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Canopy wetness patterns in a Mediterranean deciduous stand

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SUMMARY

This study provides detailed information on the canopy drying process subsequent to rainfall events in a Mediterranean deciduous stand. Since this is a study of a deciduous forest (*Quercus pubescens* Willd.), it has been possible to assess the differences in canopy structure as well as in meteorological conditions between seasons. Results show clear seasonal differences in wetness duration during the drying phase after rainfall, with longer wetness duration in the leafed period (8 h) than in the leafless one (4 h). There is better canopy ventilation in the leafless season, increasing canopy boundary layer conductance. However, there is a wind shelter effect in the leafed season, which entails low turbulence transfer within the canopy. Likewise, canopies remain wet longer at night in both seasons, but the differences in wetness duration between day and night are greater in the leafless season. Finally, the results indicate that the methods commonly used to separate rainfall events give an erroneous indication of the real canopy drying duration. This leads to inaccuracy in the number and duration of rainfall events and, thus, in their properties (such as rainfall depth and intensity) and represents a challenge to rainfall interception models.

1. Introduction

Rainfall interception loss is the volume of rainfall that is retained by the vegetation canopy and subsequently evaporates without reaching the ground. It is controlled by several factors. Abiotic factors are related to rainfall characteristics and the meteorological conditions controlling the evaporative demand, while biotic factors are related to the structural characteristics of the vegetation cover, such as vegetation roughness and the storage capacity of vegetation elements (canopy, branches, trunks etc.). Storage capacity is the volume of water stored in the vegetation (Leyton et al., 1967; Rutter et al., 1972) and vegetation roughness controls the aerodynamic conductance of the evaporation of stored water (Monteith, 1965).

In deciduous forest, the seasonal changes in canopy structure, which affect both the characteristics of the vegetation elements and the microclimate within the canopy, add complexity to the rainfall partitioning process. This complexity is greater in Mediterranean areas due to the variability of the rainfall-interception loss relationship, caused by the characteristic Mediterranean precipitation regime (David et al., 2005; Llorens et al., 2011).

There are no clear conclusions about seasonal differences in rainfall interception loss and wet evaporation rates in deciduous forest. Some studies show significant seasonal throughfall and stemflow differences, whereas others do not. In forests where oaks are dominant, or one of the dominant tree species, in the leafed season throughfall represents about 80–85% of bulk rainfall, whereas in the leafless season it varies widely, from 67% to 94% (Deguchi et al., 2006; Dolman, 1987; Muzylo et al., 2012a; Price and Carlyle-Moses, 2003; Šraj et al., 2008). Similarly, the factors determining the wet evaporation rate in deciduous forest and the role of seasonal changes are open to debate. While some authors found higher wet evaporation rates during the leafed season (e.g. Dolman, 1987; Deguchi et al., 2006) and explain these differences by the combined role of the meteorological variables, other authors reported higher wet evaporation rates during the leafless season (e.g. Herbst et al., 2008; Staelens et al., 2008). The latter attributed this to the increased wind speed in the leafless season. Moreover, the role of available radiation should not be ignored, especially during the leafed season (e.g. Šraj et al., 2008).

Despite the importance of canopy wetness duration for wet canopy evaporation, few studies of rainfall partitioning have measured canopy wetness duration. Leaf wetness measurements are important in agriculture and ecology, because the frequency and duration of water on leaves have important consequences for plant growth and photosynthetic gas exchange, as well as for plant

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disease through pathogen infection forecasting (Brewer and Smith, 1997; Dietz et al., 2007; Huber and Gillespie, 1992) and for atmospheric pollutant deposition, especially in foggy regions (Burkhardt and Eiden, 1994; Klemm et al., 2002). Even though several physical or empirical models have been worked out to predict leaf wetness from meteorological variables for crop protection (Sentelhas et al., 2008), leaf wetness under natural field conditions cannot be easily predicted from meteorological variables or rainfall. In fact, many other factors are involved that clearly influence wetness duration, such as type of vegetation, boundary layer conditions and leaf characteristics (hydrophobicity, particle load, etc).

In this context, little is known about the duration of leaf wetness under natural field conditions, its variability within the canopy or its relationship with the microclimate inside the stand. Only the studies by Klemm et al. (2002) in temperate forest and Dietz et al. (2007) and Chu et al. (2012) in tropical montane forests provided information on this issue. Some of the main findings of these studies highlight the greater leaf surface wetness decrease after rainfall events in forested sites than at grassy ones, due to a major atmospheric exchange of the forest surface with the boundary layer (Klemm et al., 2002). In addition, it has been emphasized that differences in wetness duration depend on the position in the canopy and on the time of day (Dietz et al., 2007; Chu et al., 2012). The importance of wetness duration for rainfall interception and transpiration modelling was also mentioned. On the one hand, the results of Chu et al. (2012) indicated that transpiration occurs from a partially wet canopy. On the other hand, the long drying time observed by Dietz et al. (2007) questions the viability of the assumption of some rainfall interception models that the canopy dries completely between rainfall events.

A review of rainfall interception modelling (Muzylo et al., 2009) indicated that the original and sparse Gash models (Gash, 1979; Gash et al., 1995) are used more frequently than the other rainfall interception models. Gash (1979) provided an analytical solution to the original Rutter et al. (1972, 1975) model that assumes the separation of rainfall events by intervals sufficiently long for the canopy and stems to dry completely. This assumption is maintained in the majority of analytical models, as well as in Calder's models (1986, 1996). This approach assumes that canopy storage compartments are empty at the beginning of each storm and, in consequence, each rainfall event has a closed water balance. In practice, a fixed number of hours is used to separate storms, either for data treatment or modelling (see Dunkerley (2008) review).

The application of different inter-event times substantially change both the number of rainfall events and their properties, such as mean rainfall duration, depth or rate (Dunkerley, 2008), and in consequence affect the simulated interception loss (Wallace and McJannet, 2006). Suspecting the constraints of defining a set number of hours to separate storms, some authors used more elaborate methods to break up events, for example by determining the inter-event period as a function of the duration of each storm (Herbst et al., 2006; Pearce and Rowe, 1981).

The main objective of this study was to analyse whether the common use of a fixed number of hours to separate rain events is consistent with the observations of canopy wetness duration, in particular for stands with seasonal changes in both canopy and rainfall characteristics. The secondary aim of this study is to evaluate whether the assumption of the use of set inter-event duration means that canopy storage compartments are empty at the beginning of each storm.

To attain these objectives, this study aims to answer the following questions: (i) What differences are observed in canopy wetness duration between events? (ii) Are there differences in canopy wetness duration between seasons? (iii) Are there differences in canopy wetness duration between day and night conditions? (iv) What driving forces explain wetness variability? and finally (v) Is the use of a set number of hours, after precipitation ending, adequate for separating events?

We attempted to answer these questions by analysing the patterns of deciduous canopy drying in a number of rainfall events in different seasons, which in turn entailed distinct canopy structures and meteorological conditions.

2. Materials and methods

2.1. Site description

The study plot is located in the Vallcebre research catchments (Gallart et al., 2005; Latron et al., 2010a) in the eastern Pyrenees at 1100 m a.s.l. The climate is Sub-Mediterranean, with a mean annual temperature of 9.1 °C. Mean annual reference evapotranspiration is 823 ± 26 mm and mean annual precipitation is 862 mm ± 206 mm (Latron et al., 2010a). Precipitation is seasonal, with autumn and spring usually the wet seasons, whereas summer and winter are dry. Summer rainfall is characterised by intense convective events, whereas in winter precipitation is caused by frontal systems (Latron et al., 2010b).

The forest canopy consists mainly of downy oaks (*Quercus pubescens* Willd.), mixed with a few other deciduous species. The forest understorey is mostly composed of *Buxus sempervirens* patches of varying density and height. The mean tree height at the study site was 11.2 m (±2 m) and tree density is 828 stems per hectare (Poyatos et al., 2005). Leaves appear in the first half of May and autumn leaf-fall is progressive, with 90% of leaves falling between October and December. The main traits of the canopy structure in the plot studied are presented in Table 1 (Muzylo et al., 2012b).

2.2. Precipitation and meteorological variable measurements

Precipitation was recorded in a nearby clearing with a standard 0.2 mm-resolution tipping bucket rain gauge (AW-P, Institut Analític, Spain) and collected data was stored on a data logger (DT500, DataTaker, Australia) every five minutes.

Net radiation (NR-Lite, Kipp&Zonen, The Netherlands), air temperature and relative humidity (HMP35C, Vaisala, Finland), wind speed (A100R, Vector Instruments, UK) and wind direction (6504, Unidata, Australia) were measured above the canopy at 13.5 m. These meteorological data were completed with measurements of air temperature, relative humidity and wind speed at the maximum crown volume level (8.0 m) and below crowns (2.5 m). Measurements were taken every minute and five-minute averages were stored on the data logger.

2.3. Leaf-wetness measurement

Twenty leaf-wetness sensors (237F, Campbell Scientific, UK) were installed on a mast in pairs at 1-m intervals throughout the canopy, from 3 to 12 m above the ground. The sensors were glued to rigid supports, which were mounted on flexible poles. This

Table 1
Stand and canopy characteristics of the *Quercus pubescens* plot.

	Leafed	Leafless
DBH (cm)	22.3	
Basal area (cm^2)	411.8	
LAI ($m^2\ m^{-2}$)	3.35 (±0.5)	
Canopy cover	0.64	0.35
Canopy storage capacity (mm)	0.49	0.17
Trunks storage capacity (mm)	0.03	0.07

Adapted from: Muzylo et al. (2012b).