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Interactive Comment

Interactive comment on “Experimental analysis of drainage and water storage of litter layers” *by* A. Guevara-Escobar et al.

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We acknowledge with thanks the comments given by the Referees. The three reviewers raised important issues that need attention. The main concerns were: 1) that the experiment and analysis does not deal with the topic of slope stability and therefore the introduction and discussion should focus only on storage and interception, 2) the relation between the different tests and their rationale must be explained clearly, also the discussion presented is limited with regard to other work and the importance of the results presented, 3) explain why the Rutter model was used. Here we reply to the main comments. Other observations will be attended including resizing figures and incorporating captions within the graph.

1.1. The introduction presented was prepared without the intention of misleading the reader or to raise high expectations in the conclusions other than the provided evidence. The aim in the introduction was to present the problem and stress known aspects of the vegetation that influence slope stability in relation to planted trees. We realize that this caused some misunderstanding that was carried out throughout the manuscript. Therefore, the structure of the introduction will be reworked to decrease the importance of soil stability as the topic of the investigation and focus on storage and interception. The importance of the research regarding slope stability will be highlighted along with other important aspects of the system involving restoration/landuse change and the sustainability of marginal or impoverished areas of the world where cattle operations take place in hill country.

2.1. Our objective was to obtain storage and drainage coefficients for the materials tested; this information is needed for further modeling to determine best management practices, certainly beyond the scope of this work. The difficulty of observing soil moisture routinely means that it is a property that needs to be modeled well, but in wooded lands the problem is not trivial. For instance, Keim et al. (2005) stressed the importance of throughfall spatial patterns, however patterns in throughfall water cannot directly be related to patterns in water content without knowledge of litter characteristics such as drainage (Raat et al. 2002).

The experimental approach used allowed to test and confirm the findings of other authors without the noise caused by the dynamics of litter decomposition, spatial distribution, interactions with grass growth, instrumentation in the field, or physical characteristics of throughfall, among others. All these factors are important, but must be studied with adequate manipulation to clearly assess a cause and effect relationship.

We realize that renaming the subsections will provide better organization and remind the reader about the purpose of each test. Hence, the sections will be named:

2.3 Effect of rainfall intensity on storage

2.4 Effect of the litter layer-soil matrix interface on drainage and storage

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2.5 Effect of wetting drying cycles on drainage and storage

Sections 3.1, 3.2 and 3.3 also will be named accordingly.

2.2. Now we explain the rationale of the performed tests, this will be succinctly incorporated in a revised manuscript as well as the objective of each test along with diagrams of the experimental setup. Here we agree with the comments of the reviewers about some “cryptic sentences”, certainly some things were left out or needed more explanation.

2.2.1. Evaluating the effect of rainfall intensity on storage was based on the work of Sato et al. (2004) and that of Keim et al. (2006). Sato et al. (2004) demonstrated that rainfall intensity increased C_{min} (storage after drainage ends) and C_{max} (storage after the rain ends) of litter layers. For example C_{min} increased from 0.44 to 1.03 mm for *Cryptomeria japonica* and from 1.33 to 1.74 mm for *Lithocarpus edulis* when rainfall intensity was 5 and 50 $mm\ h^{-1}$. On the other hand Keim et al. (2006) studied branches of eight species and showed that storage was generally about 0.2 mm greater at rainfall intensity 420 $mm\ h^{-1}$ than at 20 $mm\ h^{-1}$. Although the materials were different the discrepancy was evident and needed confirmation.

The range of rainfall intensity from 9.8 to 70.9 $mm\ h^{-1}$ was considered representative of natural conditions and was similar to the range of rainfall intensities used by Sato et al. (2004). Our results indicated that only C_{min} increased 0.2 mm with rainfall intensity and only for poplar leaf litter ($p<0.05$). This value of C_{min} was lower than the increases reported by Sato et al. (2004). Keim et al. (2006) suggested that morphological characteristics of vegetation may play a role in this process and they provided a conceptual mechanical model of canopy storage during rainfall that includes the concepts of static storage and dynamic storage to account for intensity-driven changes in storage. Sato et al. (2004) described the material used as intact samples collected from the field of relatively undecomposed litter layer, they also mention that the *C. japonica* shoot is composed twigs and needles, with 3 to 5 twings and curved, awl-shaped needles while

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L. edulis is composed of a broad, oblong-shaped leaf about 6-13 cm long and 2-4 cm wide, with a leathery texture. Putuhena and Cordery (1996) also reported different storage for pine and eucalypt forest floor, but only slightly higher maximum water detention was observed for the higher rainfall intensity. We agree with Keim et al. (2006) with respect to increased storage related to the physical characteristics of the foliage (and branches). In our study, the poplar leaves and the shoot and leaves of grass were glabrous (hairless) and, possibly drainage was faster (and storage lower) from these surfaces than from hairy leaves (with trichomes) used by Sato et al. (2004). Leaf trichomes have been considered as an important ecophysiological factor contributing to an increase in the leaf boundary layer resistance. Trichomes may modify the contact angle, capillary radius and surface tension, thus reducing water loss.

2.2.2. Evaluating the effect of the litter layer-soil matrix interface on drainage and storage had two purposes. Section 2.4 was confusing because of this and the same happened in section 3.2. We will restructure the presentation accordingly.

Firstly this evaluation was pertinent because some of the reports of litter storage and drainage have been made using trays with a wire mesh or a screen holding the litter sample in place (Pitman, 1989; Putuhena and Cordery, 1996; Sato et al., 200; Gerrits et al., 2007). This procedure was criticized by Helvey and Patric (1965) because the interface effect introduced when a mesh or another artificial barrier to natural drainage is placed between litter and soil and water filtering through the contained litter accumulates at the litter-container interface until surface tension is overcome. This problem was addressed by Sato et al. (2004) or Pitman (1989) by subtracting the amount of water held by the strands of the mesh or supporting frame. Since the problem was surface tension, we hypothesized that a litter-mesh-soil interface could result in a different response on drainage because the negative pore pressure imposed by the neighboring soil. This aspect has not been reported before.

Secondly, another interesting aspect related to the litter-soil interface is lateral movement of water which is important for the modeling of hydraulic connectivity and overland flow. Sato et al. (2004) reported increased lateral drainage when litter mass increased in the case of the broad leaf *L. edulis*. This result was reached by supplying the rainfall into only a central part of the litter surface, approximately one-third of the surface area of a 16 x 24 cm container. They concluded that the broad-leaf litter can intercept more rainwater than the needle-leaf litter of *C. japonica*, because larger amounts of rainwater spread within the flat-type litter layer the former is more likely to have wet surfaces than the latter. The work of Sato et al. (2004) is the only report to date of this phenomenon; we looked for confirmation using containers of greater area.

We recognize that this test was not perfect; the mesh was present because it was required to hold the sample in place. Also, we choose a quasi saturated condition of the soil matrix in order to reduce the lag in the drainage response and decrease the variability arising from different water content conditions between runs. Thus, capillary movement was likely only during the initial phases of the experiment and afterwards water conductivity might be limited to some extend by air bubbles in the soil matrix. In short, we could not determine when saturated flow started, although we suspect that for most of the experimental runs it occurred. Monitoring the wetting front and hydraulic conductivity by means of a tracer and time domain reflectometry was highly desirable to clarify this, but we have no means to do that.

The effect of rainfall intensity on near-surface soil hydrologic conductivity has been reported by Hawke et al. (2006), they attributed this to the disruption of the near surface soil structure. This was also a reason for using compressed and dried sewage sludge, mainly because we included control treatments without overlaying litter layers and the soil matrix was not replaced between runs. The pore structure of the sewage sludge used did not collapse under repeated rainfall simulations. If we were to use a common soil (vertisols in our region), clogged pores and water ponding in the surface would be a problem, even with soils of little clay content.

Our results showed that the litter-soil matrix had no effect on total drainage from the instrumented containers or storage capacities of the litter. Therefore, the amount of water detained by the mesh was small and the underlying soil matrix had no effect on the litter water relations. This may not be the case for clayey or dry soils.

This test showed that the drainage rate was rather smooth in the absence of a soil matrix. On the other hand, variations in the drainage rate were evident in the experiments that used a soil matrix; also the onset of drainage was delayed. Therefore, modeling of transient drainage flow exceeding steady state rate should be investigated.

2.2.3. Soaked litter for 24-h has a higher water holding capacity (maximum storage, S) than that of C_{max} of dry litter samples after a rain event. Therefore, it was possible that C (storage) could increase with repeated wetting cycles and also it could be related to litter mass. We choose a 3-h wetting period with three drying periods every hour of rain simulation. Sato et al. (2004) also used a 3-h rain simulation period but it was a continuous rain simulation; that could also explain the lower values obtained in test 1 with respect to those reported for *L. edulis*. Nonetheless, in our study C_{max} and C_{min} were similar between wetting-drying cycles, although the layer thickness decreased after the first rain cycle. These tests confirmed our previous results and also confirmed that poplar leaf litter absorbed little water during this simulation, if any.

Pitman (1989) and Putuhena and Cordery (1996) worked with intact samples of litter of varying mass and obtained a relationship between mass and C_{min} or C_{max}, resulting in a slope with units ($mm\ kg^{-1}\ m^2$). However, in the work of Sato et al. (2004) they cited the work of Putuhena and Cordery (1996) as: "Putuhena and Cordery (1996) reported the *S* of eucalyptus and pine leaf litters was 1.13 mm and 0.97 mm, respectively." Instead of 1.13 and 0.97 $mm\ kg^{-1}\ m^2$. We standardized our measurements on a mass and area basis and for simplicity the units in the Y axis of Figure 1 were (mm) although in reality they were ($mm\ kg^{-1}\ m^2$), this was mentioned in the text but apparently was not clear as one of the Referees pointed out. We ask the editor to decide on this matter.

4.1. In all models of rainfall interception loss by forest canopies the most important parameters are boundary layer conductance and canopy storage capacity. Although

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many models have been proposed to predict interception empirically, physically or stochastically the models developed by Rutter (Rutter et al., 1971) and by Gash (1979) are the two models most widely used. The Rutter model considers the tree canopy surfaces as a compartment for water storage and continuously simulates the depth of water retained. Rutter et al (1971) described drainage following empirical function of canopy storage; this modeling could provide a useful framework for the study of litter layers water relations.

However, water can be held by adsorption or absorption by materials such as leaf litter, if a material has a low absorbency but is high adsorbing, then it will dry quickly. Helvey and Patric (1965) and Sato et al., (2004) reported *S* of litter layers after soaking or immersion in water for 24-h or more. Typical values for *S* were higher than C_{max} or C_{min}, although Sato et al., (2004) compared their *S* values with C_{min} values reported by Pitman (1989), Puthuhena and Cordery (1996) and others. If water is absorbed by litter layers during a rainfall event, then the Rutter et al. (1971) model would not be appropriate because another compartment should be modeled. In particular, Rutter et al., (1971) showed an empirical relation between drainage (*D*) and water storage (*C*) but this has not been demonstrated for litter layers. For almost all models of rainfall interception it is implicitly assumed that foliage in the canopy is impervious, but for litter layers this is not always true.

Bussiere and Cellier (1994) modeled water relations of a banana leaf mulch using Rutter's model, but some required parameters used in that work were taken from a previous study of sugar cane mulch and not for a banana mulch. Other authors have reported the water storage of different litter layers, but water relations were not modeled (Pitman, 1989; Putuhena and Cordery, 1996; Crockford and Richardson, 2000; Tobon-Marin et al., 2000).

The main interest of the present investigation was on senesced poplar leaves because this is the component of agroforestry systems that needs to be managed. However, to test if the Rutter model was appropriate, we wanted to use materials with contrasting

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capacity to absorb water: fresh grass and woodchips. The evidence showed that the Rutter model was good enough for poplar litter, and that was also a reason to focus only in this relevant result. Therefore, woodchips and grass were not used in all tests.

There are a number of reasons why the model did not perform well in the case of grass and woodchips. Massman (1983) suggested that the drainage function is important in the Rutter model, but the empirical representation of D in the Rutter model depends on factors such as canopy structure and rainfall intensity and if storage is overestimated may lead to overestimation of interception loss. As with many other choices in developing models and parameterizations, the actual choice of the form of this dependence is a matter of (physically based) mathematical convenience (Ramirez and Senarath, 2000). It is possible that another function will better fit the woodchips data. At the moment we propose that a model that considers adsorption and absorption by canopies surfaces will be more suitable. A model for woodchips would be very complex because the physical structure of the material changes after wetting and it is not completely recovered after drying. The proposed model is being developed and will be tested using data from our current work evaluating the effect of surface sealants and braches with different bark characteristics on water interception.

We were asked to plot the hysteresis associated with the wetting-up and drying cycle of the materials tested. The methods used in the present study do not allow for this: first, our measurements were stopped when drainage ceased, therefore we can not plot the complete hysteresis in the capillary pressure-saturation relationship; second, hysteresis depends on the saturation history, we anticipated this and therefore every simulation run started with a new sample of litter material.

We believe that the presented information was adequate regarding the uniqueness of the estimated drainage parameters of litter layers. Even if the distance between mulch foliage elements may be small enough to retain water by surface tension, they do not form a connected network and cannot allow water movement by capillarity. The only possible transfer of liquid water is the penetration of rain through the gaps or the dripping of intercepted rain on the litter layer elements (Bussiere and Cellier, 1994). The gaps between the elements of poplar leaves and fresh grass were considered big enough to allow for this assumption. Drying and wetting soil-water characteristic curves are affected by soil density and grain size distribution and therefore a coarse-grained soil has a lower air-entry value, residual matric suction, and water-entry value and less total hysteresis than a fine-grained soil.

Although the case of woodchips was not the main interest of the present research it is worthwhile to think about it as an example of “decomposed” material, given the exposure of the conducting vessels and tracheids of the xylem, broken cell walls and shattered fibers. The tracheids behave like true capillaries but the vessels are wider and capillary movement is less important. However, water is drawn up the plant by transpiration according to the cohesion-tension theory and not by capillary movement. Many authors examined litter samples collected from the forest floor with possible varying states of decay, but none of them suggested hysteresis (Pitman, 1989; Bussiere and Cellier, 1994; Putuhena and Cordery, 1996; Crockford and Richardson, 2000; Tobon-Marin et al., 2000).

Summarizing, there are few reports of litter interception and not all of them researched storage capacity and drainage relations. The presented work indicates that rainfall intensity has a statistical significant influence on C_{min}, but the magnitude is small with regard to the effects of rainfall intensity, litter material, litter mass or wetting cycles. Litter mass increases storage but it is linearly proportional. By measuring litter mass ($Mg\ ha^{-1}$), and knowing the storage per unit of mass and area, is possible to determine storage of a given plot without adjustment for layer thickness -assuming that the litter layer is homogeneous.

The Rutter model could be useful because our modeling demonstrated that the drainage and percolation parameters were able to predict drainage from layers of recently senesced poplar leaves regardless of the rainfall intensity within the window from 9.8 to 70.9 $mm\ h^{-1}$. For other materials this representation was less accurate. The

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results involving an underlying soil matrix suggests that transient drainage modeling would be also need.

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