

Interception of water by pastures of *Pennisetum clandestinum* Hochst. ex Chiov. and *Melinis minutiflora* Beauv.

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ABSTRACT

The conversion of montane cloud forests into pastures for grazing cattle is the main cause of important impacts on rivers and streams in most of the Andes. In order to evaluate the effects of vegetation changes we need to understand water fluxes, particularly canopy interception. We measured net precipitation responses by the canopies of *Pennisetum clandestinum* Hochst. ex Chiov. and *Melinis minutiflora* Beauv. under simulated rainfall. The samples were taken from grazed pastures during 1 year, digging out round mats of grass, placing them on wire-mesh devices after eliminating soil and underground biomass, and irrigating with different water amounts. The resulting data allow us to present a validated model for each species that predicts percentage of interception at different precipitation intensities taking into account previous canopy wetness within determined biomass ranges. We use these models to estimate 2 years of interception values for pastures of both species in the upper watershed of El Cañadón, Capaz River, Venezuelan Andes. Mean annual precipitation of El Cañadón is 1244 mm and the estimate of pasture interception was 36.5% and 31.8% for *P. clandestinum* and *M. minutiflora*, respectively. Interception models, such as the ones derived in this study, provide a basis for quantifying interception rates as a function of previous wetness of canopies and grass species.

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1. Introduction

Andean cloud forests play an important role in watershed hydrology. The conversion of montane cloud forests into pastures or into various types of crops is the main cause of important impacts on rivers and streams (Bruijnzeel, 1990, 2001). One of the most significant effects of the changes in the vegetation due to human activities is the alteration of the water dynamics in the systems (Bruijnzeel, 1990; Bruijnzeel and Proctor, 1995; Cavelier and Vargas, 2002; Ataroff and Rada, 2000). In most of the Northern Andes, cloud forests have been replaced by pastures for grazing cattle, mainly by two African grasses *Pennisetum clandestinum* Hochst. ex Chiov. and *Melinis minutiflora* Beauv. (Ataroff, 2001; Cavelier et al., 2001). Understanding the water balance and main fluxes in ecosystems and agroecosystems is necessary in order to evaluate the effects of vegetation changes on catchments runoff. Canopy interception (the proportion of rain water retained and evaporated by vegetation) is one of these important fluxes as it determines the proportion of water reaching the soil.

Interception depends on the characteristics of precipitation and vegetation canopies. Pasture and prairie canopies have a particular structure and foliage mass that differs from other better studied canopies, such as forest canopies, and consequently need different methodological approaches (Clark, 1940; Seastedt, 1985; Acevedo and Sarmiento, 1990; Ataroff and Sanchez, 2000; Brye et al., 2000; Rincón et al., 2005).

Interception estimates based on net precipitation (throughfall plus stemflow) are relatively easy to study in forests. However, in pastures with mat-forming grasses (lawn hyphen like grasses), interception is hard to measure, in most cases as a consequence of the complicated aerial architecture of those systems. The use of mini-gutters (or similar devices) placed on the soil surface and under the grass canopy may lead to erroneous estimates of net precipitation. Rincón et al. (2005) using this method, found lower net precipitation values compared to soil water content. The main purpose of the present study was to model the interception of *P. clandestinum* Hochst. ex Chiov. and *M. minutiflora* Beauv., two mat-forming grass species commonly cultivated in deforested areas of cloud forests in the Venezuelan Andes. The model was based on experimental data using simulated rains under laboratory conditions and taking into account previous canopy wetness within determined biomass ranges. We used the resulting models to

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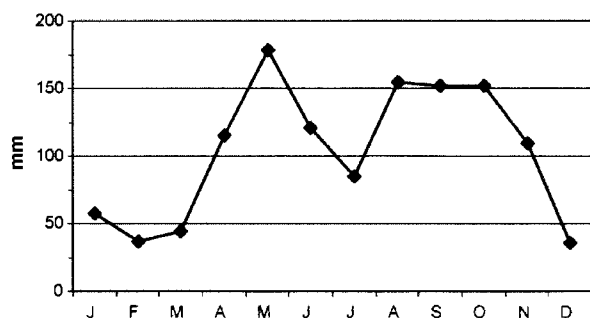


Fig. 1. Annual precipitation for the study area (mean of 2005–2006).

estimate the interception of two pastures of the cited grasses in El Cañadón, Mérida State, in the Venezuelan Andes.

2. Methods

2.1. Study area

Samples of both grass species used in this study were taken from the farm El Cañadón (x: 239561, y: 962642, Projection UTM, Datum WGS84, Zone 19N), 2200 m asl, in the upper basin of the Capaz river, Mérida State, Venezuelan Andes. The original vegetation of the area corresponded to an upper montane cloud forest with a complex structure, an irregular canopy at 30 m and supporting a high diversity of epiphytes (Ataroff, 2001). The most frequent tree species include: *Retrophyllum rospigliosii*, *Myrcia acuminata*, *Clusia multiflora*, *Alchornea triplinervia*, *Prunus sphaerocarpos*, *Guarea kunthiana*, and *Billia columbiana* (Engwald, 1999). Currently, only scattered fragments of the original forest remain since they have been replaced by pastures of *P. clandestinum* (kikuyo pasture) and *M. minutiflora* (capín melao or yaraguá pasture) for cattle raising. The mean annual temperature for the area is 14.5 °C and the annual rainfall for the 2005–2006 period was 1241 mm (Fig. 1) measured every 10 min with a rain gauge (TE525) connected to a datalogger (Campbell CR10X).

P. clandestinum pastures occupied the bottom of the valley in the study area, while *M. minutiflora* was found in top and hillside positions. The animal load for the whole farm corresponded to approximately one cattle head per ha, considered as a semi-extensive grazing system.

2.2. Experimental design

During the year 2005, every 2 months we collected six circular samples of 306 cm² for each pasture species and carefully transported them to the laboratory. In the laboratory, the soil and the underground biomass of each sample were eliminated. We then placed the aerial biomass above a wire-mesh screen of the same diameter as the sample which was installed over a funnel supported by a collector container (Fig. 2). The sample was protected by plastic walls. Simulated rain was applied equivalent to 2.5, 5, 10, 20, 50 and 80 mm and 2.5, 5, 10, 20, 50 and 80 mm h⁻¹, distributed in four applications of same volume each separated by 15 min. The nozzle used to generate the simulated rain produced 77% of drops smaller than 4 mm.

We considered net precipitation to be the water that crossed the canopy and reached the collector container. All experiments were conducted in the laboratory less than 24 h after harvesting the samples. Net precipitation was measured every 5 min for 2 h, and in all cases the final drainage was below one drop/min. We repeated the experiment under dry and wet canopies for each sample. The canopy was considered dry when no visible traces of

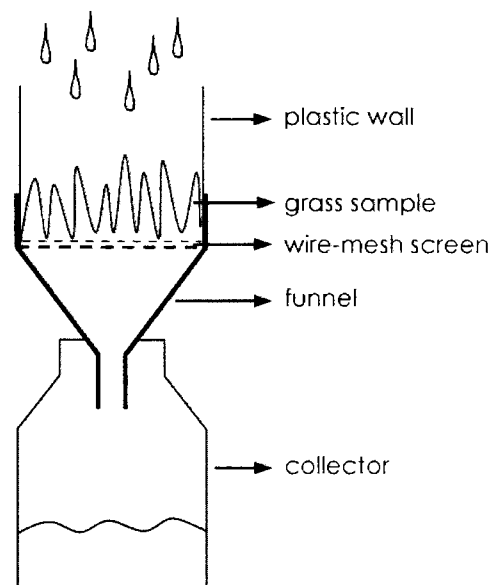


Fig. 2. Schematic design of the device used for experimentally measuring interception by mat-forming grasses.

water were found over the vegetation (leaves and culms) and the canopy had not been exposed to rain for approximately 24 h. The canopy was considered wet when it had received rain between 3 and 14 h before the experiment and showed water droplets on the surface of leaves and culms.

Interception was calculated as the difference between the simulated rain and net precipitation. Additionally, we measured the dry weight of the aerial biomass and necromass for each sample.

As in other studies on pasture ecohydrology (Ataroff and Rada, 2000; Rincón et al., 2005), we assumed that cloud water interception is insignificant, even though it needs to be further studied.

Interception estimates for a 2 year period in El Cañadón were obtained applying the resulting models from this study to every precipitation event during 2005 and 2006, recorded every 10 min, considering the canopy to be dry after 4 daytime hours or 10 nighttime hours with rainfall less than 1 mm.

2.3. Analysis of data

The comparison between the hydrological response of the wet and dry canopies, as well as between species, was carried out with *t* tests for independent samples (Pardo and Ruiz, 2001). We calculated the partial correlations and one way ANOVA to evaluate the relationship between interception and plant mass (Pardo and Ruiz, 2001).

We present a model of interception as a function of precipitation for each species, considering the previous wetness of the canopy. Since it is necessary to validate each model in order to know its prediction capability on independent data, we used the cross-validation method (CV) for estimating the prediction error. The cross-validation method directly estimates the extra-sample error, which is the generalization error when the prediction model is applied to an independent test sample (Hastie et al., 2001).

3. Results

3.1. Ecohydrology of the mat-forming grass canopies

Laboratory experiments on interception by the canopies of both species showed that drainage (equivalent to the net precipitation)

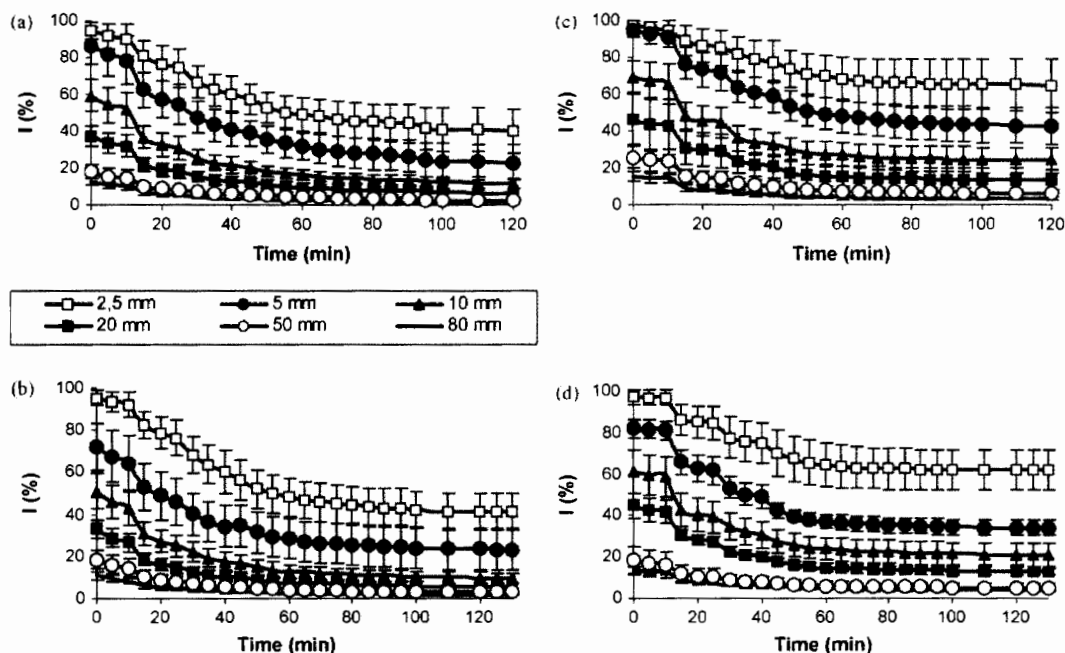


Fig. 3. Percentage of interception (I , % \pm confidence interval) during the time intervals for the experiments, at different simulated rainfall, from 2.5 to 80 mm. (a) *P. clandestinum* with a wet canopy, (b) *P. clandestinum* with a dry canopy, (c) *M. minutiflora* with a wet canopy, (d) *M. minutiflora* with a dry canopy.

was very fast when precipitation intensities were high (50 and 80 mm h⁻¹), showing that in the first 5 min after each irrigation drainage was 79–91% of the water inputs (Fig. 3). For low intensity precipitation (2.5 and 5 mm h⁻¹), drainage was slower, reaching during the first 5 min only a value of 7–36% of the total inputs. After the first 5 min, at these low intensities, drainage continued very slowly. This occurred for both species, independent of the previous wetness of the canopy.

P. clandestinum showed significant differences between the interception of the dry and wet canopy for all the amounts of precipitation studied (test for independent samples, $p < 0.05$ for all precipitation values). For the smallest precipitation amount (2.5 mm), the interception percentage was high, 70.7% with a dry canopy and 50.7% with a wet canopy (Fig. 4). On the other hand, for a very high precipitation amount (80 mm), the interception percentage was much smaller, 3.7% for the dry and 1.7% for the wet canopies (Fig. 4a).

M. minutiflora also showed significant differences between interception by the dry and the wet canopies (test for independent samples, $p < 0.05$ for all precipitation amount). For the smallest amounts of precipitation (2.5 mm), the interception percentage was 61.8% with a dry canopy and 37.5% with a wet canopy (Fig. 4b). On the contrary, for a very high precipitation amount (80 mm), the interception percentage was smaller, 3.8% for the dry and 1.4% for the wet canopies (Figs. 4b).

The previous wetness of the canopy affected the interception percentage: the dry canopies intercepted 20–24% more than the wet canopies under very low precipitation, this percentage becoming smaller as precipitation increased (Fig. 4).

Comparing the two species, the values of the interception percentage for *P. clandestinum* were consistently higher than those of *M. minutiflora* (Fig. 4), however, the differences were not statistically significant (test for independent samples: $p > 0.05$ for P 5, 20, 50 and 80 mm and a wet canopy, and $p > 0.05$ for P 2.5, 10, 20, 50 and 80 mm and a dry canopy).

In all cases, the ecohydrological behavior showed that the interception percentage was high when the precipitation was low,

diminishing drastically as precipitation increased. The relationship between interception percentage and precipitation rate was very well described, for each species, by models given by the expression $y = ax^b$. In Table 1, we present the models that allowed an estimate of the percentage of interception by *P. clandestinum* and *M. minutiflora* versus precipitation, considering the previous wetness of the canopy.

We used these models to estimate the annual interception of *P. clandestinum* and *M. minutiflora* pastures under semi-extensive

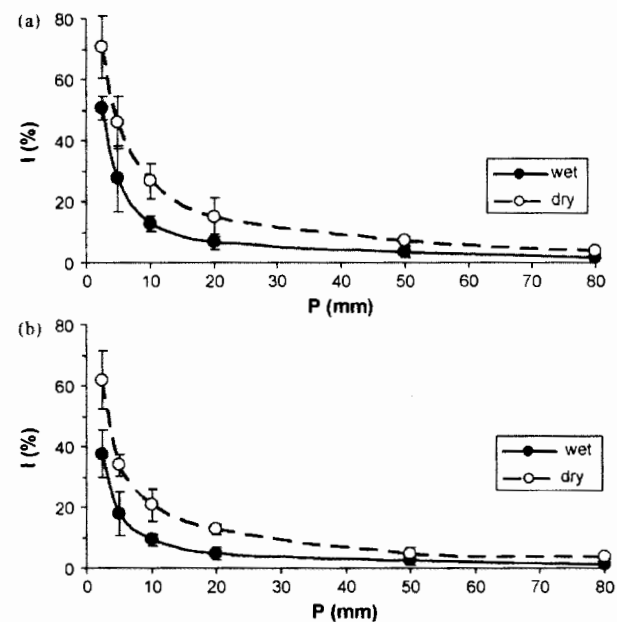


Fig. 4. Percentage of interception (I , % \pm confidence interval) versus precipitation (P , mm) under wet and dry canopies, (a) *P. clandestinum*, (b) *M. minutiflora*.

Table 1
Interception (*I*, %) versus precipitation (*P*, mm) models for *P. clandestinum* and *M. minutiflora*, with dry and wet canopies, showing the results of the validation.

Species	Canopy previous humidity	Model equations	R ² of the model	Validation error (CV)	R ² of validation
<i>P. clandestinum</i>	Dry	$I = 170.22P^{-0.8522}$	0.985	4.69	0.976
	Wet	$I = 123.14P^{-0.9621}$	0.990	3.13	0.986
<i>M. minutiflora</i>	Dry	$I = 131.57P^{-0.8164}$	0.989	2.44	0.989
	Wet	$I = 82.51P^{-0.9336}$	0.986	2.68	0.989

Table 2
Interception values estimated by equations given in Table 1, by *P. clandestinum* and *M. minutiflora* pastures in El Cañadón, upper watershed of the Capaz River, Venezuelan Andes.

	Precipitation (mm)	<i>P. clandestinum</i> (%)	<i>M. minutiflora</i> (%)
2005	1313	35.5	30.9
2006	1175	37.4	32.7
Mean	1244	36.5	31.8

grazing in the study area. Table 2 summarizes the results, showing a high percentage of interception for both species during both years.

3.2. Grazing effect

The main effect of grazing on interception is its impact on the biomass and necromass of the pastures. In this context, we measured the annual variation of these variables on the grazing cattle conditions of the study area, considered a semi-extensive system (approximately one cattle head per ha).

The *P. clandestinum* pasture under study showed relatively constant aerial biomass and necromass values throughout the year, varying between 0.7 and 1.2 kg m⁻² for the biomass and between 0.6 and 1.1 kg m⁻² for the necromass, in both cases these minimum and maximum values were obtained in January and July, respectively (Fig. 5a). The total mass varied between 1.3 and

2.4 kg m⁻², occurring in January and July, respectively. On the other hand, the behavior was different in the *M. minutiflora* pasture: between January and March biomass values were higher than the necromass, this was the opposite the rest of the year (Fig. 5b). The biomass varied between 0.4 and 0.7 kg m⁻² in September and March, respectively; while the necromass varied between 0.5 and 1.1 kg m⁻², in January and September, respectively (Fig. 5b). The total mass for *M. minutiflora* varied between 1.1 and 1.5 kg m⁻², in January and September, respectively. In general, the biomass of *P. clandestinum* was doubled that of *M. minutiflora* (annual average for *P. clandestinum* = 0.96 kg m⁻² and *M. minutiflora* = 0.58 kg m⁻²). For both species, the decrease in biomass observed in September coincides with the month of highest grazing.

Considering the total aerial mass (biomass + necromass, aerial parts with interception capacity), *M. minutiflora* did not present statistically significant variations throughout the year (ANOVA $F = 1.170$; $p = 0.344$). However, *P. clandestinum* showed differences (ANOVA $F = 5.261$; $p = 0.001$) only due to the July value which was almost twice the smallest value which occurred in January. If this July value is not included, the differences were not significant (ANOVA $F = 3.731$; $p = 0.010$).

In order to evaluate the effect of aerial biomass, necromass and total mass on the relationship between precipitation and percentage of interception, we carried out a partial correlations analysis for each species. The results indicated that for both species that relationship was not substantially altered when evaluating the effect of the mass variables, since the correlations of order zero ($T = -0.759$ and $p < 0.001$ for *P. clandestinum*, $T = -0.711$ and $p < 0.001$ for *M. minutiflora*) did not differ from the partial correlations considering the mass variables ($T = -0.774$ and $p < 0.001$ for *P. clandestinum*, $T = -0.722$ and $p < 0.001$ for *M. minutiflora*). This can probably be attributed to the fact that the annual variation of aerial mass was not significant in the pastures under study.

4. Discussion

For the studied canopies of *M. minutiflora* and *P. clandestinum* the percentage of interception varied greatly depending on the amount or intensity of precipitation. The amount of 10 mm appears to be a threshold below which the percentage of interception was high while above it was low. The pattern of the interception percentage as a function of the precipitation for both species was well described by models with the expression $y = ax^b$. Therefore, these models can be used to estimate the percentage of interception in pastures of these species based on precipitation values and with values for aerial biomass been with the ranges here considered. Clark (1940) also found that the percentage of interception was inversely proportional to rainfall studying tall grasses and mat-forming grasses, but could not present a model that related these variables.

In the mat-forming grasses in this study, the results showed that the previous condition of the canopy (dry or wet) was very important, particularly when precipitation was low. This effect led to differences of 20% of interception between wet and dry initial canopy conditions when precipitation was 2.5 mm.

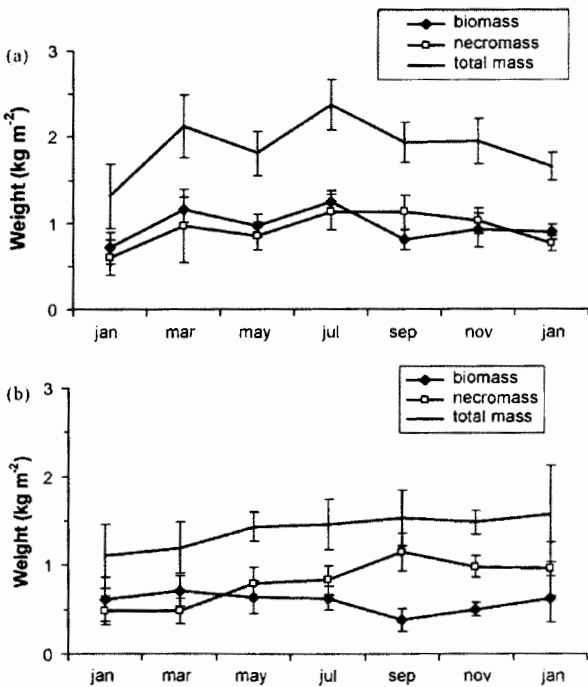


Fig. 5. Aerial biomass, necromass, and total mass (kg m⁻² ± confidence interval) throughout the year, (a) *P. clandestinum*, (b) *M. minutiflora*.

The two species showed the same ecohydrological behavior, with similar percentages of interception for the same precipitation amount, and similar differences between dry and wet canopies. Although *P. clandestinum* biomass was nearly doubled that of *M. minutiflora*, interception percentage was not significantly larger. Perhaps the pubescence on *M. minutiflora* contributed to the retention of water on the surface of the leaves. The drainage behavior was also very similar for both species, at high precipitation intensities most of the drainage occurred during the first 5 min. The drainage was slower in dry compared to wet canopies.

In pastures of *P. clandestinum* or *M. minutiflora* under semi-extensive grazing conditions (close to one cattle head per ha), the biomass does not seem to affect the percentage of interception throughout the year, since the differences were not significant. This allows the use of the proposed models under these kinds of situations. If the grazing pressure increases or decreases, the dependence between percentage of interception and the mass variables might also change. Acevedo and Sarmiento (1990) showed a high correlation among these variables as a pasture of *Digitaria decumbens* grew after cutting.

The highly entangled aerial architecture of the mat-forming grasses made it difficult to determine the importance of stemflow in the net precipitation. We think that this architecture favors the canalization of water through the culms towards the soil, facilitating a quick drainage from the canopy. Rincón et al. (2005) estimated that 60% of the water that reaches the soil in a *P. clandestinum* pasture was through stemflow when the foliage was untouched and 45% when it was cut at 5 cm from the soil surface (43% and 40% of rainfall, respectively). Seastedt (1985), in a tallgrass prairie, also found that stemflow accounted for a large percentage of water reaching the soil, from 9% to 31% depending on stem density (54–71% of the rainfall). On the other hand, Brye et al. (2000) did not find important differences in a similar tallgrass prairie measuring throughfall, and throughfall plus stemflow.

Our results show that the percentages of interception for pastures of both species in the study area were high compared with most forest values: 36.5% for the *P. clandestinum* pasture and 31.8% for *M. minutiflora*. Other authors also present high values of interception when using similar devices to the ones used in this study: from 39% to 42% on tallgrass prairies (Brye et al., 2000; Seastedt, 1985) and Clark (1940) reported percentages ranging from 16% to 74% for precipitations from 25 to 3 mm, respectively, for the mat-forming grasses *Eragrostis cilianensis* and *Buchloe dactyloides*.

Interception by the *P. clandestinum* pasture in previous works had shown values between 51% and 70% using mini-gutters, and 20% using small circular collectors (Ataroff and Sanchez, 2000; Rincón et al., 2005; Fonseca and Ataroff, 2005). Our results suggest that interception by grasses cannot be neglected, but the use of trays, troughs or mini-gutters placed in the field without taking into consideration stemflow may lead to erroneous estimates the

interception data. Hence, a more reliable approach is the use of interception models, although they have been validated only for a certain range of values of biomass and rainfall amounts and intensities.

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