

Aerodynamic conductances in a sparse mixed oak woodland (*Quercus rotundifolia* Lam. and *Quercus suber* L.)



Fernando Pereira — Escola Superior Agrária, Instituto Politécnico de Castelo Branco, Castelo Branco, Centro de Estudos Florestais, Universidade Técnica de Lisboa, Lisboa, Portugal. fpereira@esa.ipcb.pt www.esa.ipcb.pt
 Fernanda Valente — Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Lisboa, Centro de Estudos Florestais, Universidade Técnica de Lisboa, Lisboa, Portugal. valente@isa.utl.pt www.isa.utl.pt
 Luiz Carlos Gazarini — Universidade de Évora, Évora, Portugal. gazarini@uevora.pt www.uevora.pt
 Jorge Soares David — Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Lisboa, Centro de Estudos Florestais, Universidade Técnica de Lisboa, Lisboa, Portugal. soaresdavid@isa.utl.pt www.isa.utl.pt

Objectives

The study of heat and mass exchange between vegetation and its local environment plays a central role in the analysis of plant-atmosphere interactions. These studies can be undertaken at different scales, ranging from individual leaves to isolated trees or even the canopy scale. In each of these cases, heat and mass fluxes depend on the use of adequate values of transfer conductances.

Within a broader study on interception loss from a sparse cork and holm oak woodland (*montado*) of Southern Portugal (Fig. 1) and in order to calculate the evaporation rates of the intercepted rainfall, aerodynamic conductances were determined for the boundary layers of both leaves (LBL) and the entire canopy.



Methods

1. LBL conductances for convective heat transfer (g_{HL}) were measured using the heated leaf-replica method and, accordingly, g_{HL} was determined from the temperature difference between 2 identical leaf replicas as

$$g_{HL} = \frac{1}{\rho c_p} \left(\frac{P_e}{T_s^h - T_s^u} - 4\epsilon\sigma T_s^2 \right)$$

where ρ is the air density and c_p its specific heat; T_s^h and T_s^u are the surface temperatures of the heated and unheated replica respectively and P_e represents the power supplied to heat one of the replicas; σ represents the Stefan-Boltzman constant and ϵ is the emissivity of the replicas surface.

3 pairs of replicas were constructed that reproduced sun (smaller) and shadow (larger) leaves, as well as leaves with an intermediate dimension (Fig. 2). Leaf replicas were made from a brass plate, 0.2 mm thick and each one was assembled using 2 similar brass plates shaped as the natural leaves; between these plates was inserted a constant wire (with a resistance of 10 ohm) used to heat the replica. Both T_s^h and T_s^u were measured using type-T thermocouples attached to the replica's inferior surfaces by aluminium foil. After assembling was completed, all the replicas were polished to ensure a high reflectance and a low emissivity and then mounted on a supporting frame. Using an universal joint this frame was correctly positioned close to the crown of an isolated holm oak tree. Wind speed was measured at the same level as well as at the tree top.

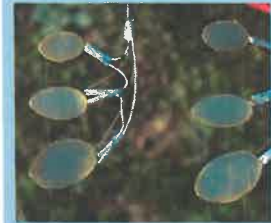


Fig. 2

Table 1 - Set of equations used to estimate g_{HL} as a function of mean wind speed (u) and leaf replicas characteristic dimension (l).

long axis of the replicas aligned with the mean wind direction	$g_{HL} = 0.0178u^{0.7}$	$r = 0.9305$
long axis of the replicas perpendicular to the mean wind direction	$g_{HL} = 0.0183u^{0.7}$	$r = 0.9270$
long axis of the replicas aligned with the mean wind direction	$g_{HL} = 0.0218u^{0.7}$	$r = 0.9264$
long axis of the replicas perpendicular to the mean wind direction	$g_{HL} = 0.0211u^{0.7}$	$r = 0.9206$
long axis of the replicas aligned with the mean wind direction	$g_{HL} = 0.0257u^{0.7}$	$r = 0.9147$
long axis of the replicas perpendicular to the mean wind direction	$g_{HL} = 0.0272u^{0.7}$	$r = 0.9131$

2. g_{HL} was also estimated using physically-based equations (usually referred as engineering equations). Since these equations are an easy to apply solution to obtain g_{HL} values, their estimates of leaf boundary-layer conductance were compared to the measured values of g_{HL} in order to access their adequacy. The equations used (Table 1) were derived from the expressions for flat plates under a laminar wind flow, considering the different characteristic dimensions of the replicas.

3. Based on the logarithmic wind profile, displacement height (d) was estimated from measurements of wind speed at different levels above the canopy. Wind speed [$u(z)$] was measured using a set of 5 cup anemometers installed along a tower 28 m high on the top of which was also installed a sonic anemometer (Fig. 3). This estimate was then used to find the roughness length (z_{0R}) as the intercept of the regression line adjusted to the log-linear profile $\ln(z-d) = f(u)$.



Fig. 3

4. Considering the whole vegetation cover, aerodynamic conductance for momentum transfer (g_{aM}) between levels ($d+z_{0M}$) and $z = 27.2$ m was determined as $g_{aM} = \{ \ln[(z-d)/z_{0M}] \}^2 / k^2 u$ where k is the von Karman constant ($=0.41$).

5. Additionally, plotting friction velocity (u_*) against wind speed measured at $z = 27.2$ m allowed to establish another relationship for $g_{aM} = f(u(z))$ and to obtain a different estimate of z_{0M} . This analysis was made considering data sorted according to wind direction.

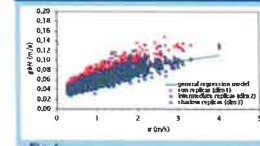


Fig. 4

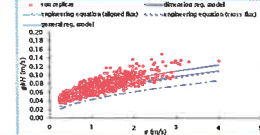


Fig. 5

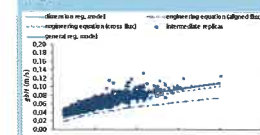


Fig. 6

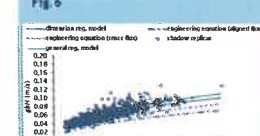


Fig. 7

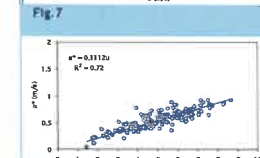


Fig. 8

Results and discussion

- Field measurements of g_{HL} ranged between 0.025 – 0.150 ms^{-1} for wind speeds from 0.25 to 4.0 ms^{-1} (Fig. 4).
- These values were systematically higher than those estimated from formulae (Figs. 5, 6, 7), with the mean ratio between measured and estimated conductances being 1.3 , a value which is within the range of values referred by different authors under natural conditions.
- The measured values of g_{HL} are similar to those obtained for leaves with identical dimensions but, as expected, are higher than those of larger leaves.
- For the 3 different dimensions of the replicas, measurements of g_{HL} were analysed according to wind direction (parallel or perpendicular to the replicas long axis) and replicas inclination (replicas positioned horizontally and with a 40° inclination angle). For each combination of these 3 factors, regression models of the type $g_{HL} = au^b$ were adjusted and differences between them were statistically evaluated (Table 2). Although a fully differentiated model had the highest R^2 (0.82), a simpler model, accounting only for the influence of leaf size, showed an identical predictive capacity (dimension differentiated model, $R^2 = 0.80$). Therefore, the use of the latter should be preferable whenever the distribution of leaf area per leaf dimension class is known. The overall relationship ($g_{HL} = 0.06u^{0.7}$) for the entire data pool (general model, $R^2 = 0.72$) makes it possible to estimate LBL conductance from wind speed alone, regardless dimension, inclination or aspect of the leaves.
- Boundary layer conductances for heat convective transfer (g_{HL}) were converted in conductances for water vapour (g_{wv}) according to $g_{wv} = 1.08 g_{HL}$ (Jones 1992).
- These conductances can be scaled up to the whole tree (g_{aM}) as a sum of parallel conductances over the total leaf area $g_{aM} = LAI * \overline{g_{wv}}$ where LAI represents the leaf area index and $\overline{g_{wv}}$ the mean value of g_{wv} considered to be representative of the LBL conductance of each individual leaf.
- Estimated values for d and z_{0M} based on the logarithmic wind profile are 6.02 and 0.51 m, respectively.
- Aerodynamic conductance for momentum transfer between the level ($d+z_{0M}$) and ($z = 27.2$ m) above the surface may then be determined as a function of wind speed, according to $g_{aM} = 0.0121 u(z)$. This expression yields values of g_{aM} in the range of 0.012 - 0.109 ms^{-1} for wind speeds from 1.0 to 9.0 ms^{-1} .
- From the relationship between u_* and $u(z)$, aerodynamic conductance can be expressed as $g_{aM} = 0.0124 u(z)$ and a new estimate for z_{0M} is 0.53 m. Although not completely independent, these new estimates seem to confirm the values derived from the logarithmic wind profile.
- Assuming an equal distribution for the source/sink of momentum and air humidity, aerodynamic conductance for water vapour (g_{wv}) can be considered identical to g_{aM} , representing the bulk conductance that controls the evaporation flux of rainfall intercepted by the vegetation.
- When compared to the LBL conductance, g_{aM} is considerably lower. This is what might be expected once g_{aM} integrates all the conductances associated to the water vapour flux from every element of the surface (not only trees but also grasses and bushes) up to an higher level ($z = 27.2$ m). Since small vegetation has a lower aerodynamic conductance than trees and water evaporated from grasses is transported across a longer path, the overall aerodynamic conductance for the *montado* is likely to be smaller than conductance for a single, isolated tree.

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