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IMPORTANCE OF CLOUD-WATER IN VENEZUELAN ANDEAN CLOUD FOREST WATER DYNAMICS

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Abstract: Clouds are the main ecological factor acting on Andean cloud forest, however there are very few data to evaluate its importance in water dynamics. We have studied precipitation, throughfall, stemflow and runoff of a Venezuelan Andean cloud forest (2300 m) for the last two years, and have measured cloud-water interception since August 1997 by a Standard Fog Collector (SFC) and a Cylindrical Collector (CC). The results show that cloud-water interception might be 2 to 6% of rainfall depending on collector type (SFC and CC respectively). Adding cloud-water interception values to rainfall values (2959mm, mean of two years), the mean annual total water input increases to 3142mm, throughfall proportion drops from 55.2 to 52.0% and runoff decreases from 1.4 to 1.3%. An effort must be done to study cloud-water interception by vegetation, particularly epiphytes, since they probably play an important role in catching and retaining small droplets.

1. INTRODUCTION

Clouds are the main ecological factor acting on Venezuelan Andean cloud forest (from 2200 to 3000 m), since energy and water balances are mainly controlled by the daily presence of clouds. Nevertheless, relationships between cloud cover and key ecological factors such as radiation, evapotranspiration and cloud-water interception is poorly known. Studies focusing on the importance of water dynamics in ecological processes of Venezuelan Andean cloud forests are scanty (Steinhardt 1979, Cavelier and Goldstein 1989), in spite of the recognition of hydrology as an especially important factor in maintaining the flow of Venezuelan Andean rivers.

The results presented here are part of a larger ecological research program in Andean cloud forest. We have studied the water dynamics (precipitation, throughfall, stemflow, runoff) and erosion of a cloud forest for two years and recently we started to measure cloud-water interception to analyze its importance on the water balance of this system.

2. STUDY SITE

The study area is located at La Mucuy, in the Sierra Nevada National Park, Mérida State, Venezuela. The natural vegetation is an Upper Montane Andean Cloud Forest type, characterized as follows: altitudinal range is from 2200 to 3000 m., mean annual temperature ranges from 12 to 9°C (in lower and higher altitudinal limits) and mean annual precipitation ranges from 1000 mm to 2500 mm. Vegetation structure is very complex, with an irregular canopy at 20-30 m, and diverse, nearly 50 tree species per ha supporting a high epiphytic biomass and diversity, more than 120 species of vascular epiphytes, and an unknown number of non-vascular epiphytes (Sarmiento *et al.* 1971, Vareschi 1992, Veillon 1994, Kelly *et al.* 1994).

Two study sites were chosen: one in the bottom of the valley of Quebrada del Oro (2300 m), "bottom valley site", and the second on the slope side (2400 m), "slope site". The bottom of the valley is very narrow, with debris left by torrential water flows, and mainly shrubby vegetation, due to remotion of the original forest vegetation during the construction of an experimental trout farm. The "bottom valley site" has a SW aspect. The "slope site" is 100 m (right angle) above the "bottom valley site", with an average of 30° slope. The front of the cloud-water collectors, facing NW, was cleared of vegetation, but natural forest was left intact at the rear of the collectors.

3. MATERIALS AND METHODS

Stations at each site have a Standard Fog Collector "SFC" (1 m^2 double layer Raschel mesh, approximately 60% shade coefficient, Schemenauer and Cereceda 1994) and, additionally the "bottom valley site" has a Cylindrical Collector "CC" (plastic cylinder over a funnel 13.7 cm diameter, 50 cm vertical, approximately 53% shade coefficient), and a rain-collector funnel (13.7 cm diameter) as control, all at a height of 5 m. A rain gauge collector connected to a Data Logger LI-COR 1000 is also used for standard rain recordings.

Three 10x3 m erosion-runoff plots, six throughfall channel type collectors (3x0.2 m) and a 20x15 m plot with annular and spiral stemflow collectors in all plants over 2.5 cm and 10 cm diameter stems, respectively, were set in the forest at the "slope site".

Data on rain precipitation, throughfall, stemflow and runoff were recorded since January 1996. We recorded data of cloud-water interception since August 1997 in the "bottom valley site" and since January 1998 in the "slope site". The data was collected daily during the first month and weekly since September.

4. RESULTS AND DISCUSSION

Assuming that values obtained by these methods are estimators of cloud-water interception by vegetation, our results show that 2 to 6% of total water income in the system is due to this source (Table 1). None of the weekly values in 28 weeks of the analysis showed higher cloud-water interception values than those recorded for rain. Similar results were obtained by Cavelier and Goldstein (1989) who reported 3.7% of rainfall as annual cloud-water interception (72 mm) in an elfin cloud forest in El Zumbador, Venezuelan Andes (3100 m, 1938 mm rainfall), using small cylindrical collectors (8 cm in height and 8 cm in diameter).

During the study period, the absolute values of cloud-water interception follow the same trends than rainfall (Figure 1). The highest values were found on September: 290.6 mm of rain, 19.5 mm of cloud-water with SFC and 6.5 mm with CC (6.7 and 2.2 % respectively). The lowest values were found in January: 8.3 mm of rain, 0.1 mm of cloud-water with SFC and 0.03 mm with CC, 1.2 and 0.4 % respectively. It is interesting to note that the months with the highest percentage of cloud-water interception have intermediate values of rainfall: December 37.1 mm of rain, 2.6 mm SFC and 1.2 mm CC, 7.0 and 3.2 % respectively, and February 44.4 mm rain, 3.6 mm SFC and 2.8 mm, 8.1 and 6.3 % respectively. Other authors have reported that the importance of cloud water increase during the driest months (Cavelier and Goldstein 1989, Juvik and Nullet 1993). Our results have so far departed from this pattern, a behavior probably caused by unusually dry air and high temperatures, which according to local climatologists could be due to effects of the El Niño 1997-98 event.

The mean values for two years of precipitation, throughfall, stemflow and runoff are 2959 mm of rain, of which 55% reach the ground as throughfall and 0.1% as stemflow, whereas 1.4% are lost by runoff (Table 1). If cloud-water supply values are added to rain values and expressed as total water income values for the period August to February, throughfall proportion drops from 54.4 to 51.3% and runoff drops from 1.5 to 1.4%.

About 49% of total incoming water to the system (or 45% of rainfall) is retained by vegetation. This is a high value for a tropical montane forest (Bruijnzeel and Proctor 1993), which could be due to the complex vertical structure, but in our opinion mainly due to the high quantity of "tank type" and "cushion

TABLE 1: Measurements of rainfall (PP), thoughfall (TF), stemflow (SF), runoff (RF), and cloud-water collection with standard fog collector (SFC) and cylindrical collector (CC) in an Andean montane cloud forest, La Mucuy, Mérida, Venezuela (values expressed as percent of incident rainfall).

	PP (mm)	TF (%)	SF (%)	RF (%)	SFCbv (%)	CCbv (%)	SFCs (%)
1996-1997	2959 *	55.2	0.1	1.4			
Aug97-Feb98	1005	54.4		1.5	6.2	2.0	
13J98-29F98	45	56.7		1.5	8.1	6.3	5.9

*: mean anual precipitation bv: bottom valley site s: slope site

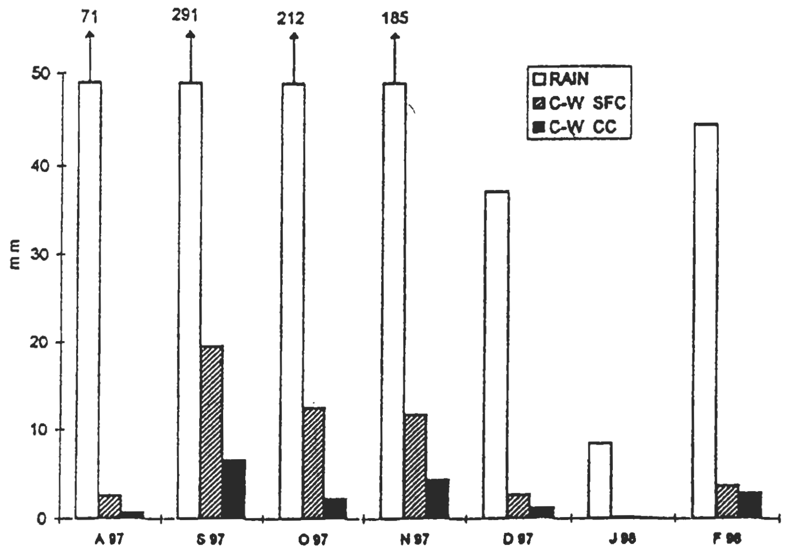

Figure 1: Rainfall and cloud-water intercepted by Standard Fog Collector and Cylindrical Collector, during the study period.

type" epiphytes. Even though the role played by these plants in water retention is not well known, Veneklaas *et al.* (1990) have shown that it might be in the order of 80% of incoming water.

First data of "slope site" shows lower values of cloud-water interception than the "bottom valley site", but additional wind speed and direction data will be needed to understand this difference.

Cavelier and Goldstein (1989) explained the small volumes of cloud-water collected in high Andes pointing out that the predominant stratiform clouds of this region have smaller droplet size distribution and lower water contents than dominant cumuliform clouds in coastal mountains. If this is so, the mesh or collector type could influence values obtained in these environments more than in others. Both methods we have used show the same monthly variation patterns (Figure 1), but average values are three times higher with the SFC.

However, even if droplets were too small to be intercepted by the artificial collectors, we still ignore how efficient is the tree foliage or epiphytes in collecting them. We believe that, despite the methodological drawbacks, an effort should be made to evaluate cloud water interception by vegetation and its role in forest water dynamics and understory microclimatic conditions.

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