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Rainfall interception and fog precipitation in a tropical montane cloud forest of Guatemala

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Abstract

Tropical montane cloud forest hydrology is complex because of the presence of epiphytic life-forms that increase canopy surfaces and fog persistency. Fog precipitation is a hydrological input common to cloud forests, and forms when fog droplets are intercepted by the canopy and fall to the forest floor. Interception and fog precipitation was determined for a 2100 m site and a 2550 m site in a first-order tributary of the Sierra de las Minas Biosphere Reserve, Guatemala by calculating the difference between throughfall and gross precipitation for a 44-week period. Both sites were situated within closed-canopy cloud forests. The 2100 m site was on the windward slope of Montaña de Miranda near the lower boundary of the cloud forest and the 2550 m site was at the summit. Fog precipitation was found during periods in which throughfall exceeds gross precipitation. Fog precipitation was greater at 2550 m than at 2100 m. Data collected by precipitation and throughfall gauges demonstrate the existence of seasonal fog precipitation with the greatest fog precipitation occurring in the dry season (November–April). Fog precipitation contributes approximately 1 mm per day to the hydrological budget of the cloud forest at 2550 m during the dry season, and 0.5 mm per day during the rainy season (May–October).

Keywords: Interception; Cloud forest; Fog precipitation; Guatemala

1. Introduction

An altitudinal frontier has emerged in montane environments in Latin America as cloud forests are modified by settlers searching for new agricultural land (Richards, 1996; Young, 1998; Young and León, 2000). The lower portion of cloud forests has long been known to be well-suited for coffee plantations, and as that industry continues to expand, the cloud forest inevitably retreats upslope. These changes in land use can have profound impacts on water resources, especially in cloud forest environments (Bruijnzeel and Proctor, 1995). Guatemalan cloud forests have been one of the last montane forest types to be seriously threatened by human activity (Tum and Budowski, 1997). Cloud forests generally have unstable and steep slopes, cool temperatures, heavy precipitation, and soils that often are nutrient-poor (Daugherty, 1973).

Cloud forest hydrology differs from that of most mid-latitude temperate forests and lowland tropical forests because of the frequency of fog interception and fog precipitation (Stadtmüller, 1987; Bruijnzeel, 1990). Fog precipitation occurs when intercepted cloud droplets coalesce on foliar and woody surfaces and drip to the forest floor as fog passes through the

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forest canopy. During a rainfall event, vegetation intercepts precipitation and stores the water in the canopy (Kittredge, 1948; Helvey, 1967). Interception is a dynamic process in which the canopy approaches and sometimes reaches its storage capacity during a rainfall event, and the intercepted water evaporates during and shortly after the event (Rutter, 1967). The interception of fog by the canopy of cloud forests often produces fog precipitation, especially when the maximum canopy storage capacity is reached.

Past studies suggest that fog precipitation may represent a significant proportion of the annual inputs to tropical cloud forests (Weaver, 1972; Vogelmann, 1973; Zadroga, 1981; Clark et al., 1998). Cavelier and Goldstein (1989) found that 48% of the annual water input to a cloud forest in Colombia was from fog precipitation. Local factors that influence the quantity of fog precipitation include canopy height (Kittredge, 1948), canopy architecture (Kimmins, 1987), wind velocity (Lovett et al., 1982), foliar surfaces (Smith and McClean, 1989), hillslope orientation (Ellis, 1971; Zadroga, 1981), and orientation of foliage and branches (Cavelier and Goldstein, 1989).

A common characteristic of cloud forests is the abundance of epiphytes and tree ferns that contribute to the floristic diversity of the ecosystem and to the surface area of the canopy (Seiler, 1981; Frahm and Gradstein, 1991; Ingram and Nadkarni, 1993; Hamilton et al., 1995; Richards, 1996; Young and León, 2000). Cloud forests are common in the tropics where moist air rises abruptly due to changes in elevation and water vapor condenses at ground level (Lawton and Dryer, 1980). This change in elevation over short distances provides heterogeneous climates and patches of vegetation with distinct species composition (Grubb and Whitmore, 1966; Baynton, 1969; Tanner, 1977; Cavelier et al., 1996). Cloud forests are common in zones along the upper slopes of tropical mountains where fog persists (Grubb, 1971; Bruijnzeel and Veneklaas, 1998).

Changes in species composition and canopy surface area in cloud forests may be reflected in comparisons of interception differences along an elevation transect (Veneklaas and van Ek, 1990; Frahm and Gradstein, 1991). The filtering of water droplets that produces fog precipitation may be directly affected by changes in species composition and stand characteristics that occur along an elevational gradient. This study examines differences in rainfall interception between two cloud forest sites as a function of elevation in the Sierra de las Minas Biosphere Reserve, Guatemala.

2. Site description

An examination of canopy interception and fog precipitation within a tropical cloud forest was conducted within the Sierra de las Minas Biosphere Reserve, Guatemala, 10 km east of the village of Chilascó (Fig. 1). The Sierra de las Minas Biosphere Reserve was established in 1990, and consists of approximately 2400 km^2 of rugged mountainous terrain located between the Río Motagua and Río Polochic (Lehnhoff and Núñez, 1998). The reserve is a protected evergreen cloud forest with a high diversity of plant and animal life (Catling and Lefkovitch, 1989; Ack and Lehnhoff, 1992). Because of the steep slopes within the Sierra de las Minas, access to the cloud forest is difficult. Consequently, the cloud forest has not been seriously threatened by deforestation unlike other tropical montane forests in many Latin American countries (Young, 1994). Nevertheless, the region near the southern border of the Sierra de las Minas is more heavily deforested than the more remote northern border.

The Sierra de las Minas is an east-west oriented mountain range. Prevailing winds are from the northeast and produce a rainshadow on the south slope of the mountain range. Cloud forests dominate the windward slopes and summits of the Sierra de las Minas. Xerophytic vegetation dominates the Río Motagua Valley, the driest valley in Central America.

The Sierra de las Minas is bordered to the north and south by two large structural depressions that correspond to two major faults, the Motagua and the Polochic (Dengo, 1982; Tobisch, 1986). The mountain range is the result of thrust faulting. Steep slopes are common on the southern edge of the ridge adjoining the Motagua River Valley. A pre-Mesozoic metamorphic basement complex consisting of mylonite gneiss, garnet and chloritoid-bearing mica schist, phyllitte, and schistose gneiss crops out in the Sierra de las Minas (Johnson, 1983). The Sierra de las Minas is part of the ancient Nuclear Central America, and is among the most complex ranges in Central America (Dengo and Case, 1990).

Fig. 1. Location of study area in the Sierra de las Minas Biosphere Reserve in east-central Guatemala.

Two sites with different elevations within a first-order cloud forest watershed near the windward slope of Montaña de Miranda (2600 m) were selected to measure interception and fog precipitation by the cloud forest canopy. The lower site (2100 m) was located within the cloud forest, but near a transition between lower elevation coniferous forest and cloud forest. The boundary between lower elevation coniferous forest and higher-elevation cloud forest lies approximately along the 2000 m contour. The higher site (2550 m) was located within the cloud forest near the summit of Montaña de Miranda. Based on observations in the field, the duration of fog occurrence appears to be greater at the summit of Montaña de Miranda than at the 2100 m site.

The vegetation type at the 2100 m site is classified as a lower montane cloud forest based on the large percentage cover of bryophytes representing a total population of epiphytes in the forest (Frahm and Gradstein, 1991; Bruijnzeel and Veneklaas, 1998). Below the elevation of 2000 m on the windward slope, conifers are the dominant trees. The base of the mountain is approximately 1900 m on the windward slope. The vegetation type at the 2550 m site is classified as upper montane cloud forest based on the stunted trees and presence of mossy epiphytes, and may have formed at this elevation because of the Massenerhebung effect (Frahm and Gradstein, 1991; Bruijnzeel et al., 1993). The Massenerhebung effect is the tendency for large mountain ranges to be warmer at comparable elevations than isolated mountains along the same latitude because large mountain ranges have large upland surfaces that are heated by solar radiation (Richards, 1996). The cloud forest only extends to approximately 2300 m on the leeward slope of Montaña de Miranda.

3. Materials and methods

Because the actual rates of evaporation and cloud water impaction are not easily quantifiable during cloudy and cloud-free events in the field, apparent cloud water interception and apparent interception are often derived in studies that measure net precipitation by comparing rainfall, throughfall, and stemflow. This study uses this approach to estimate apparent rainfall interception and apparent fog interception.

Fifty-eight throughfall gauges were positioned at a closed-canopy cloud forest site with an elevation of approximately 2100 m. Another closed-canopy cloud forest site at an elevation of 2550 m was chosen for the placement of 36 throughfall gauges. The experimental site at 2100 and 2550 m occupied an area of 0.26 and 0.24 ha, respectively. The gauges were made of plastic funnels with a diameter of 200 mm and 20 l plastic containers. The funnels had a steep angle and a rim with a height of 35 mm. The throughfall gauges were positioned based on randomly generated coordinates within two permanent plots in an experimental watershed of the Sierra de las Minas. Five precipitation gauges were positioned in an abandoned agricultural clearing adjacent to the experimental watershed at an elevation of 2550. Because the 2100 m site did not have large enough canopy openings to position precipitation gauges, such as clearings or large treefall gaps, data from the precipitation gauges at the 2550 m site were applied to the 2100 and 2550 m site. Because precipitation varies widely across an area and along an elevational gradient, the reader should be cautious of the measurements of interception between the two sites. The results from this study should be viewed as estimates of hydrological fluxes in the cloud forest. The volume of precipitation (ml) and throughfall (ml) collected in each gauge was divided by the area of the orifice of the funnel to determine the depth equivalent (mm). Throughfall and gross precipitation was measured approximately every week from 24 July 1995 to 7 June 1996 for a total of 36 sampling periods.

Apparent interception (I) was calculated at each site approximately every week for each gauge with the equation

$$I = P_g - T \tag{1}$$

where P_g is the average depth equivalent of rainfall collected by the five precipitation gauges (gross precipitation) and T the average throughfall for each site. Stemflow was not determined in this study.

Eq. (1) is an estimate of interception and does not take stemflow or other hydrological inputs such as cloud water impaction or evaporation into account. Interception by definition is >0 mm. As a result of the process of interception, a rain gauge in the open commonly receives more water during a rainfall event than throughfall gauges positioned under a canopy. In cases where throughfall exceeds gross precipitation, additional hydrological inputs from fog precipitation likely produce interception values <0 mm. This study assumes that interception values <0 mm are the result of fog precipitation as other studies commonly report (Weaver, 1972). Fog precipitation (FP) was calculated as

$$\mathrm{FP} = |P_g - T| \tag{2}$$

during sampling periods of approximately 1 week in which interception <0 mm. During sampling periods in which interception $\geq$0 mm, no fog precipitation was recorded.

4. Results

Precipitation and throughfall over the 44-week study period are shown in Table 1. During 2 weeks (13 August–20 August 1995 and 3 September–10 September 1995) precipitation exceeded 275 mm. Based on the precipitation data, the dry season began at the end of October and persisted through the beginning of April. This precipitation pattern corresponds with data collected in Central America by Portig (1965) and Peña and Douglas (2002). Approximately 80% of gross precipitation occurred during the rainy season. The plot of gross precipitation and throughfall recorded from each sampling period is somewhat scattered (Fig. 2). The relationship between gross precipitation and throughfall at 2100 m ($R^2 = 0.96$) and 2550 m ($R^2 = 0.93$) was influenced by two data points in the scatterplot representing sampling intervals in which gross precipitation and interception exceeded 200 mm. The canopy intercepted approximately 35% of gross precipitation at 2100 m. Only 12% of gross precipitation was intercepted at 2550 m over the 44-week study period. These differences in interception between the 2100 and 2550 m site may be influenced by the use of the same precipitation gauges at 2550 m. Because precipitation varies widely across even a short distance, it is likely that the interception errors are greater at 2100 m than at 2550 m. Fig. 3

Table 1
Precipitation and throughfall measurements in the Sierra de las Minas from 24 July 1995 to 7 June 1996

Date	Precipitation (mm)		Throughfall, 2100 m (mm)		Throughfall, 2550 m (mm)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
24 July–30 July 1995	159.88	0.66	167.95	3.22	167.55	2.86
30 July–7 August 1995	141.11	0.46	85.22	1.99	127.56	1.63
7 August–13 August 1995	80.93	0.15	96.25	2.12	58.89	1.83
13 August–20 August 1995	378.64	2.40	239.35	4.91	275.92	7.36
20 August–27 August 1995	11.28	0.03	5.56	0.25	4.51	0.24
27 August–3 September 1995	138.77	0.24	65.04	1.61	87.91	2.30
3 September–10 September 1995	293.57	0.83	213.14	4.49	232.18	5.53
10 September–17 September 1995	137.59	0.45	74.34	2.37	88.66	2.48
17 September–24 September 1995	77.14	1.11	43.61	1.40	52.69	1.47
24 September–1 October 1995	97.62	0.36	54.15	1.49	69.20	1.71
1 October–8 October 1995	82.02	0.31	39.57	1.27	71.93	3.34
8 October–15 October 1995	28.06	0.04	11.95	0.45	23.43	0.97
15 October–22 October 1995	86.89	0.19	45.23	2.08	84.66	4.54
22 October–29 October 1995	26.71	0.04	15.39	0.75	23.76	1.17
29 October–5 November 1995	23.37	0.04	10.61	0.37	15.15	0.46
5 November–12 November 1995	20.12	0.05	11.26	0.55	16.73	0.91
12 November–19 November 1995	12.54	0.04	5.13	0.27	12.06	0.87
19 November–26 November 1995	32.21	0.07	23.25	0.91	64.84	3.65
26 November–3 December 1995	7.58	0.04	3.31	0.16	7.31	0.51
3 December–10 December 1995	33.29	0.05	24.50	1.00	42.48	2.81
10 December–17 December 1995	38.62	0.05	35.24	1.45	64.78	4.15
17 December–31 December 1995	43.85	0.21	27.52	1.23	56.10	2.79
31 December 95–7 January 1996	1.48	0.01	0.32	0.01	4.32	0.39
7 January–14 January 1996	35.19	0.29	21.41	0.91	63.97	3.41
14 January–21 January 1996	0.59	0.03	0.28	0.01	0.31	0.01
21 January–28 January 1996	6.50	0.02	1.77	0.10	5.06	0.28
28 January–11 February 1996	51.97	0.06	36.37	1.50	86.48	3.95
11 February–25 February 1996	30.86	0.08	25.36	0.93	48.03	2.67
25 February–12 March 1996	24.63	0.34	10.69	0.51	50.29	3.42
12 March–26 March 1996	4.33	0.02	2.01	0.10	10.81	0.90
26 March–2 April 1996	19.22	0.02	9.96	0.40	16.14	0.89
2 April–16 April 1996	50.89	0.12	23.22	0.77	32.53	1.05
16 April–27 April 1996	103.85	0.20	57.56	1.28	76.73	2.55
27 April–11 May 1996	62.43	0.16	29.24	1.10	39.62	1.35
11 May–18 May 1996	64.78	0.18	33.98	1.14	56.79	2.49
18 May–7 Jun 1996	150.67	0.45	91.00	2.61	113.01	5.04

illustrates that the relationship between gross precipitation and interception varies with elevation between 2100 and 2550 m. During 11 of the 36 sampling periods at 2550 m and 2 of the 36 sampling periods at 2100 m, throughfall exceeded gross precipitation, and indicated the presence of fog precipitation.

Fog precipitation was most common at 2550 m, as indicated by a trend of decreasing interception with increasing elevation. Additionally, fog precipitation was more common during the dry months (November–April) than during the rainy season (May–October) at 2550 m (Fig. 4). Seasonal differences in fog precipitation occurred in the evergreen cloud forest at both sites, but were most pronounced at 2550 m. Interception as a percentage of gross precipitation was more negative during the dry season than during the rainy season at 2550 m. Interception was <0% of gross precipitation during 2 of the 17 sampling periods in the rainy season at 2100 m. The time between sampling periods was approximately 1 week over the 44-week study. Interception varied from −19 to 57% in the rainy season and 9 to 79% in the dry

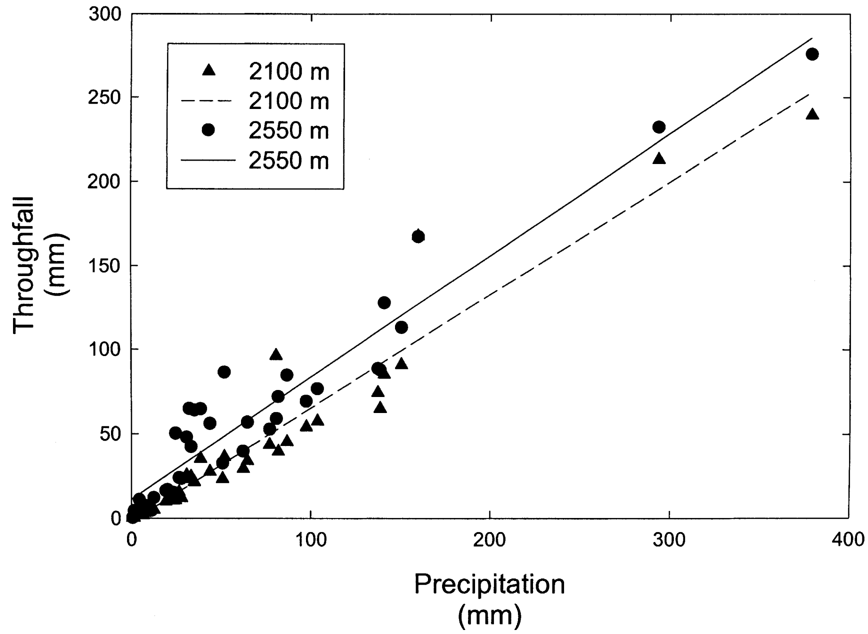

Fig. 2. The relationship between gross precipitation and throughfall in closed-canopy cloud forest at 2100 m ($R^2 = 0.96; y = 0.65(x) - 2.41$) and 2550 m ($R^2 = 0.93; y = 0.71(x) + 11.03$).

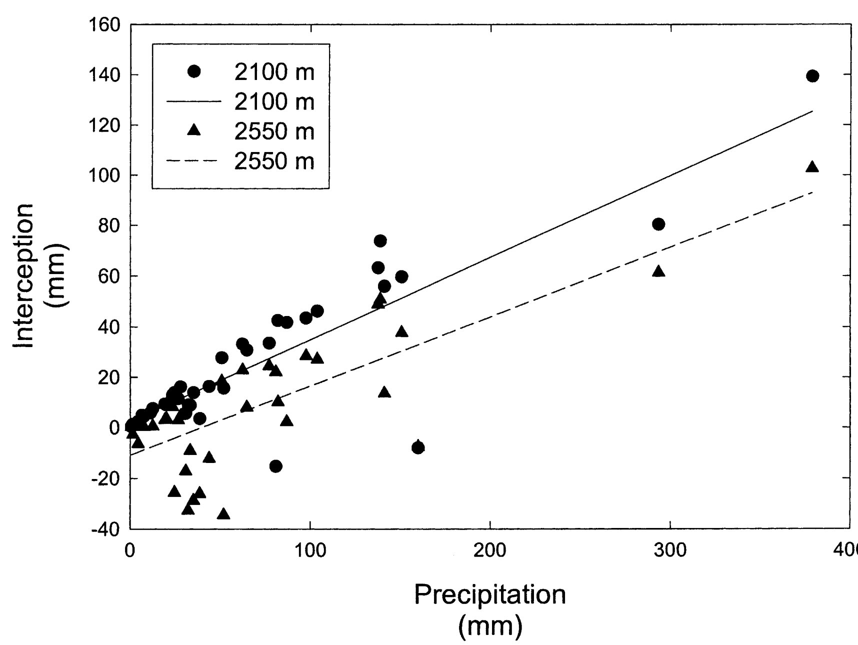

Fig. 3. The relationship between gross precipitation and interception at 2100 m ($R^2 = 0.86; y = 0.34(x) + 2.41$) and 2550 m ($R^2 = 0.69; y = 0.29(x) - 11.03$).

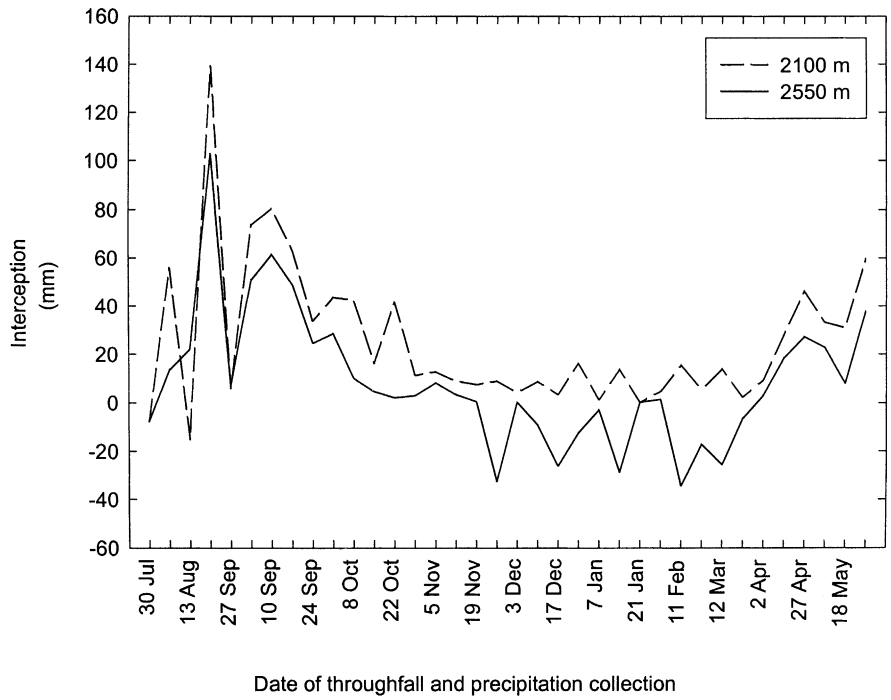

Fig. 4. Interception at 2100 and 2550 m over the 44-week study period in 1995–1996. Note that the sampling intervals are not of equal duration, and the time between sampling intervals are not indicated by the length along the *x*-axis.

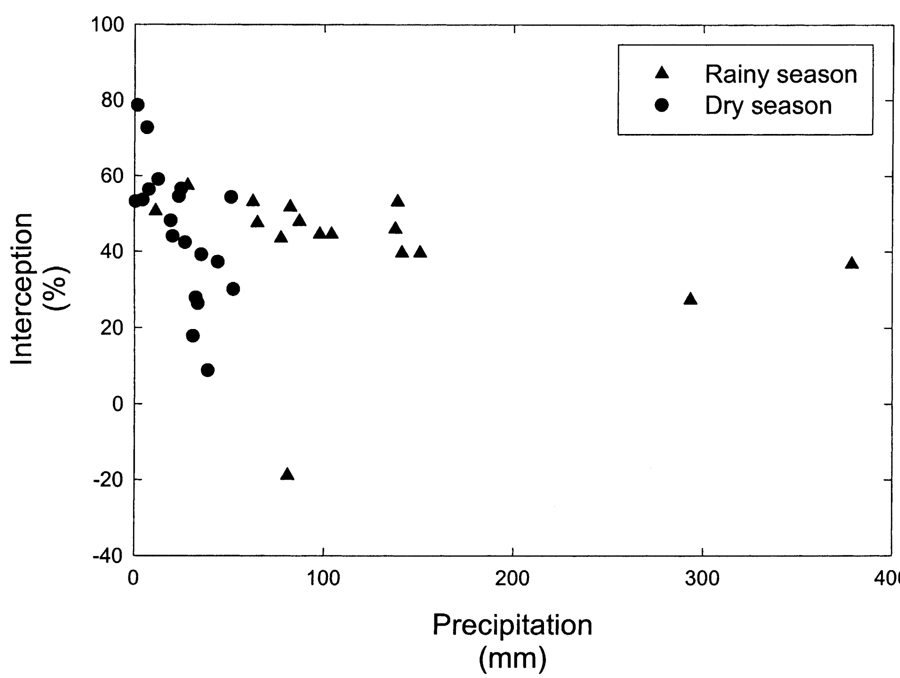

Fig. 5. The relationship between gross precipitation and interception during the dry season and the rainy season at 2100 m.

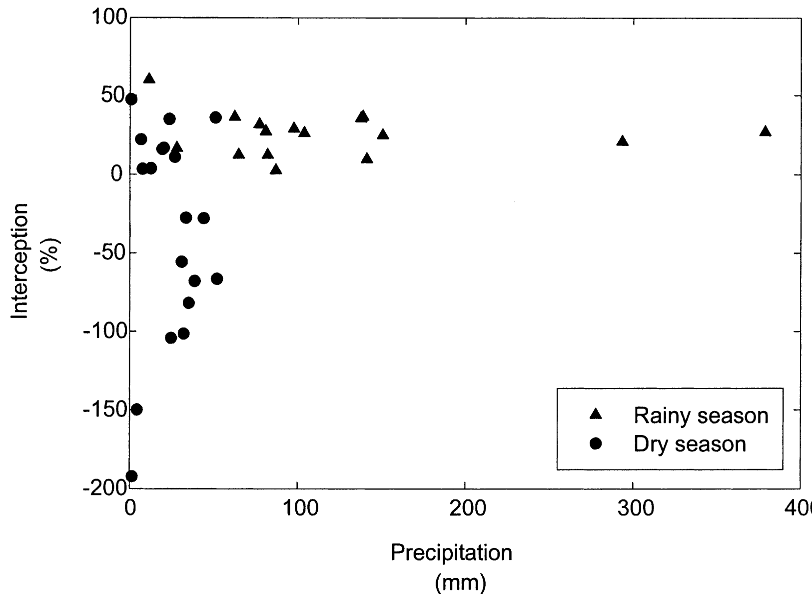

Fig. 6. The relationship between gross precipitation and interception during the dry season ($R^2 = 0.02$) and the rainy season ($R^2 = 0.12$) at 2550 m.

season at 2100 m (Fig. 5). Interception variability was also greater at 2550 m than at 2100 m (Fig. 6). Interception was <0% during 11 out of 36 sampling periods (dry season, $n = 10$; rainy season, $n = 1$). During 4 out of 19 dry season sampling periods, interception was $<-100\%$ of gross precipitation at 2550 m.

5. Discussion

5.1. Relationships between interception and elevation

Rainfall interception was greater at 2100 m than at 2550 m (Figs. 3 and 4). These results should be viewed with caution, especially at the 2100 m site in which the distance from the throughfall gauges and the precipitation gauges was greater than at the 2550 m site. A canopy opening large enough to position precipitation gauges in the immediate vicinity of the 2100 m site was not available, so the calculation of interception at 2100 m was determined by the precipitation gauges located adjacent to the 2550 m site. Although the distance between the throughfall gauges and rain gauges were larger at the 2100 m site, interception totals from this study were in the range of results of previous studies of rainfall interception in tropical montane cloud forests (Table 2). Veneklaas and van Ek (1990) found an increase in interception (%) in Colombian cloud forests with an increase in elevation, however the depth equivalent of interception (mm) remained relatively constant between their two sites. The trend of increasing interception with increasing elevation was not found in this study and another Colombian cloud forest study (Vis, 1986), although the elevations of the study sites by Veneklaas and van Ek (1990) were greater than in this study. The highest elevation of study sites by Vis (1986) and Veneklaas and van Ek (1990) was >3000 m while in this study elevation of the study sites did not exceed 2600 m. In high-elevation sites the forest may lie above the cloud belt. Weaver (1972) found a trend of decreasing interception with increasing elevation in cloud forest of Puerto Rico, although the cloud forest sites he selected were determined on the basis of exposure to prevailing wind and the range of sites varied from 930 to 1015 m.

The height of the cloud forest at the summit of Montaña de Miranda (2610 m) is approximately 5–10 m shorter than along the windward slope of the mountain. Canopy height, canopy architecture, and stand characteristics such as basal area commonly

Table 2
Interception differences between cloud forest sites

Location	Period of measurement	Elevation (m)	Interception (%)	Interception (mm)	Precipitation (mm)	Source
Colombia	1 year	2550	12.4	261.5	2115	Veneklaas and van Ek (1990)
Colombia	1 year	3370	18.3	265.2	1453	Veneklaas and van Ek (1990)
Colombia	16 months	1700	24.6	978	3968	Vis (1986)
Colombia	16 months	1950	15.1	420	2779	Vis (1986)
Colombia	16 months	3000	11.4	243	2123	Vis (1986)
Guatemala	44 weeks	2100	35.0	918	2559	This study
Guatemala	44 weeks	2550	4.3	307	2559	This study
Panama	1 year	1200	37.2	1306		Cavelier et al. (1997)
Puerto Rico	8 months	930	1.0		1646	Weaver (1972)
Puerto Rico	8 months	1000	−20.0		1456	Weaver (1972)
Puerto Rico	8 months	1015	−35.0		1228	Weaver (1972)

influence interception (Ford and Deans, 1978; Stogsdill et al., 1989; Cape et al., 1991). Tall trees with large canopies have higher surface areas that result in increased canopy storage capacity (Helvey, 1967; Aston, 1979; Hutchings et al., 1988). A decrease in interception loss from 2100 to 2550 m in this study may be explained by canopy structure and fog precipitation.

Interception values exceeded 50 mm during 6 out of 36 sampling periods at 2100 m and 4 out of 36 sampling periods at 2550 m. These values are rather large (>7 mm per day) in comparison to previous studies (Veneklaas and van Ek, 1990). Fog precipitation is most likely to occur when the canopy has reached storage capacity (e.g., following a rainfall event). Evaporation of precipitation intercepted by the canopy may have occurred following periods when maximum canopy water storage capacity was reached, thereby reducing fog precipitation at periods during the week when the canopy storage was less than maximum (Schellekens et al., 1999). The fog precipitation data in this study are aggregated into sampling intervals that are approximately 1 week. Therefore, the data do not show the exact times within a sampling interval when fog precipitation was at a maximum or at a minimum. Generally, fog precipitation is at a maximum following a rainfall event because the canopy is close to storage capacity, and fog precipitation is at a minimum following an extensive rainless time period. Additionally, the abundance of epiphytes may have contributed to a large canopy storage capacity (Stadtmüller, 1987).

It should also be noted that stemflow measurements were not recorded during this study. In a preliminary study in the Sierra de las Minas, Brown et al. (1996) found that stemflow accounted for <2% of gross precipitation. During rainfall events exceeding 200 m, stemflow may contribute a larger proportion of gross precipitation than the <5% of gross precipitation reported from previous cloud forest hydrology studies (Weaver, 1972; Cavelier et al., 1997).

5.2. Evidence of fog precipitation

Fog precipitation is an additional input into forests (Pook et al., 1991a) and can produce a significant proportion of the hydrological budget of cloud forest watersheds (Vogelmann, 1973; Zadroga, 1981; Cavelier and Goldstein, 1989; Schemenauer and Bridgman, 1998). Fog persistency contributes to the creation of fog precipitation in diverse regions (Cereceda and Schemenauer, 1991). The formation of fog precipitation is a function of fog occurrence and duration (Ingraham and Matthews, 1995; Schemenauer and Bridgman, 1998). Based on field observations, fog cover is more persistent near the summit of Montaña de Miranda than at lower elevations.

Assuming that the throughfall that exceeded gross precipitation was fog precipitation, sampling periods in which interception is <0% indicate the presence of fog precipitation. Fog precipitation occurs with greater frequency at 2550 m than at 2100 m. Fog precipitation was recorded during 2 out of 36 sampling period at 2100 m and 11 out of 36 sampling periods at

2550 m. Interception may not sharply decrease with elevation as the data in this study suggest. Fog precipitation contributions in cloud forests reduce interception measurements, and comparisons between throughfall and gross precipitation gauges may not reflect the hydrological complexity of the cloud forest canopy (Cape et al., 1991; Pook et al., 1991b; Hutley et al., 1997). For example, comparisons between throughfall and gross precipitation provide data on net precipitation. Other hydrological processes such as evaporation and cloud water interception are continually occurring during and after rainfall events.

Results from this study show that fog precipitation was more significant in the dry season than in the rainy season. Fog precipitation contributions may have been greater because monthly temperatures are lower during the dry season months. Fog precipitation during the driest months of the year may have hydrological importance to cloud forest vegetation. Fog precipitation and long periods of fog may favor vegetation that experiences moisture stress during months when gross precipitation is lowest by providing sources of water and reducing evapotranspiration.

Fog precipitation may be of hydrological importance to humans that live in watersheds with cloud forest vegetation. Potable water is commonly obtained from springs upslope from communities. By adding the quantity of fog precipitation generated during each sampling period (Table 1) and dividing by the total number of days during each season, the cloud forest at the 2550 m site produces approximately 1 mm per day to the hydrologic budget in these catchment basins during the dry season (November–April) and 0.5–1 mm per day during the rainy season (May–October). Although these values for fog precipitation do not appear to be large, the accumulation of fog precipitation over several weeks help to maintain high soil moisture in these humid cloud forest environments, and may directly contribute to throughflow and groundwater.

Additionally, the fog precipitation totals presented in this study may be larger than reported because stemflow was not measured in this study and fog precipitation likely occurs during intervals when throughfall is less than incident precipitation. Although stemflow was not measured in this study, the preliminary work of Brown et al. (1996) suggests that stemflow accounts for <2% of the hydrological inputs to the cloud forests in the Sierra de las Minas. Previous studies of tropical cloud forests in Puerto Rico and Panama reported that stemflow accounts for <5% of annual rainfall (Weaver, 1972; Cavelier et al., 1997). Although the proportion of water in stemflow that came from intercepted fog is not known, this proportion would likely produce larger daily values for fog precipitation. Fog precipitation is not equal to the difference between incident precipitation and throughfall because evaporation of rain and cloud water and canopy storages during the process of interception are not accounted for Eq. (2). The results reported are conservative estimates of fog precipitation in cloud forests. Because only the negative values of apparent interception were assumed to indicate the presence of fog precipitation and the actual rates of evaporation and cloud water impaction were not measured, the values for fog precipitation were underestimated in this study.

5.3. *Significance of fog precipitation*

Because additional hydrologic inputs from fog precipitation during the dry season may contribute to the water demands of the growing population in the xeric valleys, the remaining cloud forests of the Sierra de las Minas should be preserved. A reduction in the canopy surface area (deforestation) would reduce quantities of fog precipitation and water yield (Zadroga, 1981; Stadtmüller, 1987). Although the experimental watershed is relatively small and is a fraction of the size of cloud forest catchment areas, it is representative of land use and watershed interactions, in that communities are harvesting water from the catchment. In the more populated and more arid leeward slope of the Sierra de las Minas, people depend on the additional water inputs of fog precipitation in cloud forests, especially in the 6-month dry season.

The Sierra de las Minas Biosphere Reserve includes an area of 2400 km^2. The core zone of the biosphere reserve which contains pristine cloud forests contains 57,200 ha. The area of the Sierra de las Minas that exceeds 2100 m elevation, including points outside the Sierra de las Minas Biosphere Reserve, is approximately 350 km^2. Given the importance of this range for generating potable water to lowland communities, the preservation of the remaining cloud forests should be prioritized (LaBastille and Pool, 1978). The core zone of the biosphere reserve may generate greater than 250 million liters per day of fog precipitation assuming an average amount of fog precipitation between the two sites reported in this study. Further ecophysiological and hydrological investigations need to be conducted to determine the percentage of fog precipitation that contributes to stream discharge for human use downstream and to sustain the cloud forest during the dry season. Because major water-demanding industries are moving into the Río Motagua Valley and the population of the valley is increasing, fog precipitation in regions >2100 m may become important in the near future. The hydrological inputs in cloud forests may be vital to the livelihood of people in the lowland regions.

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