AERODYNAMIC CHARACTERISTICS OF A *EUCALYPTUS GLOBULUS* PLANTATION IN PORTUGAL[1]

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ABSTRACT

The interactions between vegetated surfaces and the atmosphere are influenced by the aerodynamic characteristics of the canopy – zero plane displacement (*d*) and roughness length (z_0). This study presents estimates of *d* and z_0 for a *Eucalyptus globulus* plantation in central Portugal during a two-year period. The two aerodynamic parameters were determined from the log mean wind speed profile above the canopy, under atmospheric neutral conditions. Mean values of *d* and z_0 ranged from 3.6 to 8.0 m and 1.0 to 2.5 m, respectively. The influence of vegetation density and height on *d* and z_0 values is discussed.

Keywords: zero plane displacement; roughness length; eucalyptus.

INTRODUCTION

Under adiabatic conditions, the mean wind speed above an aerodynamically rough surface increases with height according to the logarithmic wind profile. For a vegetated surface this profile is determined, to a large degree, by both the zero-plane displacement and the aerodynamic roughness length (Garratt, 1992).

Accurate information on these parameters is important for the analysis of momentum, heat and mass (*e.g.* pollutants) fluxes between the atmosphere and the surface (Sauer *et al.*, 1996) and for mesoscale weather models requiring detailed information on surface properties (Hurtalová & Matejka, 1999). In addition, little information on these parameters is available for forest canopies, particularly in SW Europe.

This work presents estimates of zero plane displacement and roughness length for a *Eucalyptus globulus* plantation and analyses the influence of the geometric characteristics of the vegetation on the canopy aerodynamic properties.

MATERIAL AND METHODS

The research was carried out from February 1997 to December 1998 in a 600 ha *Eucalyptus globulus* Labill. plantation in Herdade de Espirra (38º38'N, 8º36'W). This site is located near Pegões, 90 km SE from Lisbon. The terrain was ideal for micrometeorological measurements due to flat topography and homogeneity of the plantation. At the beginning of the study the eucalypt trees had a mean height of 4.5 m. In February 1998 a sprout selection reduced the vegetation density in about 50%. At the end of the study the mean height of the plantation was 11.5 m. Trees were planted 3 m apart.

Wind speed and air temperature were measured at 14.4, 16.0, 17.8 and 20.0 m using cup anemometers and properly shielded and ventilated thermocouples installed in a 24 m tower. A CR10 data logger (Campbell Scientific Ltd.) measured wind speed and air temperature every 10 seconds and recorded the 30 minutes averages.

Values of *d* and z_0 were obtained from the mean wind speed logarithmic profile under neutral conditions, described by the equation (Thom, 1975)

$$u(z-d) = (u_*/k)\, ln[(z-d)/z_0] \quad (1)$$

where $u(z-d)$ is the horizontal mean wind speed at height z, u_* is the friction velocity, and k is the von Karman constant (0.41). A computer program was written for *Genstat 5.0 for Windows* to calculate *d* and z_0. Zero plane displacement was determined by numerical iteration (Monteith & Unsworth, 1990) as the value satisfying

$$(u_1-u_2)/(u_1-u_3)=ln[(z_1-d)/(z_2-d)]/ln[(z_1-d)/(z_3-d)] \quad (2)$$

where u_1, u_2 and u_3 are the mean wind speeds at heights z_1, z_2 and z_3. Because equation 2 requires only 3 measurement levels, *d* was calculated every half hour using 4 combinations of the 4 measurement heights. After finding *d*, z_0 was determined from the intercept of the linear regression between wind speed and $ln\,(z – d)$. Wind speeds lower than 1 m s^{-1} were not used in the analysis to excluded possible periods with stalling. Values of *d* and z_0 were rejected whenever *d* was inferior to z_0 or *d* was superior to mean tree height, because they represented situations with no physical meaning.

To prevent stability effects to interfere with the results, only wind profiles obtained under neutral stability conditions were analysed. Atmospheric stability was defined by Richardson number *Ri* (Sutton, 1990) determined at a reference height of 16 m. Neutral conditions were assumed for $Ri \in [-0.1, 0.1]$ (Thom, 1975).

For statistical analysis the averages and standard deviations of the half-hour *d* and z_0 were calculated monthly. Means comparison was made through One-Way Analysis of Variance.

RESULTS AND DISCUSSION

Between February 1997 and December 1998 the monthly averages of *d* increased from 3.6 to 8.0 m and those of z_0 increased from 1.0 to 2.5 m, following the natural growth of the trees. Because *d* and z_0 depend on the height of the rough elements, the variation of both parameters was related with mean tree height *h*.

Zero plane displacement increased linear and significantly ($p < 0.001$) with *h*, as shown in Fig 1. The positive slope of the linear regression fitted to the data ($d = 0.73\ h$; $r^2 = 0.995$) indicates that the effective height of the plantation for the absorption of momentum increased in direct proportion with the growth of the trees. Other authors have confirmed the relation between *d* and *h*, namely for forest canopies (Rauner, 1976; Jarvis *et al.*, 1976). Consequently, *d* values must be normalised by *h*.

In the present study *d/h* varied between 0.66 and 0.85, with a global average of 0.73. This value is similar to others found for forest canopies. Jarvis *et al*. (1976) summarized results for *d* and z_0 for ten different forest species with mean tree height from 10 to 28 m and found average values of *d/h* from 0.61 to 0.92.

Although mean tree height is normally assumed to be the dominant parameter, vegetation density can also

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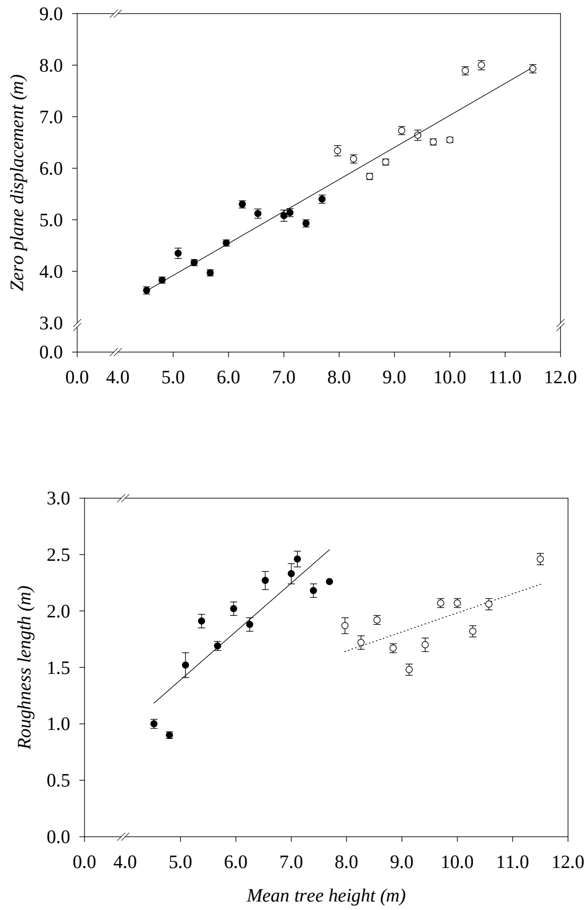

Figure 1. Zero plane displacement and roughness length relationships with the height of eucalyptus trees, before (closed symbols) and after (open) sprout clearance.

affect the aerodynamic properties of the canopy (Garratt, 1992). The sprout selection made during February 1998 in the eucalyptus plantation did not change the mean tree height but opened the structure of the canopy, reducing vegetation density. Fig 1 shows this operation did not affect *d*.

The relation between monthly average values of z_0 and h is also shown in Fig 1. Values of z_0 increased as trees grew from 5 to 8 m high. At this time z_0 decreased abruptly and started to increase again, although more slowly, until trees were 11.5 m tall. The abrupt decrease on z_0 coincided with the cleaning of the plantation. Mean values of z_0 increased linearly with h before ($z_0 = 0.429\ h - 0.755$; $r^2 = 0.79$; $p < 0.001$) and after ($z_0 = 0.168\ h + 0.299$; $r^2 = 0.50$; $p = 0.022$) cleaning, suggesting that the ability of the plantation to absorb momentum increased with the growth of the trees.

Values of z_0/h varied between 0.16 and 0.35. The global averages of 0.29 and 0.20, respectively before and after cleaning, were highly different from the 0.1 value frequently referred for z_0/h. Garratt (1992) summarised z_0/h values from 0.03 to 0.08 for four different forest species with a range in mean tree height from 10.4 to 35 m. Also Landsberg & Jarvis (1973) refer a z_0/h of 0.03 for a *Picea sitchensis* plantation with a mean tree height of 11.5 m. Dolman (1986) found a value of z_0/h of 0.10 for an oak tree forest with mean tree height of 9.6 m. Jarvis *et al*. (1976) refer z_0/h values between 0.11 and 0.26 m, closer to those found in this study.

The significant decrease in z_0 associated to the clearing of the plantation suggests a positive correlation between this aerodynamic parameter and vegetation density. In the literature there are different interpretations for the relation between z_0 and vegetation density. Some authors relate high densities with rougher canopies and therefore with higher values of z_0 (Jarvis *et al.*, 1976). According to Garratt (1992), when the density of sparsely placed elements increases, z_0 increases until a maximum at some optimal value of the roughness element density. As the elements density increases from this point forward, flow will cease to enter the inter-elements spaces and skim over their tops, so that effective roughness decreases. It is unlikely that the sparsely placed eucalyptus trees had reached the optimal value of the roughness element density and therefore a positive relation between z_0 and the elements density is entirely realistic.

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