Measuring and modelling interception loss by an isolated olive tree in a traditional olive grove - pasture system

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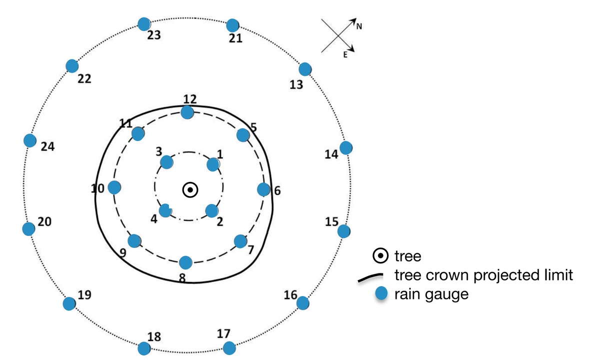
Introduction

Water losses associated to the rainfall interception process by trees can be an important component of the local hydrologic balance and must be accounted for when implementing any sustainable water management programme. In many dry areas of the Mediterranean region where agro-forestry systems are common, those programmes are crucial to foster adequate water conservation measures.
Traditional olive groves are low-density extensive agricultural systems where trees are well spaced apart.
Recent studies have shown that the evaluation of interception loss in sparse forests or tree plantations should be made for individual trees, being the total value determined as the sum of the individual contributions. Following this approach, rainfall interception was measured and modelled over two years, in an isolated *Olea europeaea* L. tree, in a traditional low-density olive grove.

Methods

Site
Location
Castelo Branco, east-central Portugal
Tree density
70 – 100 trees/ha
Canopy cover fraction
0.194
Climate
Mediterranean under continental influence



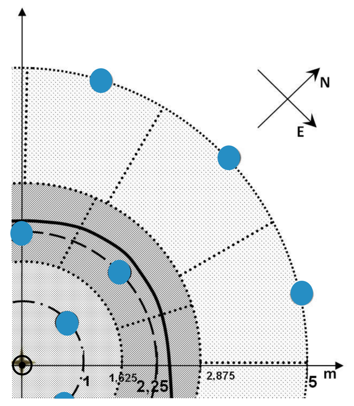
Studied tree	
Species	*Olea europea* L.
Variety	Galega
Age (years)	80 - 90
Height (m)	4.9
Crown Height (m)	3.6
DBH (m)	0.4
Crown diameter (m)	5.4
Crown projected area (m²)	22.9
Leaf area index (on a tree crown projected area basis)	3.1

Gross rainfall (P_g) was measured above the canopy through a funnel installed at the top of a 4 m high tower, connected to an identical rain gauge. This rain gauge was part of an automatic weather station mounted in the same tower and used for the measurement of all the micrometeorological variables necessary for estimating the evaporation rate.

Throughfall (T_f) was measured by an array of automatic tipping-bucket rain gages installed around the monitored tree. Stemflow (S_f) was collected by a rubber trough spiralling around the tree trunk and connected to an automatic tipping-bucket.

Methods

Interception loss was determined by a semi-direct procedure, from the measurements of T_f, S_f and P_g, as the difference between gross and net rainfall volumes ($T_f + S_f$) and considering the influence areas (circular quarters or sectors) outlined in the diagram



Influence areas associated to each raingauge

The sparse version of the Gash analytical model (Valente et al., 1997) was used for modelling interception loss, parameterized according to the table

Gash analytical model parameters

Parameter	Value	Method
Canopy cover fraction (*c*)	1	assumption
Storage capacity (*S*)	0.91 mm	Pereira *et al.* (2009b)
Trunk storage capacity (S_t)	0.065 mm	Valente *et al.* (1997)
Drainage partition coefficient (p_d)	0.036	Valente *et al.* (1997)
Trunk-canopy vaporation ratio (ε)	0.02	Valente *et al.* (1997)
Mean evaporation rate ($\bar{E}$)	0.224 mm h^{-1}	Pereira *et al.* (2009b)
Mean rainfall rate ($\bar{R}$)	1.954 mm h^{-1}	Gash (1979)

The methodology adopted for estimating the mean rate ($\bar{E}$) at which intercepted rain evaporates from the saturated wet tree crowns was the wet bulb approach described by Pereira et al. (2009a). This approach considers that the evaporation rate for a single tree can be estimated using a simple Dalton-type diffusion equation for water vapour as long as its surface temperature (T_s) is known.

$$\lambda E = \frac{\rho_a c_p}{\gamma} g_{bV}\left[e_s(T_s) - e_a\right] \qquad \text{(Eq.1)}$$

T_s is shown to be dependent upon the available energy (A) and windspeed (through its influence upon tree's bulk aerodynamic conductance g_{bV})

$$T_s = \frac{1}{\rho_a c_p}\frac{\gamma}{\Delta+\gamma}\frac{A}{g_{bV}} + T_w \qquad \text{(Eq.2)}$$

However, when the radiative energy input to the tree reduces to zero as under rainy conditions, the surface temperature of a fully saturated tree crown should approach the wet bulb temperature (T_w).
The tree bulk aerodynamic conductance g_{bV} was estimated as the product of the average leaf boundary-layer conductance (g_{lV}) by the tree leaf area index (L^*)

$$g_{bV} = \overline{g_{lV}}\, L^* \qquad \text{(Eq.3)}$$

g_{lV} was estimated as a function of wind speed at the crowns level (u) using the "engineering formula"

$$g_{lV} = 0.051 u^{0.5} \qquad \text{(Eq.4)}$$

derived following Monteith and Unsworth (2008) and assuming leaves to be represented as flat plates, with an average characteristic dimension of 29.5 mm.
The value of L^*= 3.068 was obtained by partial-destructive sampling of the monitored tree at the end of the observation period.

Results

Cumulative measured values of gross rainfall, throughfal, stemflow and interception loss for the entire experimental period: Sep/2011 – May/2013.

Gross rainfall (P_g)	Throughfall (T_f)		Stemflow (S_f)		Interception loss (I)	
(mm)	(mm)	(% P_g)	(mm)	(% P_g)	(mm)	(% P_g)
1352.2	1073.5	79.4	35.2	2.6	243.5	18.0

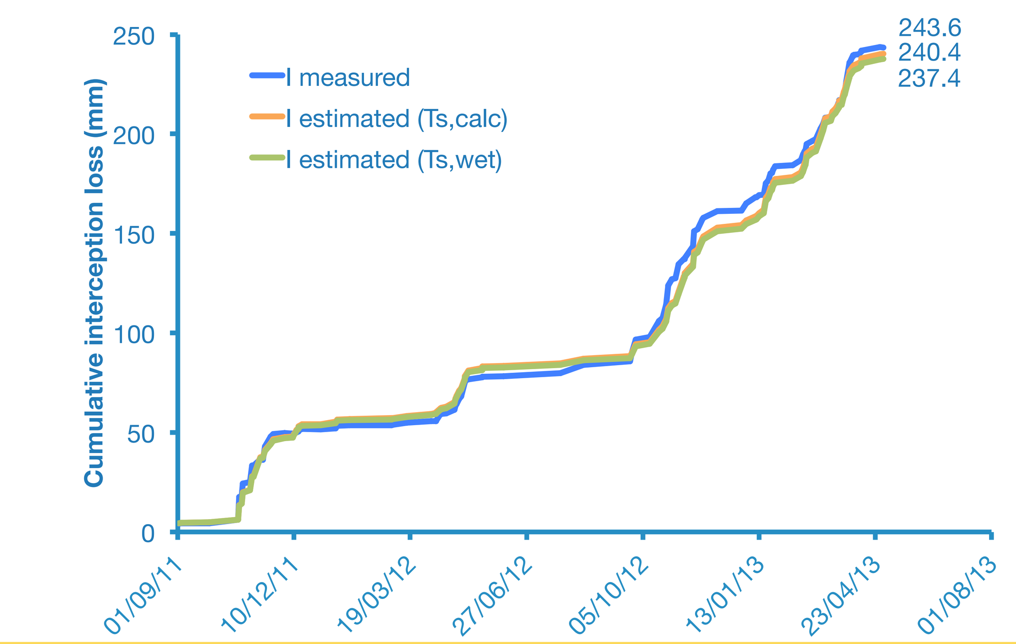
Modelled throughfall, stemflow and interception loss. The Gash analytical model was run both on a storm and daily basis. In the last case, considering one storm per rain day. All values represent totals for the study period.

	Modelled (mm)	
Rainfall partitioning	**by storm**	**by day (1 storm per day)**
Throughfal (T_f)	1076.2	1057.6
Stemflow (S_f)	35.6	33.0
Interception loss (I)	240.4	272.5

Modelling performance was assessed by calculating the Modelling efficiency as well as the Normalized mean bias.

	Modelling efficiency $1-\frac{\sum_{i=1}^{n}(M_i-O_i)^2}{\sum_{i=1}^{n}(O_i-\bar{O}_i)^2}$	Normalized mean bias $\left(\frac{\bar{M}}{\bar{O}}-1\right)x100\%$	
Rainfall partitioning	**by storm**	**by storm**	**by day**
Throughfal (T_f)	0.989	0.2	-1.5
Stemflow (S_f)	0.934	1.2	-6.2
Interception loss (I)	0.705	-1.3	11.9

Modelling results presented in the previous tables were obtained considering the mean evaporation rate estimated by Eq. 1 and the saturated canopy surface temperature estimated by Eq. 2 ($T_{s,calc}$).
However, interception loss was also modelled assuming the crowns surface temperature to be identical to the air wet bulb temperature ($T_{s,wet}$). The results obtained in both cases are presented in the graph, along with the observed interception loss.



Discussion

Measured values of rainfall interception loss and canopy storage capacity (*S*) for several Mediterranean tree species.

Tree species		*I* (% *Pg*)	*S* (mm)	Local	Reference
Quercus suber		27	2.0	California	Xiao *et al.* (2000)
Pyrus calleryana		15	1.0	California	Xiao *et al.* (2000)
Olea europea		21.7	2.7	Spain	Gomez *et al.* (2001)
Quercus rotundifólia		26.8	-------	Spain	Mateos and Schnabel (2001)
Quercus ilex ssp *rotundifolia*		23-30	1.16	Portugal	Pereira *et al.* (2009b)
Quercus brantii	*Leafed*	30	1.4 – 1.8	Iran	Fathizadeh *et al.* (2013)
	Leafless	14	0.5 – 0.6		
Olea europea		**18**	**0.91**	**Portugal**	**This study**

The values of *I* and *S* from this study are in the lower bound of the range of values observed in other Mediterranean tree species.
Combining the Gash interception model with the wet bulb approach for estimating the mean evaporation rate allowed for a good modelling performance. This good performance could also be achieved even when the canopy surface temperature was assumed to be identical to the air wet bulb temperature.
The usual simplification of considering a single storm per rain day resulted, in this study, in overestimating *I* by about 12%.
This is probably related with the fact that nearly 73% of the storms extended for longer than a day, although their average duration was 24h.

End of the event	Relative frequency (%)
In the same day	27.4
In the next day	55.8
Two days later	14.2
Three days later	2.7

Conclusions

1. Although *I* only represents 3.5% of P_g considering the olive grove ground cover fraction, when referenced to the projected crown area of individual trees, interception loss is about 18% of P_g and, thus, can not be neglected;
2. The use of Gash's model yielded good estimates of the interception loss as confirmed by the observations.
3. Moreover, the good modelling results obtained for this sparse olive grove – pasture system evidenced the adequacy of modelling the interception process at the tree level rather than at the grove scale. In these conditions, adopting the wet bulb approach for estimating the average evaporation rate also proved to be the correct choice.
4. The use of the wet bulb approach can be particularly simple in similar cases since the tree bulk aerodynamic conductance may be easily estimated using an engineering formula, while the surface temperature of the wet tree crowns can be assumed equal to the air wet bulb temperature.

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