

Temporal variability of water fluxes in a *Pinus sylvestris* forest patch in Mediterranean mountain conditions (Vallcebre research catchments, Catalan Pyrenees)

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Abstract The Vallcebre research catchments are representative of Mediterranean mountain areas with spontaneous afforestation by *Pinus sylvestris* as a consequence of the abandonment of agriculture since the 1950s. In this context, transpiration, rainfall interception and internal fluxes in a Scots pine patch have been monitored. This paper presents the results obtained on temporal variability of these water fluxes. The result underline the importance of rainfall interception losses, representing about 24% of the bulk rainfall, and their high temporal variability depending on the meteorological conditions and on rainfall event characteristics. Soil water content has been found to be a limiting factor for tree transpiration during summer periods, even in the studied area where the annual rainfall exceeds the reference evapotranspiration.

Key words evapotranspiration; Mediterranean mountain areas; *Pinus sylvestris*; rainfall interception; sap flow

INTRODUCTION

The effects of land use and cover change on water resources of Spanish Mediterranean mountainous areas are a major research issue as they are the water source areas for the more populated downstream regions. Mediterranean mountainous areas have undergone important land-use changes throughout the twentieth century, primarily due to spontaneous pine afforestation of old agricultural lands (García Ruiz *et al.*, 1996). The hydrological consequences of these land-use changes have been largely demonstrated at the catchment scale (Bosch & Hewlett, 1982; Sahin & Hall, 1996). However, information is lacking on the processes describing water use by pine forest in areas with larger water deficits, as in the case of the Mediterranean.

This work presents the results obtained on measurement of the temporal variability of transpiration, rainfall interception and internal fluxes in a Scots pine patch representative of spontaneous afforestation of old agricultural lands.

MATERIALS AND METHODS

Study area

The study plot is located in the Vallcebre research catchments (42°12'N, 1°49'E) on the southern margin of the Pyrenees. These catchments are representative of Mediterranean mountain areas with spontaneous afforestation by *Pinus sylvestris* as a consequence of the abandonment of agriculture since the 1950s (Poyatos *et al.*, 2003). The climate is sub-Mediterranean with a mean annual precipitation of 925 mm, highly variable throughout the seasons, and with a mean annual reference evapotranspiration, estimated using the Penman-Monteith FAO method, of ~700 mm (Gallart *et al.*, 2002).

Experimental plot

The experimental plot (198 m²) is located at 1500 m a.s.l. on a south facing slope. It has a monospecific cover of *Pinus sylvestris* with a poor understorey and a density of 2400 stems ha⁻¹. Trees are about 40 years old and their heights and diameters are very heterogeneous: mean height is ~10 m with a coefficient of variation of 28%, and mean diameter at breast height (DBH) is ~17 cm with a coefficient of variation of 43.5%. The experimental plot was instrumented in 1993 for the continuous monitoring of rainfall interception and tree transpiration. Interception was calculated as the difference between bulk rainfall, measured in a clearing near the forest plot, and throughfall and stemflow measured under the forest canopy. Throughfall was measured with nine collectors (1 m² each) and stemflow was monitored using rings in seven trees (Llorens *et al.*, 1997). Tree transpiration was measured using sap flow meters based on the heat dissipation method described by Granier (1985) and (Oliveras & Llorens, 2001). All these instruments were connected to a data logger storing bulk rainfall, throughfall and stemflow at 5 min intervals and sap flow every 15 min. Soil water content under the forest was measured weekly using the TDR method in two 0–80 cm depth profiles (with four vertical 20-cm long probes) (Gallart *et al.*, 1997).

RESULTS

Rainfall interception

Mean throughfall in the studied plot during the period July 1993–August 2000 represented about 74% of bulk rainfall, while stemflow accounts for only 2%, leading to a rainfall interception rate of 24% of bulk rainfall (Fig. 1).

In the study area, no clear seasonal control on rainfall interception has been observed. Mean seasonal relative interception rates (expressed as a percentage of seasonal bulk rainfall), analysed at the event scale, were similar throughout the year, ranging from 21 to 28%, as a consequence of the compensation between the characteristics of the events, principally its magnitude, and the atmospheric conditions. As an example, relative interception in spring was higher than in summer, as evaporative demand in summer was counterbalanced by smaller rainfall events (less than 10 mm) in spring (Gallart *et al.*, 2002).

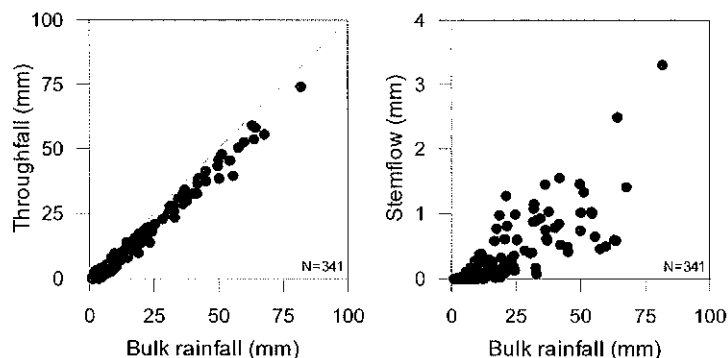


Fig. 1 Relationships between event-scale bulk rainfall and throughfall (a), and stemflow (b), for the study period (1993–2000).

Table 1 Classification of the rainfall events depending on their duration, rainfall intensity and atmospheric conditions.

Class	Duration (h)		Rainfall intensity (mm h ⁻¹)		Vapour pressure deficit (mb)		Interception rate (%)
I	26	long	1.6	low	0.3	wet conditions	15
II	5	short	7.6	high	1.1	dry conditions	13
III	12	medium	1.2	low	2.0	very dry conditions	49

Observation of the role of meteorological conditions on rainfall interception at the event scale, analysed by Llorens *et al.* (1997), lead to the identification of three types of events, considering their duration, the differences in atmospheric conditions and rainfall intensity. Long events with low rainfall intensities and wet atmospheric conditions (class I) are the most frequent events measured. Short events with high rainfall intensities and dry atmospheric conditions (class II) and medium events with low rainfall intensities and very dry atmospheric conditions (Table 1).

Transpiration

Tree transpiration during the study periods (May–September from 1995 to 2000) showed important differences between wet and dry summers (Fig. 2).

During summer 1995, mean soil water content (0–80 cm profile) was about 28%, reaching 40% after rainy periods. The mean relative transpiration (quotient between transpiration and reference evapotranspiration) was 0.45. There was a marked temporal correlation between transpiration and evaporative demand, as enough water was available for transpiration. During this period a large increase of transpiration in response to a rainy period (59 mm of net rainfall) in June and a significant decrease during a mild drought period (July–August) were observed.

During the 1998 dry summer, mean soil water content was only 18%, with a lower temporal variability (ranging from 15 to 21%). The great dependence of tree transpiration on soil water content clearly broke the relationship between transpiration and evaporative demand, with a mean relative transpiration of only about 0.22. In these

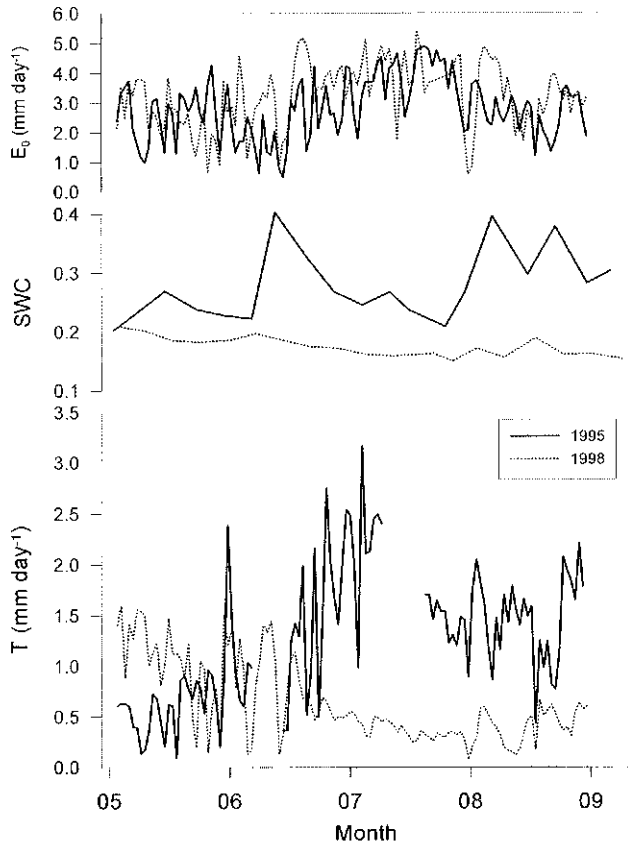


Fig. 2 Daily reference evapotranspiration (E_0), weekly soil water content (SWC) and daily tree transpiration (T) for the periods May to August 1995 and 1998.

conditions, trees showed a continuous decrease in transpiration rates with respect to atmospheric demand due to soil water depletion.

DISCUSSION AND CONCLUSIONS

The measured interception rate (24%) in this Mediterranean area was comparable to rates obtained for this species in several studies in humid-temperate climates (e.g. Aussenac, 1968; Gash *et al.*, 1980). However, rainfall interception is only partially explained by mechanisms similar to those described for humid-temperate areas, where low evaporation rates are efficient because of the length of time during which the canopy is wet (Calder & Newson, 1979), or because of the frequent wetting and drying of the canopy (Rutter, 1975). Data from the study area indicated that the main difference between Mediterranean-type events and temperate-humid ones is related to atmospheric demand, which plays an important role during events with low rainfall intensities, allowing extreme interception losses, but does not have major importance in intense Mediterranean showers (Llorens *et al.*, 1997).

The dependence of transpiration on soil water content in Scots pine forest has been illustrated in some empirical studies (e.g. Irvine *et al.*, 1998; Sturm *et al.*, 1998). Nevertheless, the critical role of soil water content in many evaporation models, and the difficulty of establishing clear relationships between soil water content and transpiration, indicate that more field experiments, of the type presented here, are required to illustrate the effect of water stress on transpiration, especially in areas where the duration and frequency of droughts are significant.

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