distinct roles of conductive transport pathways and elastic internal water storage pools become clear. This distinction helps explain why Ψ_{stem} shifts during transient changes in transpiration or soil water supply (Baert et al., 2015; Salomón et al., 2017). Such compact, interpretable models enable daily calibration using a moving window without overfitting, and yield parameters that map onto plant function and can be translated into simple on-off rules around a defined stress baseline (Baert et al., 2015; Calabritto et al., 2025; De Pauw et al., 2008; Steppe et al., 2006, 2008). At the same time, there is a broader call for practical indicators that operate under non-steady-state field conditions and improve drought-impact prediction and management (Jones, 2007; Naor, 2000; Scholz et al., 2011; Shackel et al., 2021; Torres-Ruiz et al., 2024).

The objective of this study was to further refine and calibrate the mechanistic water flow and storage model originally developed by Steppe et al. (2006, 2008), and later applied to kiwifruit (*Actinidia chinensis* Planch. var. *chinensis*, cv. 'Zesy002') by Calabritto et al. (2025), for its targeted use in a pear orchard (*Pyrus communis* L. cv. 'Conference'). Specifically, we aimed to (1) validate model reliability by reproducing diurnal Ψ_{stem} from sap flow rate and soil water potential measurements under field conditions, and (2) establish estimates of R_{stem} and C_{stem} via daily moving-window calibration, using apparent hydraulic resistance as defined by van den Honert (1948) as a benchmark for R_{stem} , where applicable. Together, these objectives establish a mechanistic basis for translating continuous plant sensor measurements into physiologically meaningful information for the future development of plant-based irrigation scheduling.

2. Materials and methods

2.1. Experimental site and plant material

The experiment took place during the summer of 2024 from August 25 until September 22 (Day of Year, DOY, 238–266) in a well-established rainfed intensive low-stem pear (*Pyrus communis* L. cv. 'Conference') orchard, located at pcfuit npo in Sint-Truiden, Belgium (50°46'N 05°10'E). Harvest occurred during the beginning of the monitoring period (DOY 241). The trees were planted in 1996 on Quince Adams rootstocks and were trained in a spindle-bush system. Tree density was 2286 trees per hectare, with intra-row spacing of 1.25 m and inter-row spacing of 3.5 m, consisting of a tree strip (1.5 m width) and a grass-covered alleyway (2 m width). The soil at the experimental site

was classified as Aba1 according to the Belgian soil classification system, referring to dry loamy soils with a B-horizon and a thin A-horizon (< 40 cm) (Vandamme, 2019), with a soil carbon content of 1.09% and soil pH (KCl) of 6.26. Nitrogen fertilizer was applied yearly as 185 kg ha⁻¹ calcium ammonium nitrate (CAN; 27% N) in early spring. In the previous year, the trees received 100 kg ha⁻¹ potassium sulfate (50% K₂O). Orchard management followed standard conventional practices as typically applied by commercial growers and the orchard was not irrigated. Two healthy, representative trees of similar vigor and free from border effects were selected for sensor installation.

2.2. Climate, soil and plant physiological measurements

Four climate variables were monitored during the growing season at 1 m above tree level: photosynthetically active radiation (PAR; JYP 1000, SDEC, Reignac-sur-Indre, France), relative humidity (RH) and air temperature (T) measured in a radiation shield with natural convection (SHT25, Sensirion AG, Stäfa, Switzerland) and precipitation (all-in-one weather station, Crodeon Technologies BV, Zwijnaarde, Belgium). Vapor pressure deficit (VPD; kPa) was calculated using Eq. (1), following Jones (2013):

$$\text{VPD} = 0.61078 \exp\left(\frac{17.2694 T}{T + 237.3}\right) \left(1 - \frac{\text{RH}}{100}\right) \quad (1)$$

with T the air temperature (°C) and RH the relative humidity (%). All meteorological data were aggregated to daily values prior to analysis and PAR was converted to the daily light integral (DLI; mol m⁻² day⁻¹). Summarized values are reported as mean ± standard deviation (SD) across days. Soil water potential (Ψ_{soil} ; MPa) was monitored continuously at a depth of 30 cm and a distance of 30 cm from the tree with a tensiometer (TEROS 21, METER Group, WA, United States of America), targeting the shallow, active root zone near the tree.

Both trees were equipped with two plant sensors. Sap flux density (L h⁻¹ cm⁻²) was continuously measured with Sapflow+ sensors (Vandegehuchte and Steppe, 2012) used in the heat ratio method (HRM) mode (Burgess et al., 2001). Prior to installation, the thermistors were calibrated using an RTC-156B reference temperature calibrator (AMETEK, Allerød, Denmark). The sensors were subsequently installed on the northern side at the base of the stem, approximately 30 cm above the soil, following a standardized procedure (Vandegehuchte and Steppe, 2012). The thermistor elements were positioned 5 mm below the cambium, with a needle spacing of 7.5 mm. Sap flux density was converted to sap flow rate (F_{stem} ; L h⁻¹) after multiplying by sapwood area (cm²). Stem water potential (Ψ_{stem} ; MPa) was continuously measured with a FloraPulse microtensiometer (FloraPulse Co., Davis, CA, USA) (Lakso et al., 2022).

All meteorological, soil and plant sensors were connected to a dedicated, custom-made logger, enabling real-time data acquisition, storage and calculations through the PhytoSense cloud service (v1.6; Plant AnalytiX, Mariakerke, Belgium). This setup provided data points every two minutes for Ψ_{soil} and Ψ_{stem} , every 15 min for F_{stem} and every hour for meteorological data (PAR, RH, T and precipitation).

Because destructive determination of the sapwood area was not possible for the experimental trees, representative trees were examined using microscopy, radial measurements of wood moisture content and density, and dye perfusion as a qualitative assessment of xylem conductivity. These assessments provided no evidence of a distinct inactive heartwood zone, supporting the consideration of the entire xylem cross-section as hydraulically active sapwood (Supplementary S1). Accordingly, sapwood area per tree (cm²) was estimated from stem diameter derived from circumference measurements, after correcting for bark thickness. Bark thickness (7.5 mm) was obtained from small Trephor cores.

The total leaf area per tree was calculated by multiplying the specific leaf area (SLA) by the total dry leaf mass. SLA (101.29 ± 13.12 cm² g⁻¹)

was determined on 40 fresh leaves per tree. Leaves were sampled on the morning of October 7, 2024, placed in moist resealable plastic bags and kept in the dark during transport. Fresh weight and leaf area were measured three hours later. Leaf area was measured with a LI-3100C leaf area meter (LI-COR Biosciences, Lincoln, NE, USA) following Cornelissen et al. (2003). On the same day, the trees were wrapped in bird netting and all leaves were collected on December 11, 2024, after complete leaf drop. SLA samples and all collected leaves were dried at 70 °C for four days in an oven (EU 170 Jouan SA, Saint-Herblain, France) to obtain dry mass. The Huber value (H_v ; m² sapwood m⁻² leaf) per tree was calculated as sapwood area divided by total leaf area and was used as a structural proxy for hydraulic supply capacity relative to tree transpirational demand (Huber, 1928).

2.3. Mechanistic modelling

The model applied in this study was adapted from Calabritto et al. (2025), which, in turn, is a simplified version of the mechanistic ‘water flow and storage’ model developed by Steppe et al. (2006, 2008) and subsequently refined to address the specific objectives and conditions of the present research.

The model describes the water transport from the soil through the stem and its interaction with stem water storage (Fig. 1). The main principle is based on the soil-plant-atmosphere continuum (SPAC), where the onset of transpiration creates a water potential gradient that drives water movement from the soil, through the roots and stem, towards the atmosphere (van den Honert, 1948; Steppe et al., 2015). The model uses two input variables, sap flow rate (F_{stem}) and soil water potential (Ψ_{soil}), to describe this vertical pathway of water transport, with the aim of simulating the stem water potential (Ψ_{stem}). The stem is represented as two concentric cylinders: an outer cylinder corresponding to the storage compartment (extensible living cells of the stem bark, external to the xylem) and an inner cylinder corresponding to the xylem compartment (conductive stem tissues transporting water from roots to leaves). The storage compartment serves as a water reservoir that buffers water supply during periods of high demand, compensating when root water uptake lags behind transpiration, and thereby reducing the risk of xylem embolism (Meinzer et al., 2004). Storage dynamics are

described in terms of water content in the storage compartment (W_{stem}), its maximum water content ($W_{\text{stem,max}}$; fixed at 6 kg), hydraulic capacitance of the storage tissue (C_{stem}), and the resulting storage water potential (Ψ_{stem}^s) (De Pauw et al., 2008; Steppe et al., 2006). $W_{\text{stem,max}}$ was estimated from the aboveground woody volume by approximating the main stem as a cone based on stem circumference and tree height. Maximum water storage was estimated as 40% of the woody volume (Steppe et al., 2006), corresponding to 4.8 and 5.6 kg for the main stems of Trees 1 and 2, respectively. Accounting for the lateral branches supported the use of a common rounded value of 6 kg for both trees. The radial water flow between the xylem and the storage compartment (f_{stem}^s) captures the exchange of water between both compartments and the resulting change in storage water content over time (t). The modelled soil-to-stem water flow (F_{soil}) represents water uptake from the soil through the roots into the stem xylem. Axial water transport from the soil to the stem xylem is governed by the stem hydraulic resistance (R_{stem}), whereas radial water exchange between the xylem and the storage compartment is governed by the hydraulic resistance in the storage compartment (R_{stem}^s ; fixed at 1×10^{-6} MPa h kg⁻¹) (Calabritto et al., 2025).

Model implementation, identifiability analysis, calibration and simulation were performed with the plant modelling software PhytoSim (Plant AnalytiX, Mariakerke, Belgium). Since there was an interruption in data collection between DOY 250 and 256 due to logger failure, the modelling was split into two parts: part one from DOY 238 to 249 and part two from DOY 257 to 266. Firstly, an identifiability analysis was performed to determine which model parameters could be calibrated based on the gathered data (De Pauw et al., 2008). The model parameter subset $\{R_{\text{stem}}, C_{\text{stem}}\}$ was considered identifiable since the collinearity index was lower than 15 for all performed tests, indicating limited linear dependency among parameters (Brun et al., 2002). Model calibrations were based on the Shuffled Complex Evolution method (global search, accuracy 1×10^{-5} , three complexes; Duan et al., 1993) with Ψ_{stem} as the calibration variable. The difference between measured and simulated Ψ_{stem} values was minimized using a weighted sum of squared errors. Both identifiable parameters $\{R_{\text{stem}}, C_{\text{stem}}\}$ were recalibrated daily using a moving-window approach with a one-day window size, ensuring a consistently good model fit and enabling assessment of daily variability

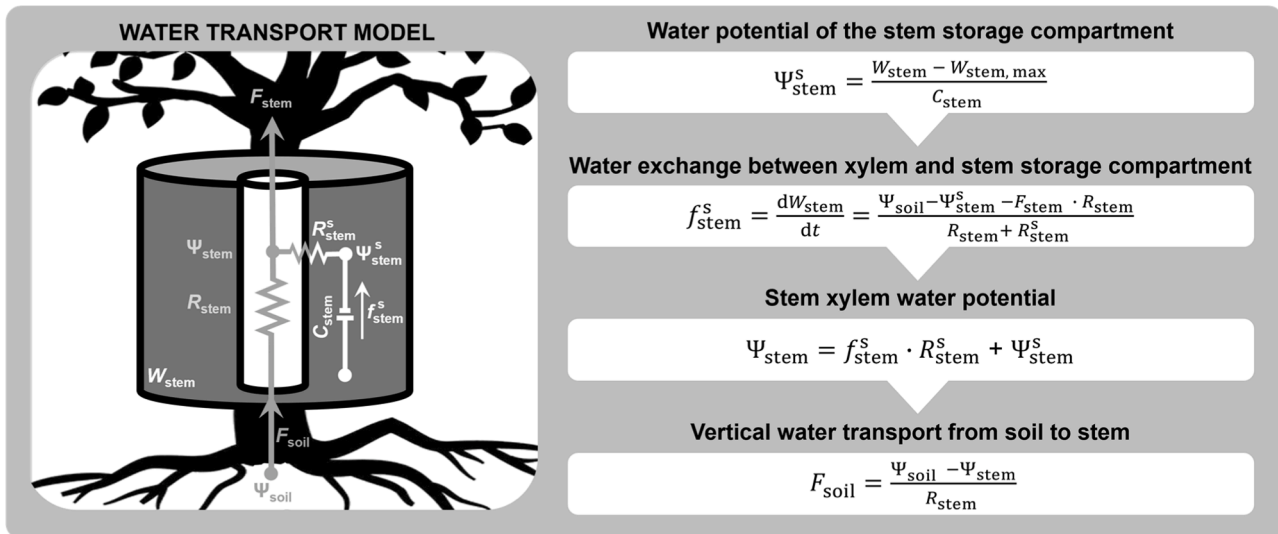


Fig. 1. Schematic diagram and mathematical expressions of the mechanistic water flow and storage model, adapted from Steppe et al. (2006, 2008) and Calabritto et al. (2025). The model is driven by stem sap flow rate (F_{stem}) and soil water potential (Ψ_{soil}) to determine hydraulic resistance in the xylem compartment (R_{stem}) and hydraulic capacitance of the stem storage compartment (C_{stem}). The grey cylinder represents the stem storage compartment, and the white cylinder represents the xylem compartment within the stem. Other parameters used in the model: F_{soil} = soil-to-stem water flow, representing water uptake from the soil through the roots into the stem xylem; Ψ_{stem}^s = stem water potential in the storage compartment; W_{stem} = water content in the storage compartment; $W_{\text{stem,max}}$ = maximum water content in the storage compartment (6 kg); f_{stem}^s = radial water flow between the xylem and storage compartment; R_{stem}^s = hydraulic resistance of the storage compartment (1×10^{-6} MPa h kg⁻¹); Ψ_{stem} = stem water potential in the xylem compartment.

of calibrated parameters in response to changes in Ψ_{stem} (Steppe et al., 2008). Parameter uncertainty was derived from the covariance matrix, computed as the inverse of the numerically approximated Hessian at the optimum. Estimates were flagged as unreliable when the parameter covariance matrix was non-positive semidefinite. Following the PhytoSim User Guide (Plant AnalytiX, 2022), we first ruled out numerical artifacts (tighter accuracy, smaller step sizes, switching step-size model). Remaining cases were attributed to local non-identifiability (Raue et al., 2009). DOY 260 (Tree 2) persisted as indefinite and was excluded from regressions and summary statistics but retained in figures for transparency. Model simulations were performed using a fourth-order Runge-Kutta numerical integrator with a fixed step size of 1 h. An additional scaling analysis was performed to examine how proportional changes in F_{stem} affected the calibrated R_{stem} and C_{stem} estimates (Supplementary S3).

To provide a model-independent, observation-based benchmark for comparison with model-calibrated R_{stem} , we computed the apparent hydraulic resistance (R_{app} , MPa h kg⁻¹) from the van den Honert equation (Eq. 2; van den Honert, 1948):

$$R_{\text{app}} = (\Psi_{\text{soil}} - \Psi_{\text{stem}}) / F_{\text{stem}} \quad (2)$$

The resistance is termed ‘apparent’ because it can be computed throughout the day, but only reflects the true hydraulic resistance when the system is under steady-state. To approximate steady-state conditions, daily ‘plateau’ windows were identified by selecting time stamps with F_{stem} at or above the daily 85th percentile, typically a short midday window. For each selected time stamp, Ψ_{soil} and Ψ_{stem} were time-aligned with F_{stem} using nearest-time matching within ± 5 min. R_{app} values were computed for all matched triplets and summarized per day as mean and

standard deviation (SD). This diagnostic assumes (i) negligible storage fluxes over the selected window (near-steady state) and (ii) a quasi-constant conductive pathway during the window (Steppe et al., 2006). Days affected by re-watering following rainfall were treated as transient, non-steady-state observations. In addition, days showing pronounced depression in F_{stem} due to rapidly fluctuating radiation rarely achieved steady state. Under such conditions storage fluxes are non-negligible and the van den Honert equation (Eq. (2)) does not yield a reliable R_{app} value. These days are indicated in the corresponding figures.

2.4. Statistical analysis

Data processing, including creation of model input files and visualization datasets, was performed in R (v4.3.2; R Core Team, 2023) within the RStudio integrated development environment (v2024.12.1.563; Posit Team, 2025). Linear regression analyses were performed with ordinary least squares using the ‘stats’ package (function ‘lm’; R Core Team, 2023). Model assumptions of normality and homoscedasticity were verified via residual diagnostics (Q-Q plots, residuals versus fitted). Fits for R_{stem} and C_{stem} as a function of daily mean Ψ_{stem} were computed after excluding days affected by re-watering (rainfall) and DOY 260 (non-positive-semidefinite covariance matrix for C_{stem}). For each model, we report the slope, intercept, and coefficient of determination (R^2).

3. Results

3.1. Variation in evaporative demand during the measurement period

The measurement period was divided into two phases with

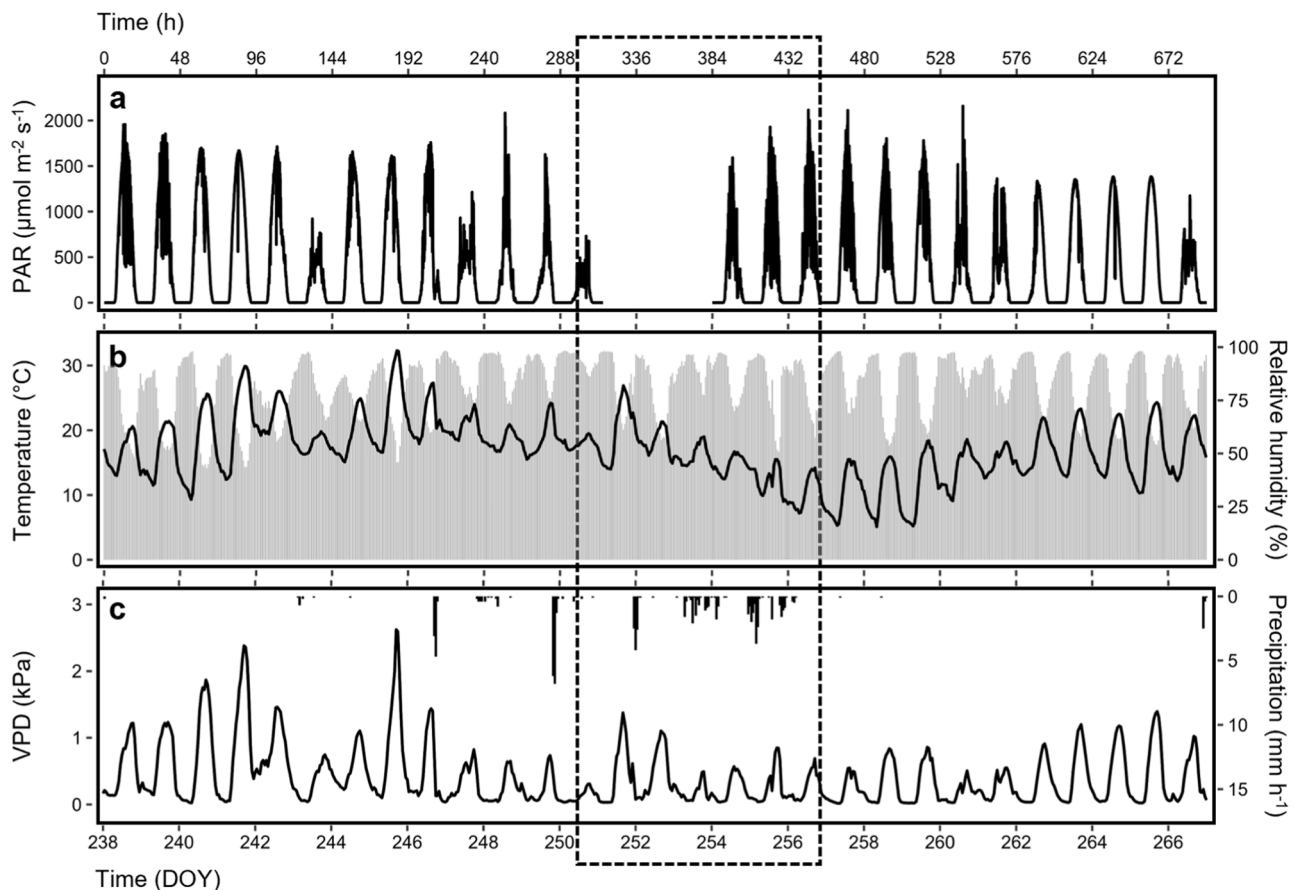


Fig. 2. Meteorological conditions during the measurement period (Day of Year (DOY) 238–266). (a) Photosynthetically active radiation (PAR). (b) Air temperature (T_{air} , solid line, left axis) and relative humidity (RH, grey bars, right axis). (c) Vapor pressure deficit (VPD, solid line, left axis) and precipitation (bars, right axis). Time is expressed in hours (top axis) and in DOY (bottom axis). The dashed box indicates the period of missing sensor data (DOY 250–256).

contrasting evaporative demand. The first phase (DOY 238-249) showed relatively high evaporative demand due to increased radiation, temperature and VPD, while the second phase (DOY 257-266) was marked by more moderate conditions with lower evaporative demand. During the first phase, conditions were characterized by a high daily light integral (DLI, $34 \pm 12 \text{ mol m}^{-2} \text{ day}^{-1}$; Fig. 2a), elevated daily maximum temperatures (T , $25 \pm 4 \text{ }^{\circ}\text{C}$; Fig. 2b), and low daily minimum relative humidity (RH, $58 \pm 12\%$; Fig. 2b). Consequently, vapor pressure deficit (VPD) reached its highest levels in this period, with two days exceeding 2 kPa (DOY 241 and 245; Fig. 2c). The subsequent break between phases coincided with substantial rainfall and declining temperatures (Fig. 2b-c). In contrast, the second phase (DOY 257-266) showed lower DLI

($29 \pm 7 \text{ mol m}^{-2} \text{ day}^{-1}$; Fig. 2a), reduced daily maximum T ($20 \pm 3 \text{ }^{\circ}\text{C}$; Fig. 2b), and higher daily minimum RH ($63 \pm 8\%$; Fig. 2b). Accordingly, average daily maximum VPD was markedly lower ($0.90 \pm 0.30 \text{ kPa}$) compared to the first phase ($1.35 \pm 0.64 \text{ kPa}$; Fig. 2c).

3.2. Model application and performance in simulating stem water potential

Fig. 3 shows the application of the mechanistic water flow and storage model (Fig. 1), with sap flow rate (F_{stem} ; Fig. 3a) and soil water potential (Ψ_{soil} ; Fig. 3b) as inputs and simulated stem water potential (Ψ_{stem}) compared to the measurements as outputs (Fig. 3 c-d). F_{stem} was

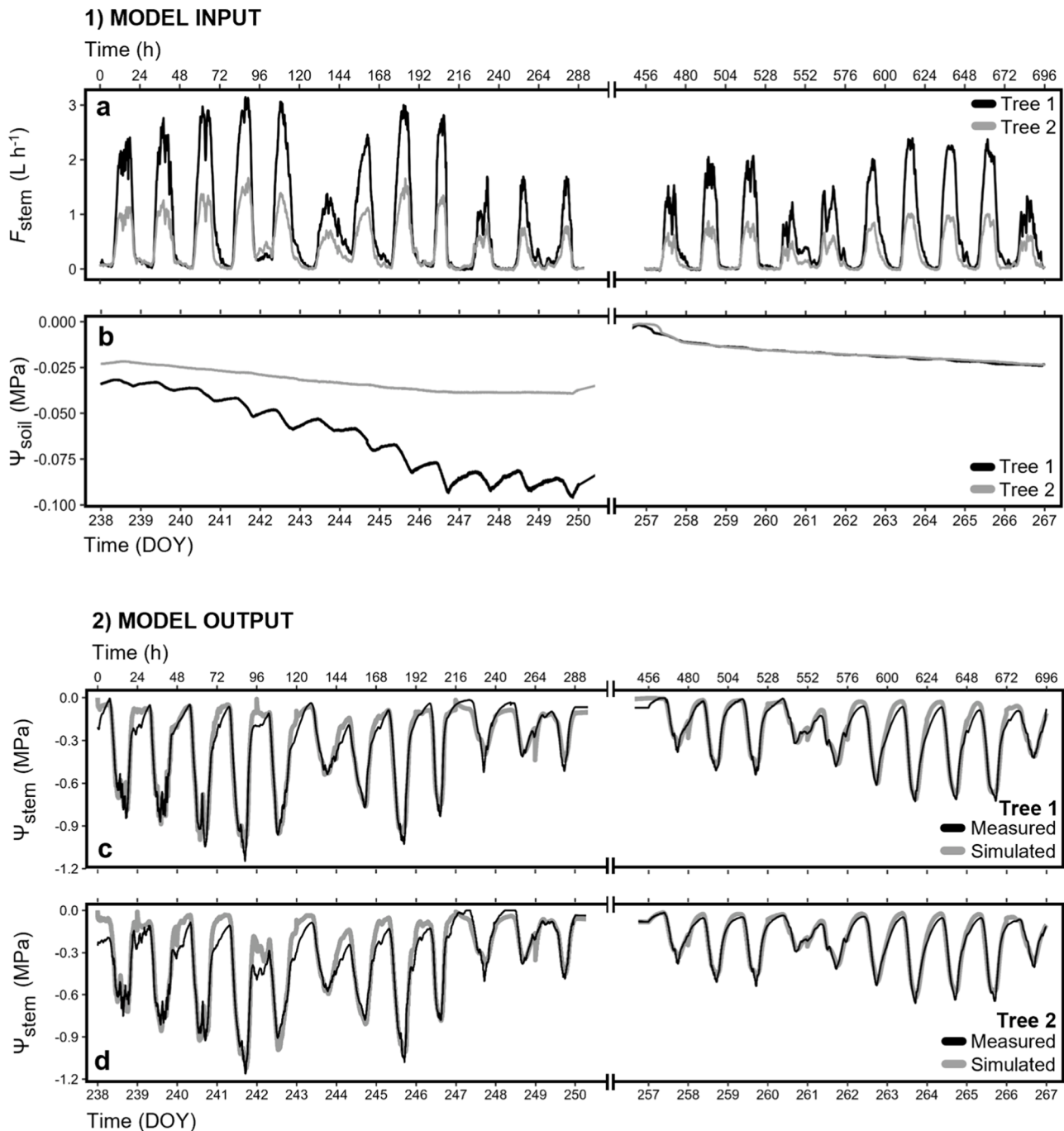


Fig. 3. Model input and output during the measurement period (Day of Year (DOY) 238-249 and 257-266). (a) Measured sap flow rate (F_{stem}) and (b) soil water potential (Ψ_{soil}) were used as model inputs, with Tree 1 shown in black and Tree 2 in grey. (c-d) Model output: comparison between measured (black) and simulated (grey) stem water potential (Ψ_{stem}) for Tree 1 (c) and Tree 2 (d). The break in the x-axis corresponds to the period of missing data (DOY 250-256).

closely related to atmospheric demand, with VPD showing the strongest association among the tested environmental variables. Mean VPD explained at least 70% of the variation in daily F_{stem} ($R^2 = 0.70$ for Tree 1, $R^2 = 0.79$ for Tree 2). On average, Tree 1 exhibited a daily F_{stem} of $66.2 \pm 33.0 \text{ L day}^{-1}$, more than twice that of Tree 2 ($31.2 \pm 17.0 \text{ L day}^{-1}$). This difference can partly be explained by the higher total leaf area of Tree 1 (7.19 m^2) compared to Tree 2 (6.33 m^2). However, when normalized by leaf area, Tree 1 still maintained a substantially higher sap flow rate ($9.20 \text{ L m}^{-2} \text{ day}^{-1}$) than Tree 2 ($4.93 \text{ L m}^{-2} \text{ day}^{-1}$). Remarkably, Tree 1 had a smaller sapwood area (93.6 cm^2) than Tree 2 (110.6 cm^2), resulting in Huber values (H_v) of 0.0013 and 0.0017 $\text{m}^2 \text{ m}^{-2}$ for Tree 1 and Tree 2, respectively.

At the start of measurements, a short rain-free period during the first phase reduced Ψ_{soil} to -0.0949 MPa in Tree 1 and -0.0385 MPa in Tree 2 (DOY 249; Fig. 3b). Heavy rainfall during the measurement break (58 mm; Fig. 2c) restored soil water potential to saturation, after which values declined only slightly to -0.0223 and -0.0225 MPa , respectively, during the second phase (Fig. 3b).

Using measured F_{stem} and Ψ_{soil} as model inputs, Ψ_{stem} was successfully simulated. Simulated values closely matched measurements for both trees across both phases, with a linear regression R^2 of 0.95, indicating excellent model performance (Fig. 3 c-d).

3.3. Dynamics of stem hydraulic resistance and capacitance

Daily calibrated hydraulic parameters are shown as a function of stem water potential (Ψ_{stem} ; Fig. 4) and as day-to-day variation across the measurement period (Fig. 5). For between-tree comparison, the corresponding time series were min-max scaled within each tree to a 0–1 range (Supplementary S2). Daily calibration, based on a one-day moving window of Ψ_{stem} , was required to maintain good model performance across all days (Fig. 3).

After excluding rain-affected days and DOY 260, ordinary least-squares regressions for the remaining days (hereafter referred to as ‘normal days’) revealed no discernible dependence of daily stem hydraulic resistance (R_{stem}) on Ψ_{stem} in either tree (slopes ≈ 0 ; $R^2 = 0.00$ for

Tree 1 and 0.01 for Tree 2, respectively; Fig. 4a-b). This stability was also reflected in the temporal patterns (Fig. 5a-b), where R_{stem} remained relatively constant throughout both phases and consistently higher in Tree 2 than in Tree 1. Mean R_{stem} during the whole measurement period, on normal days, was $0.308 \pm 0.037 \text{ MPa h kg}^{-1}$ for Tree 1 and $0.683 \pm 0.052 \text{ MPa h kg}^{-1}$ for Tree 2. Mean R_{stem} in the first phase (DOY 238–249) was $0.298 \pm 0.025 \text{ MPa h kg}^{-1}$ for Tree 1 and $0.670 \pm 0.047 \text{ MPa h kg}^{-1}$ for Tree 2, increasing slightly to 0.317 ± 0.047 and $0.697 \pm 0.055 \text{ MPa h kg}^{-1}$, respectively, in the second phase (DOY 257–266), corresponding to increases of 6% and 4%, respectively, when re-watering and anomalous days were excluded. Min-max scaled R_{stem} time series showed similar temporal dynamics in both trees. Tree 1 versus Tree 2 values aligned closely with the 1:1 reference, with a fitted relationship (Tree 2 = $0.754 \cdot \text{Tree 1} - 0.001$, $R^2 = 0.647$) and a low mean absolute error (MAE) of 0.141 from the 1:1 line (Supplementary S2).

In contrast, stem-storage hydraulic capacitance (C_{stem}) decreased as Ψ_{stem} became more negative, with tight linear fits ($R^2 = 0.69$ for Tree 1 and $R^2 = 0.81$ for Tree 2; Fig. 4 c-d). The slope was steeper for Tree 1 ($25.59 \text{ kg MPa}^{-1}$) than for Tree 2 ($11.86 \text{ kg MPa}^{-1}$), indicating greater responsiveness of C_{stem} in Tree 1. Day-to-day patterns further confirmed this trend (Fig. 5 c-d): average $C_{\text{stem}} \pm \text{SD}$, on normal days, rose sharply after the rainfall break, increasing from 0.869 ± 0.815 to $6.160 \pm 1.032 \text{ kg MPa}^{-1}$ in Tree 1 and from 0.831 ± 0.425 to $3.885 \pm 0.433 \text{ kg MPa}^{-1}$ in Tree 2 (factors of 7.09 and 4.68, respectively). Over the entire period, average $C_{\text{stem}} \pm \text{SD}$, on normal days, was $3.514 \pm 2.876 \text{ kg MPa}^{-1}$ for Tree 1 and $2.358 \pm 1.631 \text{ kg MPa}^{-1}$ for Tree 2. For C_{stem} , the min-max scaled profiles closely overlapped across the entire period. This strong between-tree agreement was further supported by the comparison between Tree 1 and Tree 2, where data points clustered around the 1:1 line and the fitted regression was close to unity (Tree 2 = $0.966 \cdot \text{Tree 1} + 0.089$, $R^2 = 0.938$), with a very low MAE from the 1:1 line of 0.089 (Supplementary S2). To examine whether these temporal patterns depended on the absolute magnitude of F_{stem} , F_{stem} of Tree 1 was reduced to 43.7% of its original magnitude, based on the ratio between the median daily sap flow of Tree 2 and Tree 1. This

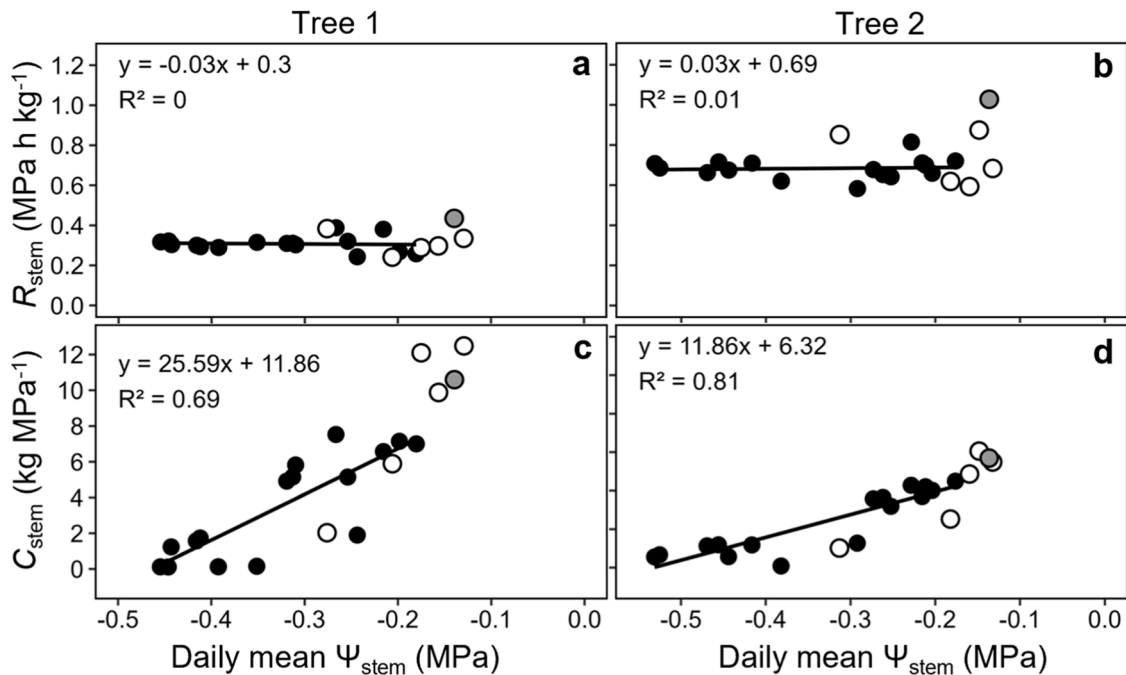


Fig. 4. Relationships between measured daily mean stem water potential (Ψ_{stem}) and (a-b) xylem hydraulic resistance (R_{stem}) and (c-d) stem-storage hydraulic capacitance (C_{stem}) for Tree 1 (left panels) and Tree 2 (right panels). Points represent daily calibrated values. Open symbols denote days affected by re-watering following rainfall and the grey symbol marks DOY 260 with deviating values. Ordinary least squares (OLS) linear regressions are shown as solid lines, regression equations and coefficients of determination (R^2) are reported in each panel. Regressions were fitted after excluding the highlighted days (open and grey points).

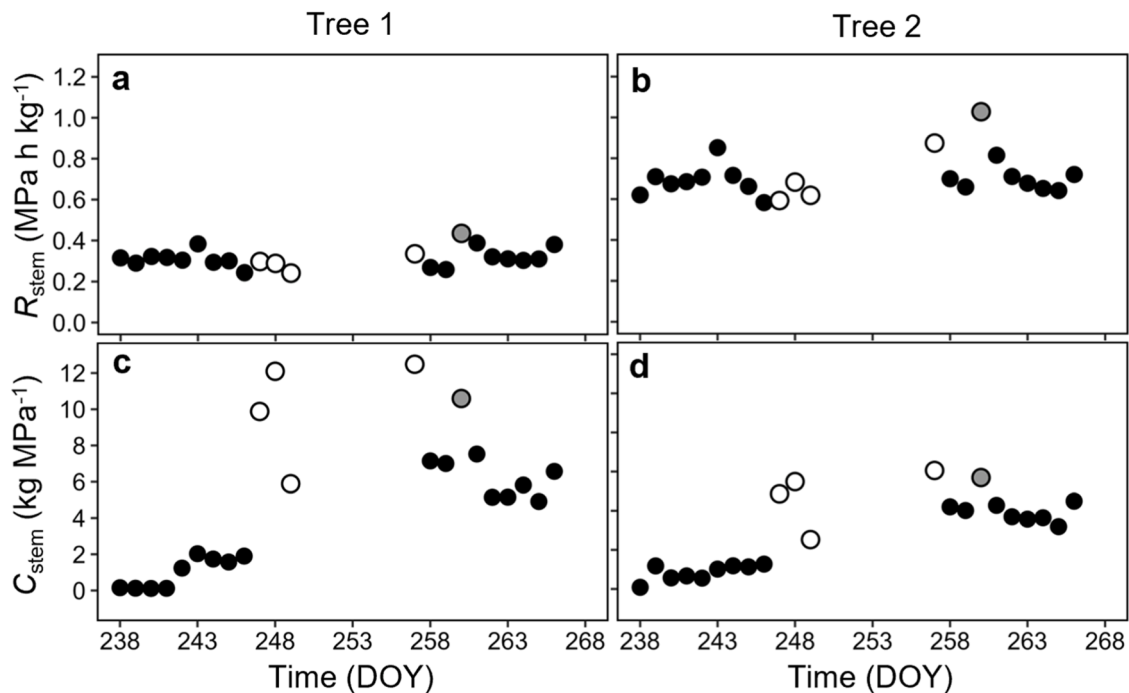


Fig. 5. Day-to-day variation in (a-b) xylem hydraulic resistance (R_{stem}) and (c-d) stem hydraulic capacitance (C_{stem}) as a function of day of year (DOY) during the measurement period for Tree 1 (left panels) and Tree 2 (right panels). Points represent daily calibrated values. Open symbols indicate days affected by re-watering following rainfall, and the grey symbol marks DOY 260. The two measurement phases (DOY 238-249 and 257-266) were separated by a brief plant sensor gap.

increased the estimated R_{stem} by a factor of 2.29 and decreased C_{stem} by a factor of 0.437. The temporal dynamics of both parameters remained unchanged, with day-to-day changes occurring at the same time and in the same direction (Supplementary S3).

The linear correlation between daily R_{stem} and C_{stem} remained close to zero on normal days (mean $\pm$ SD; Tree 1: 0.075 ± 0.158 ; Tree 2: 0.115 ± 0.072), indicating good practical identifiability of both parameters. Split by phase, correlations were near zero in phase 1 (Tree 1: -0.022 ± 0.062 ; Tree 2: 0.080 ± 0.067) and slightly positive in phase 2 (Tree 1: 0.161 ± 0.170 ; Tree 2: 0.150 ± 0.062). Correlations were higher on re-watering days (Tree 1: 0.257 ± 0.134 ; Tree 2: 0.260 ± 0.176). Apparent increases in R_{stem} on re-watering days likely reflect partial confounding with C_{stem} rather than a true physiological rise in stem hydraulic resistance. On the anomalous DOY 260, the model did not reliably calibrate R_{stem} and C_{stem} , which was reflected in the elevated correlation (0.560 in Tree 1, not available for Tree 2; see Materials and Methods for more details). Although both parameters remained formally identifiable and yielded numerical estimates, these results should be interpreted with caution.

3.4. Comparison of model-calibrated and van den Honert estimates of stem hydraulic resistance

Daily estimates of stem hydraulic resistance (R_{stem}) from model calibration and apparent resistance (R_{app}) obtained using the van den Honert equation (Eq. (2)) are shown in Fig. 6a-b. On days where a steady-state window was identified (black circles), both approaches yielded similar values. Larger deviations were observed on days without a steady-state period (open circles) or during rainfall (grey circles), when the assumptions of the van den Honert approach were not fulfilled and estimates became unreliable. For the model-calibrated R_{stem} , the SD was smaller than the symbol size and therefore not visible, while the van den Honert estimates (R_{app}) displayed greater variability. On average, the daily SD of R_{stem} was $0.0008 \text{ MPa h kg}^{-1}$ for Tree 1 and $0.0016 \text{ MPa h kg}^{-1}$ for Tree 2 with the model calibration, compared to $0.041 \text{ MPa h kg}^{-1}$ for Tree 1 and $0.095 \text{ MPa h kg}^{-1}$ for Tree 2 with the van den Honert

approach.

To illustrate these differences, three representative days are highlighted in Fig. 6c-h. On DOY 245 (I), a short steady-state period occurred between 15:00 and 17:00, during which both F_{stem} and Ψ_{stem} remained stable (Fig. 6c-d). In contrast, DOY 247 (II) exemplifies a day without steady state due to rainfall: F_{stem} dropped sharply around 14:00, and Ψ_{stem} failed to reach a stable plateau (Fig. 6e-f). DOY 260 (III) represents a day with strongly deviating patterns in the absence of rainfall (Fig. 6g-h). Here, F_{stem} did not approach zero in the evening, and Ψ_{stem} remained more negative than usual. This anomaly coincided with unusually high relative humidity and very low vapor pressure deficit (Fig. 2), leading to the absence of steady state and unreliable van den Honert estimates.

Overall, model-calibrated R_{stem} values closely matched those derived from the van den Honert equation under steady-state conditions, but deviated strongly on days when the steady-state criterion was not met, underscoring the limitations of applying the van den Honert method on such days.

4. Discussion

Stem water potential (Ψ_{stem}) is a common plant-based indicator for orchard irrigation, but its use as a fixed trigger is complicated by transient conditions and buffering by internal water storage. We assessed whether a compact water flow and storage model could deliver reliable daily estimates of stem hydraulic resistance (R_{stem}) and capacitance (C_{stem}) in a rainfed ‘Conference’ pear orchard, providing proof of concept for their potential contribution to future irrigation scheduling.

4.1. Between-tree variation and temporal hydraulic dynamics

Hydraulic functioning often varies substantially between individual trees of the same species, reflecting differences in architecture, water-use strategy, and responsiveness to environmental conditions (Lu et al., 2022; Mencuccini et al., 2019; Rice et al., 2022; Rosas et al., 2019; Shinohara et al., 2013). In our study, Tree 1 exhibited consistently higher sap flow rates (F_{stem} ; Fig. 3) and a lower Huber value (H_v)

compared to Tree 2. The higher whole-tree F_{stem} of Tree 1 could partly be attributed to its larger leaf area (7.19 vs. 6.33 m²), but persisted after leaf-area normalization (9.20 vs. 4.93 L m⁻² day⁻¹). During the initial rain-free period, higher F_{stem} coincided with a stronger decline in local soil water potential, which reached -0.0949 MPa around Tree 1 compared with -0.0385 MPa around Tree 2 on DOY 249. After the 58 mm rainfall event, Ψ_{soil} returned close to saturation and subsequently remained similar between trees ($\approx$ -0.022 MPa), whereas F_{stem} remained consistently higher in Tree 1. Calibrations also revealed a higher R_{stem} and smaller rewetting-induced rise in C_{stem} in Tree 2 compared with Tree 1 (Fig. 5).

These observations indicate persistent between-tree contrasts, but their physiological basis cannot be resolved unambiguously. Despite its higher H_v , Tree 2 exhibited lower F_{stem} and higher calibrated R_{stem} . A higher H_v represents a larger sapwood area per unit leaf area and would, all else being equal, be expected to support greater leaf-specific hydraulic conductance (Melcher et al., 2012; Tyree and Zimmermann, 2002). However, H_v alone does not determine hydraulic functioning, and potential differences in xylem anatomy and sapwood-specific conductivity were not quantified. The remaining contrast in F_{stem} should therefore be considered when interpreting the absolute between-tree differences in R_{stem} and C_{stem} , as both parameter estimates depend directly on F_{stem} magnitude (Fig. 1, Supplementary S3). Sap flux density measured at a single stem position may not fully represent the whole-tree average because radial and azimuthal variation makes the measured value dependent on sensor position (Poyatos et al., 2021; Shinohara et al., 2013). Evaluations of heat-pulse and other thermometric sap-flow methods similarly report high precision in tracking transpiration dynamics, despite uncertainty and proportional bias in absolute flow estimates (Forster, 2017; Flo et al., 2019). Accordingly, the sensitivity analysis showed that proportional changes in F_{stem} directly affected the absolute magnitudes of R_{stem} and C_{stem} , while their temporal trajectories were preserved (Supplementary S3). Uncertainty in the hydraulically active sapwood area would produce an equivalent proportional effect on whole-tree F_{stem} . Most importantly, despite these between-tree differences, the daily calibrated trajectories of R_{stem} and C_{stem} showed comparable temporal development across both phases (Fig. 5). Within-tree scaling further confirmed the between-tree correspondence, showing clear agreement for R_{stem} and C_{stem} (Supplementary S2). This interpretation is consistent with previous model-based studies showing that temporal changes in hydraulic resistance and capacitance reflect changes in plant water status and drought response (Baert et al., 2015; Salomón et al., 2017; Calabritto et al., 2025). Together, these findings demonstrate that the main strength of R_{stem} and C_{stem} lies in their ability to consistently capture temporal changes in stem hydraulic functioning, supporting their use as robust indicators of hydraulic dynamics over time.

4.2. Apparent versus calibrated hydraulic resistance: the importance of hydraulic capacitance

Benchmarking steady-state apparent hydraulic stem resistance (R_{app}) against model-calibrated R_{stem} highlighted the advantage of explicitly representing C_{stem} in the model: it delineated when steady-state assumptions were met and maintained reliable R_{stem} estimates when storage exchange occurred.

The classical cohesion-tension theory and the van den Honert equation (Eq. (2)) implicitly assume steady state conditions and neglect internal water storage. As a result, transpiration and Ψ_{stem} are not independent, with stomatal feedbacks coupling water flow and water potential and biasing hydraulic resistance estimates when storage flows occur (García-Tejera et al., 2021; Scholz et al., 2011; van den Honert, 1948). In our dataset, late-afternoon steady-state windows showed close agreement between R_{app} and calibrated R_{stem} (Fig. 6), whereas rainy days or days characterized by rapid PAR fluctuations without steady state (e.g., DOY 247, 260) displayed large divergences and much

higher variability in R_{app} . This behavior directly results from the water-balance relationship (Fig. 1): neglecting storage (dW_{stem}/dt) biases R_{app} high during morning release and low during evening refill (Goldstein et al., 1998; Meinzer et al., 2004; Steppe et al., 2006).

Hydraulic capacitance is commonly treated as a fixed trait, but growing evidence indicates substantial temporal variation that directly affects model accuracy and physiological interpretation (O'Keefe et al., 2023; Scholz et al., 2007; Steppe and Lemeur, 2007; Steppe et al., 2008; Zhang et al., 2025). For example, Salomón et al. (2017) reported seasonal declines in C_{stem} of up to 60% in *Quercus ilex* L., underscoring that C_{stem} must be represented, and preferably allowed to vary, to reproduce both Ψ_{stem} and stem-diameter dynamics in mechanistic modelling. Consistent with this view, we observed a strong post-rainfall increase in C_{stem} (Fig. 5 c-d) together with a decline in C_{stem} as Ψ_{stem} became more negative (Fig. 4 c-d). The higher C_{stem} values in the second phase were consistent with re-watering and refilling of stem water storage pools, increasing tissue water content, and the effective buffering capacity against fluctuations in water potential (O'Keefe et al., 2023). Calibrating R_{stem} and C_{stem} with a daily moving window further enhanced model accuracy under transient forcing and underscored the value of time-varying hydraulic capacitance for estimating hydraulic resistance in the field (Calabritto et al., 2025; De Pauw et al., 2008; Steppe et al., 2006).

4.3. Reliability of calibrated parameters under transient conditions

Due to the rainfed design of our experiment, we could not control the water inputs to the trees. Moreover, 2024 was the wettest year on record in Belgian history with an annual rainfall of 1170.7 mm, with a particularly wet spring and summer preceding our measurement period (Royal Meteorological Institute of Belgium, 2024). Consequently, the orchard experienced little to no sustained drought stress. Notably, however, our first measurement window overlapped with the driest period of that year. Our model was hence evaluated primarily under low to mild drought stress. The performance of our two-parameter scheme $\{R_{\text{stem}}, C_{\text{stem}}\}$ should therefore be viewed as reliable within, but not necessarily beyond, these conditions. For example, in a kiwifruit orchard (*Actinidia chinensis* Planch. var. *chinensis* 'Zesy002') in Metaponto (southern Italy), Calabritto et al. (2025) reported more severe drought conditions with a steep day-to-day decline in midday Ψ_{stem} ($\approx$ -0.1 MPa d⁻¹) accompanied by a clear increase in R_{stem} as drought stress intensified. To capture these pronounced dynamics, they extended the water flow-and-storage model by adding an extra parameter: the initial water content of the stem storage compartment (W_{stem}).

From a modelling perspective, the reliability of the daily calibration of R_{stem} and C_{stem} depends on practical identifiability and observability. In practice, this requires sufficient diurnal information in the data to constrain the water flow and storage model's parameters, which in our case was mainly provided by non-rainy days with clear diurnal dynamics (De Pauw et al., 2008; Steppe et al., 2006). On rainy or weak-gradient days, when Ψ_{stem} approached zero, the diurnal variation in Ψ_{stem} and F_{stem} was strongly reduced and parameters, especially C_{stem} (e.g., DOY 260), became poorly identifiable. Consistent with this, correlations within the parameter set $\{R_{\text{stem}}, C_{\text{stem}}\}$ were near zero on normal days but increased on days with a mean Ψ_{stem} close to zero, reaching 0.560 on DOY 260, indicating increased parameter correlation and, hence, lower confidence in estimates for those conditions. A one-day moving-window calibration helped stabilize inference under transient dynamics, but it could not, by itself, provide robust parameter estimates on days with small diurnal changes in water potential or sap flow. Under these conditions, the data contained too little information to constrain R_{stem} and C_{stem} reliably (Mencuccini et al., 2019; Salomón et al., 2017; Steppe and Lemeur, 2007; Steppe et al., 2006, 2008). For irrigation decision support, this limitation is typically of minor consequence, because rainy, weak-gradient days do not usually call for irrigation.

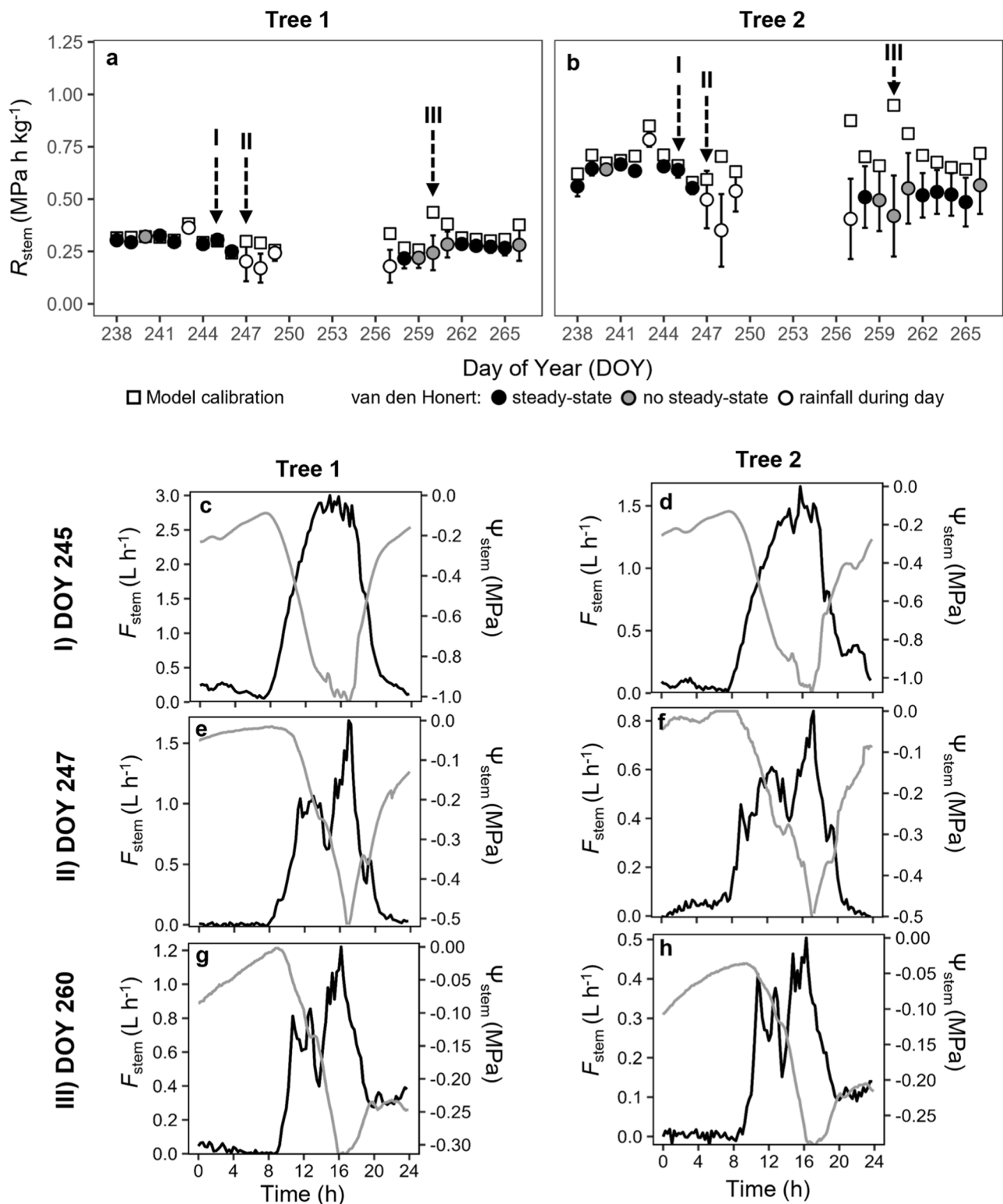


Fig. 6. Daily estimates of stem hydraulic resistance (R_{stem}) for Tree 1 (a) and Tree 2 (b) across the measurement period. Squares show values from model calibration, while circles show estimates derived from the van den Honert equation. Black circles indicate days on which the steady-state criterion was met during a portion of the day, typically a short midday window. Open circles indicate days without a steady-state window and grey circles indicate days with rainfall during the day. Error bars represent the standard deviation (SD) of the daily estimates for both approaches. For the model-calibrated R_{stem} , the SD was smaller than the symbol size of the squares and is therefore not visible. Dashed arrows mark three example days: DOY 245 (I, c-d), DOY 247 (II, e-f) and DOY 260 (III, g-h) for which panels c-h show diurnal courses of sap flow (F_{stem} , black line, left axis) and stem water potential (Ψ_{stem} , grey line, right axis) for Tree 1 (c, e, g) and Tree 2 (d, f, h).

4.4. Potential implications for irrigation scheduling

Translating continuous plant sensor signals into actionable irrigation decisions could provide a physiology-based alternative to fixed water potential triggers in pome fruit orchards. Rather than using a fixed midday Ψ_{stem} value as the irrigation trigger, we propose treating Ψ_{stem} primarily as a gatekeeper for filtering informative measurement periods, for example excluding wet days or weak tensions near 0 MPa. The compact water flow and storage model could then be used to estimate daily R_{stem} and C_{stem} from the three continuous sensor signals (F_{stem} , Ψ_{soil} , Ψ_{stem}), with the resulting parameters used to guide irrigation decisions (Baert et al., 2015; Salomón et al., 2017; Steppe et al., 2008). This approach is consistent with reports that well-watered Ψ_{stem} ranges and agronomic Ψ_{stem} thresholds are highly context dependent (e.g., environmental conditions, rootstock and tree age, phenological stage; see Fernández, 2017; Naor et al., 2008; Shackel et al., 2021). Values are often cited between -0.5 and -1.5 MPa in non-limiting conditions, yet meaningful exceptions occur at both ends. For example, in peach (*Prunus persica* (L.) Batsch ‘Tardibelle’), midday Ψ_{stem} of well-irrigated trees always remained above -1 MPa during pit hardening (stage II of the double sigmoid fruit growth curve; see Chalmers and van den Ende, 1975). However, midday Ψ_{stem} of trees that received a deficit-irrigation treatment declined to around -1.8 MPa. This moderate stress resulted in increased perceived sweetness, juiciness and peach-flavor intensity in comparison to the well-irrigated control (Vallverdu et al., 2012). In contrast, less negative operational set points are often applied during more sensitive phenological stages or in young trees (Fernández, 2017; Shackel et al., 2021). In the implementation by Steppe et al. (2008), a threshold value of -1 MPa was used in the water flow and storage model for apple (*Malus domestica* Borkh. ‘Cox Orange’). This value corresponded to the Ψ_{stem} at which photosynthesis started to decline. For low-stem *Pyrus communis* ‘Conference’ orchards, fixed midday Ψ_{stem} targets are rarely stated, but Janssens et al. (2011) reported yield reductions when Ψ_{stem} dropped to -1.5 MPa or below during summer deficit periods (Belgium, sandy loam, Quince Adams rootstock, planted in 1996). Naor (2001) also reported yield decline below -1.5 MPa for ‘Spadona’. For ‘Bartlett’ and ‘d’Anjou’, summer trials typically operated within the -1.2 to -1.5 MPa range, with fruit size penalties reported once Ψ_{stem} declined below -1.4 MPa (Blanco and Kalcsits, 2023; Marsal et al., 2002). In our case, Ψ_{stem} reached -1.2 MPa on DOY 241 (Fig. 3d) while no stress signal was yet apparent in R_{stem} (i.e., no rise in R_{stem} ; see Fig. 5a-b). Prioritizing R_{stem} as the actuator, with Ψ_{stem} retained as a quality/safety margin, avoids false positives by anchoring decisions to the characteristic increase in hydraulic resistance under effective water limitation (Baert et al., 2015; Steppe et al., 2008).

The absolute magnitudes of R_{stem} and C_{stem} differed between our two case trees (Fig. 4), directly illustrating why a universal absolute threshold is unlikely to be robust across individuals. Yet, the dynamic signal was conserved, showing comparable temporal behavior in both trees (Fig. 5, Fig. S4 in Supplementary S3). This consistency in dynamics suggests that future work should evaluate within-tree changes in R_{stem} relative to well-watered conditions as a possible basis for irrigation scheduling. Because conditions remained mild, R_{stem} largely fluctuated within baseline variability and clear exceedances were not available to delineate trigger boundaries for irrigation. Future work should therefore determine whether sustained changes in R_{stem} can be used to define validated tolerance bands and persistence criteria aligned with the maximum drought-stress level acceptable for the intended production goals.

In our study, R_{stem} remained comparatively stable during non-stress periods (Fig. 5). Previous mechanistic modelling studies reported that hydraulic resistance increased as drought intensified (Baert et al., 2015; Calabritto et al., 2025). By contrast, C_{stem} decreased with increasing drought stress (Calabritto et al., 2025; Salomón et al., 2017) and showed a strong post-rainfall response in our data (Fig. 5). Its interpretation may

therefore depend more strongly on post-watering refill transients, which could complicate early drought detection. Taken together, these patterns suggest that R_{stem} may be more straightforward to interpret than C_{stem} as a candidate irrigation decision variable.

A major constraint on the commercial uptake of plant- and model-based irrigation approaches remains the combination of instrument cost, data volume, and operational complexity, even where decision quality improves (Blanco and Kalcsits, 2024; Jones, 2004; Levin and Nackley, 2021). A future resistance-based approach would require three sensors (F_{stem} , Ψ_{soil} , Ψ_{stem}) to estimate R_{stem} . Given the limited sample of two trees, the present study should be considered proof of concept rather than validation of an operational irrigation strategy. Further research under controlled drought and irrigation treatments is needed to characterize tree-specific well-watered baselines across phenological stages and determine the magnitude and persistence of deviation in R_{stem} that indicate an actionable level of drought stress. Following the establishment and validation of such criteria, daily operation could be simplified by integrating the three continuous sensor signals into a single R_{stem} deviation from the baseline. This deviation could ultimately serve as a simple input for an on-off irrigation decision, thereby reducing the amount of data requiring direct interpretation and lowering operational complexity. At the orchard scale, implementation could potentially rely on monitoring a limited number of representative trees per management block, thereby limiting overall sensor requirements and associated costs. The comparable temporal dynamics observed in the two case trees suggest that such representative monitoring may be feasible. However, further orchard-scale research is needed to determine the minimum number of sensor-equipped trees required to represent a management block and support accurate irrigation scheduling (Blanco and Kalcsits, 2024; Shackel et al., 2021).

5. Conclusions

By integrating sap flow rate (F_{stem}) and soil water potential (Ψ_{soil}) within a compact mechanistic water flow and storage model, we successfully reconstructed diurnal stem water potential (Ψ_{stem}) patterns in rainfed ‘Conference’ pear and derived daily hydraulic traits from routine field measurements. First, regarding model validity, simulated Ψ_{stem} closely tracked observations across contrasting late-season periods, indicating that F_{stem} and Ψ_{soil} contain sufficient information to capture the dominant dynamics of plant water status under field conditions. Second, daily moving-window model calibration yielded non-correlated estimates of stem hydraulic resistance (R_{stem}) and hydraulic capacitance (C_{stem}). R_{stem} remained effectively constant on normal, non-rainy days, consistent with a stable hydraulic pathway in the absence of effective stress, whereas C_{stem} varied with water status and increased after re-watering, reflecting internal water storage refilling. Agreement with the van den Honert equation was confined to quasi-steady windows, underscoring the need to account for internal storage whenever transient flows are non-negligible. From an operational perspective, the present study provides proof of concept for deriving dynamic hydraulic information from continuous plant sensing. The limited sample and low to mild drought conditions prevented the definition of operational thresholds. Further validation should combine orchard-scale trials across seasons and phenological stages with controlled drought and irrigation treatments. This work should establish well-watered baselines, identify irrigation-relevant changes in R_{stem} and determine the minimum number of sensor-equipped trees required per management block. Taken together, this work shows that resistance-based control derived from continuous plant sensing and hydraulic modelling offers a promising, scalable foundation for next-generation sensor-driven irrigation in pome fruit orchards, placing plant hydraulics at the heart of future smart-irrigation strategies.

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CRediT authorship contribution statement

Jana Dutordoir: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Benny De Cauwer:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Mirte Boonaert:** Investigation, Formal analysis, Data curation. **Bart Vanhoutte:** Resources, Project administration, Funding acquisition. **Serge Remy:** Resources, Project administration, Funding acquisition. **Kathy Steppe:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

SUPPLEMENTARY S1. Determination of sapwood area in *Pyrus communis* L. ‘Conference’.

SUPPLEMENTARY S2. Comparison of relative temporal variation in hydraulic parameter estimates between trees.

SUPPLEMENTARY S3. Sensitivity of hydraulic parameter estimates to sap-flow scaling.

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.scienta.2026.115222](https://doi.org/10.1016/j.scienta.2026.115222).

Data availability

Data will be made available on request.

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