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Hydrology and Earth System Sciences Discussions

Interactive comment on "Fog interception by Ball moss (*Tillandsia recurvata*)" *by* A. Guevara-Escobar et al.

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We thank the Referee for his useful comments and we apologize for replying so late. Some time was used to review data and procedures, and a final paper will be submitted shortly. First we would like to address why the present work is relevant in relation to the experimental conditions.

The Referee considers that these experiments can only be useful and relevant if the laboratory conditions are similar to the natural environment which they try to simulate. Also, we understand the criticism of the importance of wind speed and radiation on the evaporation process. However, manipulation of natural conditions and several assumptions have to be made to simplify reality and gain insight about the interception

phenomena.

We investigated the amounts of intercepted water available for drainage and evaporation using several wetting methods. The rates of interception or evaporation are also important, but their investigation requires measurements of available energy. Nonetheless, the studies of canopy storage are important to understand rainfall interception dynamics. In addition, there is little work with fog interception.

There are many factors that could be considered/controlled in the present study, not only those pointed out by the Referee. We choose to control some of them to isolate important effects. Main results were: 1) Dark and illuminated conditions influence water storage, 2) The highest canopy storage of water occurred when fog was applied in comparison to other wetting methods, 3) Soaking the plant specimens yielded lower storage than fog.

Comparing wetting methods is important because the maximum water content of epiphytes has been assessed by submerging samples in water or applying simulated rain (Pypker, 2006). However, epiphytes in nature are not wetted in this manner. Also, there is a discrepancy in specific storage measured by dipping vegetation into water compared to sprinkling experiments, especially when water is blotted from foliage to simulate windy conditions; storage measured this way is nearly an order of magnitude lower than under rainfall simulation (Keim, 2006).

Two primary methods to estimate interception losses are (i) calibrated process-based models of interception and evaporative loss and (ii) direct measurement (Dunkerley, 2000). Central to the modeling of interception loss is the storage of water on the canopy; this store is added to by intercepted rainfall and depleted by evaporation and drainage (Rutter, 1971). Two parameters of storage are important: transitory or maximum storage (Cmax), which is water that would later drip and; residual or minimum storage (Cmin), that depth of water removed only by evaporation (Pitman, 1989). These parameters are important for energy and mass balance models that calculate rates of evaporation; they also are important to explain eco-physiological adaptations, species distribution and diversity. Along with the Rutter model, the Gash's analytical model has been successfully used in a wide range of canopy conditions. These models require some knowledge of minimum storage independently estimated (Gash, 1979).

Since radiation is low during rainfall, the evaporation rate during storms is predominantly determined by the aerodynamic conductance (Rutter, 1971). Rutter defined the storage capacity (being equivalent to Cmin) as the depth of water on the projected area covered by the plant which can be stored or detained on the plant in still air. The value of Cmin is the minimum value necessary for saturation and is independent of the initial value when rain ceased (Gash, 1979). In the case of epiphytes, rainfall intensity had no effect on Cmin (Pypker, 2006). The concept of Cmin implicitly states that the projected canopy is uniformly and completely saturated and, then dried. When determining Cmin, how fast it is achieved is only important for the choice of instrument with enough resolution to assess the end of dripping. Filling and draining rates would be important for a series of consecutive precipitation events and unsaturated canopies (Villegas et al., 2007), or calibrating models.

Wind affects the kinetic energy of rain drops in experiments using rainfall simulators (de Lima, 2002). Although Villegas et al. (2007) studied the effect of wind speed on fog interception rate, the effects of turbulent wind eddies on local fog dynamics are not known. Throughfall upwind and down wind areas result from the accumulation of dripping and the rain-shadow effect (David, 2006). Ball moss is affixed to tree and shrub branches and is possible that not all surfaces are evenly wetted during rainfall events. Something similar could happen in the case of fog. Following different authors, we calculated storage parameters in still air and for saturated surfaces. Given the particular and small leaf architecture of Ball moss, it was not possible to assess if all projected surfaces were wetted. That was the reason for the extended wetting periods (e.g. 12 h) and a high fog application rate. We assumed that saturation was obtained because the samples attained a constant weight for an extended time.

Including only storms under zero evaporation conditions will yield a value which is a better estimate of the canopy storage than considering storms with non-zero evaporation (Gash, 1979). Therefore, we choose to reduce the effects of wind, radiation and evaporative demand on evaporation. All these were reasonable assumptions to determine the parameters of storage.

A standard 22°C temperature for the experiments was convenient for several reasons: during February to May, when rainfall was low, and from 8 am to 4 pm, after the potential fog period, the average T was 21.4 °C and HR was 36.1%; average temperature in the laboratory was stable and close to 22°C and; Pypker et al. (2006) used the same 22°C temperature in their laboratory measurements of rainfall interception by epiphytes. The average annual temperature at the selected sites was lower; we will include some graphs with time trends of T, rainfall and radiation for a complete description. The parameters Cmax and Cmin were determined at high HR and with a source of water available for evaporation to prevent evaporation from the sample, a similar procedure used by Pypker et al. (2006). We choose to work with fresh specimens (although not wet); but it is possible that dried specimens (as in Villegas et al. (2006)) would capture fog with different efficiency because the state of humidity of the interacting surface where the drops merge (Tobón y Barrero, 2010). Again, selecting experimental conditions not always resemble natural conditions, but reasonable assumptions allow comparison between studies and tests.

Specific comments:

1a) Although the authors refer that there are two meteorological stations near the experimental sites they only report mean air temperature (T) and relative humidity (HR) during early hours of the day (page 1676, Fig. 4). Nothing is said about radiation and wind speed or even T and HR during the other periods of the day.

R: The stations were at the sites. We will complete the meteorological information with graphs representing variables during other periods of the day. We considered as most relevant T and HR during the early hours because Ball moss gas exchange occurs at dark. Annual average for wind speed was 0.68 m s-1 and net radiation was -32 W m-2 during the early hours.

Fog was not measured in the field and therefore, we tried to provide evidence of fog formation at those sites. Fog has been related to reductions in visibility, and Shil-Chieh et al. (2002) studied fog interception rates by bryophytes when visibility was lower than 500 m. It is possible that lower than visible concentrations of liquid water are relevant to gas exchange dynamics for foliar water uptake (Burns-Limm et al. 2009). On the other hand, Villegas et al. (2007) suggested that fog interception rates by Ball moss were sensitive to the interaction between low levels of wind speed and liquid water content of fog; although their field measurements of fog interception rate were smaller than measurements in a fog chamber. The relation between wind speed and fog interception rate results from vertical settlement at low speeds and advectional impactation at high speeds. However, not only wind speed, but turbulent diffusion modified by factors like steep slopes, great exposure to the humid trade winds and presence of forest vegetation facilitate fog precipitation (Prada, 2010).

1b) In Fig. 3 (page 1675) the authors show the decaying of canopy water with time when HR is less than or equal to 30% and T is 22 Celsius degrees. Are these conditions similar to the natural ones after fog? And what about the importance of wind speed and radiation on the evaporation process? If the authors do not take into account these matters the lab data may be irrelevant for the natural evaporation process of intercepted water by Ball moss.

R: Average RH was 36.1% and T was 21.4 °C from 8:00 to 16:00 for low rainfall months, February to May; conditions in the laboratory were considered similar. Monthly averages will be presented for this condition. It was beyond the scope of the study any assessment of energy and mass fluxes using eddy covariance and gas analyzers. Also, it would be difficult to replicate turbulent fluxes and terrain effects, although the work of Villegas et al. (2007) is a good attempt.

1c) The description of the rain experiment is almost non-existent (page 1661, lines 9-11). What was the dimension of the drops? How was the spray applied (vertically, horizontally, : : :)? Did the authors try to simulate natural rain features/conditions? Once again, this information will be quite important to make reliable extrapolations from lab data to field conditions.

R: The text will be changed:

Original

Thirty specimens were used to estimate the mean minimum interception storage capacity by rain. Spray was applied manually until the weight of the wetted specimen was constant. The drying phase was 12 h or until drainage finished.

Edited

Ball moss within shrub canopies is mainly found at the mid and lower branches and throughfall interception may be more important. Drop size distribution of secondary drops ranges from 0.5 o 5.5 mm and is characteristic of particular tree species (Calder 1996). Throughfall had different drop size distribution among canopy species under conditions of little canopy vibration with low rainfall intensity and wind speed; but throughfall contained smaller drops under conditions when rainfall intensity was high (Nanko et al., 2006). Convective high intensity rainfall is typical in the region; therefore, small, low velocity drops were used. Spray was horizontally applied over the specimen to produce low velocity drops, representing throughfall within the tree canopy that could be intercepted by epiphyte vegetation. Two manual sprayers were operated at a constant time rate. Rainfall was measured with a TE-525LL-L tipping bucket (Texas Electronics Inc., Dallas TX) calibrated to record 0.254 mm per tip. Rainfall intensity was 70 to 79 mm h-1 and drop diameter was 1.8mm ± 0.2. Thirty specimens were used to estimate the mean minimum interception storage capacity by rain. The simulation stopped when the weight of the wetted specimen was constant. The drying phase was 12 h or until drainage finished.

2 The authors use a set of formulas to calculate the dew point temperature (page 1663, lines 10 and 13) which I was unable to derive/understand: a) They say that 'according to Monteith and Unsworth (1990) a factor of 4.81 is used instead of 6.11'. I am afraid I could not find that recommendation in the mentioned book.

R: Dew point temperature was recalculated using the Magnus-Tetens formula. The coefficients used were according to Murray (1967). Figures would be corrected accordingly.

3 Considering the linear relationship between Cmax/Cmin and Wf0 during fog conditions (page 1664, lines 4-5), I do not think that an r2 of 0.52/0.56 with a p-value of 0.02 is very relevant. In my opinion this shows a very weak linear relationship between these variables.

R: We do agree with the comment. Although both regressions were significant the relation between Cmin and Wf0 was not good for fog but it was better for simulated rainfall (r2= 0.79). Therefore, only rainfall interception was scaled up.

4. The authors say that 'In the present work, it was possible that coalescence increased drainage in the immersion tests for S' and therefore, C'min was higher for fog compared to rain' (page 1664, lines 16-17). This sentence does not make much sense as the C'min values for rain were not obtained by immersion! Please rewrite the above sentence.

R:Text will be changed to: In the present work, it was possible that increased coalescence was important in the immersion tests for S' because a liquid film was present and the contact line dynamics would be faster. Drop oscillation and deformation modes of larger rain drops also would increase coalescence with respect to condensation-induced coalescence of fog drops (Narhe 2005). Different mechanisms of contact line motion along with partially wet surfaces could explain the higher C'min for fog compared to rain ($p < 0.0001$).

5 I think it is quite inappropriate to call sub-section 3.2 'Field study'

R: The section will be named 'Extrapolation to natural condition'.

5a) The authors explain how they convert the rain value of C'min from mg/mg to mm (page 1665, lines 17-18). However, if the same procedure is applied to the fog C' values (mg/mg) of Table 1 (page 1672), the values obtained are not equal to those presented (in mm) in the same Table. The authors should confirm them or explain how they were obtained.

R: The values will be corrected for Cmin to 0.56 instead of 0.54 and for Cmax to 0.81 instead of 0.97. As pointed out correctly by the Referee, the same procedure should be applied for rain and fog.

5b) The authors say that 'the contribution of T. recurvata to rainfall interception was calculated as 5

R: The question is incomplete but it appears to be related to the method of estimating the contribution of rainfall interception by Ball moss. The text will be changed.

Original

The contribution of T. recurvata to rainfall interception was calculated as 5% (35.8mm) of the annual rainfall.

Edited

Tillandsia recurvata intercepted 5% of annual rainfall (35.8 mm). Rain events greater than 0.19 mm would saturate the plant surface and therefore, events were counted and multiplied by 0.19 mm; rain events smaller or equal to 0.19 mm were added up. Rainfall events were identified as storms separated by periods of time longer than 24 h.

5c) The authors present a relationship between C and t (page 1665, lines 22-23). How did they get it? Was this obtained with the data of Fig.2? Once again this should be explained in the text (and the units of the variables explicitly stated).

R: The text will be changed.

Original

In terms of fog, 57 min were needed to intercept 0.19 mm, this value was obtained using the relationship C=-0.83+0.25 ln(t), r2=0.98, p<=0.0001; where t is time and C is the stored water in an area basis.

Edited

In terms of fog, 57 min were needed to intercept 0.19 mm, this value was obtained scaling up to area basis the data presented in Figure 2 and using the relationship C=-0.83+0.25 ln(t), r2=0.98, p<=0.0001; where t was time [min] and C was the stored water [mm].

6 Minor comments

6a) Page 1660, lines 9-10 – complete information about the manufacturing companies of the mentioned instruments is missing

R: The information will be completed.

(Onset Corp., Bourne, MA, USA) (Elehum002, Sunshine, EM, Mexico)

6b) Page 1661, line 25 – What is D?

R: The original sentence "Values of S and D were determined as:" would be changed to "Values of S were determined as:"

D is drainage being equal to Wfmax-Wfmin

6c) replace '(Olalde and Aguilera, 1998)' by 'Olalde and Aguilera (1998)';

R: correction will be made.

6d) Page 1666, line 28 – replace 'infiltrataion' by 'infiltration

R: correction will be made.

6e) Pages 1668-1671 – all the references end with a number (1666, 1657,: : :). Is this correct? What is the meaning of these numbers?

R: The numbers are the page numbers where the reference was cited.

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