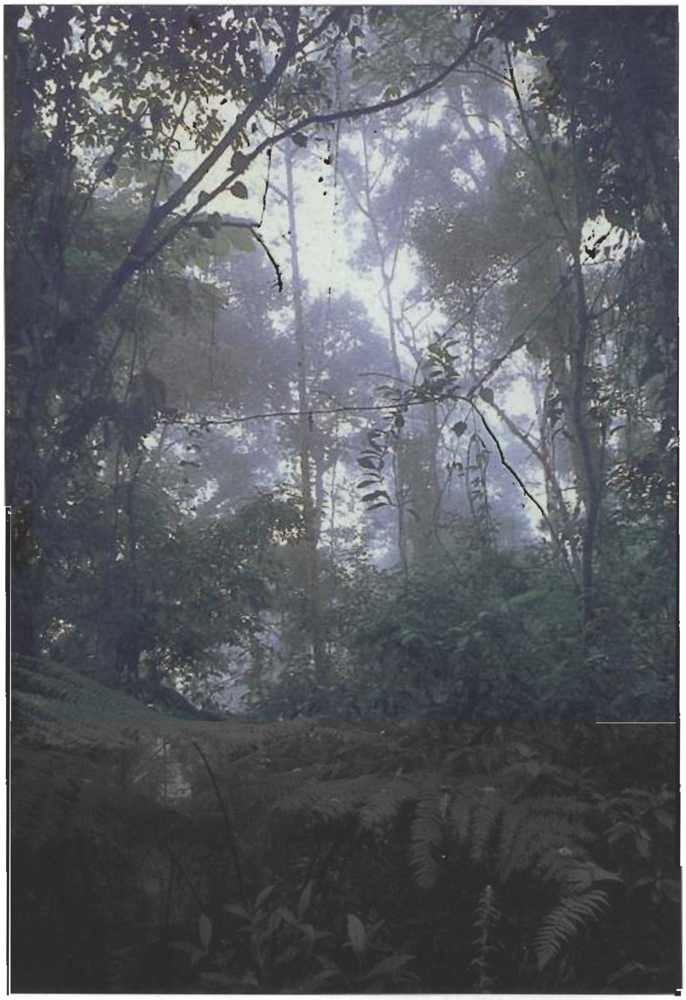
Michele Ataroff and Fermín Rada

Deforestation Impact on Water Dynamics in a Venezuelan Andean Cloud Forest

Andean cloud forests play an important role in watershed hydrology and protection against erosion. Even though most cloud forests fall under officially protected areas, a good deal of the cloud forests are being deforested and replaced by pastures for grazing cattle, which is the most important land use in Venezuelan cloud forest environments. The water dynamics of the natural forest as well as the impact of replacement by pastures are poorly understood. We have been conducting a research project since 1996, in order to study some of the water fluxes of the forest and to evaluate the hydrological impact of replacement by pasture. The study site is located at La Mucuy (2300 m with 3124 mm rainfall), Merida State, in the Venezuelan Andes. The results show that, in the forest, 91% of total incoming water was from rainfall and 9% was from cloudwater. Total foliage interception was 51%, which is a high value for a tropical montane forest. About 49% of the total incoming water reaches the ground as throughfall, whereas litter intercepts 6% of the water and a final 1.4% was lost by surface runoff. Therefore, infiltration must be about 42%. Approximately 16% was lost by transpiration leaving about 26% for drainage. Results from pastureland studies show 7% interception, while surface runoff (2%) and transpiration (about 66%) were higher than in the forest. Our first results on soil water status suggest that the forest soil (upper horizon) has a significantly higher % moisture than the pasture soil.



Understory view of a Venezuelan Andean cloud forest in a cloudy day (La Trampa, Merida State). Photo: P. Soriano.

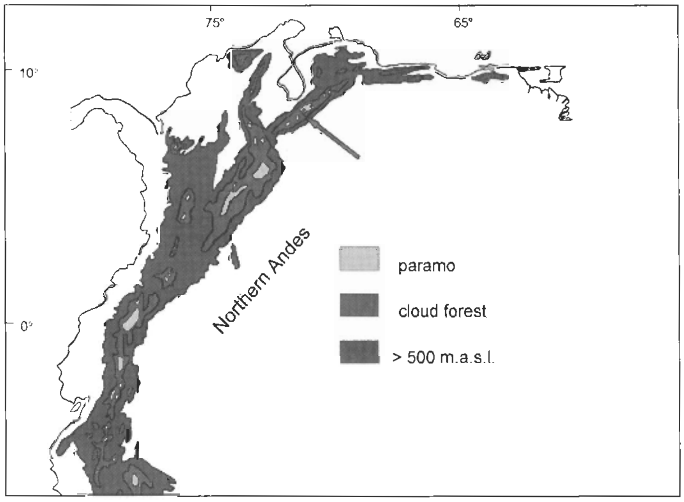


Figure 1. Cloud forest distribution in the northern Andes. Arrow indicates La Mucuy study site. (Source: 2–4).

THE CLOUD FOREST

Tropical cloud forests are ecosystems which occur at the altitudinal zone where the atmospheric environment is characterized by persistent, frequent, or seasonal cloud cover at the vegetation level. The hydrological role of cloud forests in water capture and dynamics give these ecosystems a value in terms of water resources quite distinct from other forests or types of land use (1).

The altitudinal limits of this low cloud cover occurrence are variable and so are the cloud forest limits (Fig. 1). Near the Caribbean Sea, cloud forests can be found from 500 m a.s.l. on isolated mountains and 800-1000 m in mountain chains to 2500 m, whereas in the Andes they extend from 1700 to 3500 m a.s.l. on the western slopes of Colombia and Ecuador, and up to 4000 m on the eastern slopes of Ecuador and Bolivia. In the south, they range between 1000–1500 to 2500 m from Bolivia to northern Argentina (5, 6). In the Venezuelan Andes, the cloud forest ranges from 1700 to 3000 m.

This range corresponds to the whole cloud forest belt. In some cases, upper and lower montane types have been recognized. In the Venezuelan Andes, upper montane types have been described based on both climatic and vegetation characteristics. Besides the influence of cloud cover other climatic characteristics are: mean annual values of temperature and rainfall ranging between 9° to 14°C and 1000 to 3000 mm, respectively, in the upper montane type (above 2200 m), and between 14° to 17°C and 1200 to 2500 mm in the lower montane type (from 1700 to 2200 m). Both vegetation types are evergreen forest with a very complex structure, with an irregular open canopy at 20–35 m in the lower and 10–25 m in the upper montane type (7, 8). In general, there are nearly 50 tree species ha^{-1} supporting a high epiphytic biomass and diversity, more than 120 species of vascular epiphytes ha^{-1}, 20 species of climbers ha^{-1}, 40 species in the understory ha^{-1}, and an unknown number of nonvascular epiphytes (7, 9–12). Species composition also varies between types. In an exhaustive inventory, Bono (13) reports a higher number of species for the lower montane (152, 137 and 384 for trees, shrubs and herbs-epiphytes spp., respectively), compared to the

Understory view of a Venezuelan Andean cloud forest on a sunny day. 2400 m, Monterrey, Merida State. Photo: P. Soriano.

Deforested frontier gaining up on cloud forest slopes in Venezuelan Andes, vía Piñango, Merida State. Photo: M. Ataroff.

Kikuyu pasture replacing a cloud forest. El Molino, Merida State, Venezuela. Photo: M. Ataroff.

upper montane type (113, 111 and 172 for trees, shrubs and herbs-epiphytes spp., respectively), with only 17% of species in common.

Even though most of the Venezuelan Andean cloud forests are located in officially protected areas, many of these forests are being deforested and replaced by pasturelands dominated by *Pennisetum clandestinum* (kikuyu grass) for grazing cattle. The effects and consequences of this conversion are poorly understood.

CLOUD FOREST AND HYDROLOGY

The conversion of high mountain forests into pastures or into various types of crops is the cause of important impacts on rivers and streams. In general, as shown in Figure 2, it is expected that hydrographs show that streamflow is great during and immediately after large precipitation events (time measured in hours) when a large portion of the watershed has been deforested. Once the event has ended, streamflow decreases at a fast rate, and eventually, running water ceases entirely after a certain amount of time with no rains (measured in weeks). This effect increases in intensity as the deforested area increases in size. A combination of two types of complementary studies allow for a proper approach to the problem: *i*) focusing on watershed hydrology; and *ii*) focusing on water dynamics of natural ecosystems and agroecosystems.

In the first study type (Fig. 2a), one wishes to answer the question of how much the streamflow is affected. In order to answer this question, the impact at the watershed level is quantified by correlating land use with atmospheric inputs and outputs through the main river. Studies of hydrology and landscape dynamics, natural ecosystem changes, and expansion of the agricultural frontier, should be undertaken simultaneously. In this case, what matters most is the global effect of changes in the landscape and their consequences for streamflow. Streamflow quantification allows planned use and canalization of water in the watershed and lands downriver. Unfortunately, this type of study is rare in neotropical mountain areas.

In the second study type (Fig. 2b), we want to answer the question: what are the primary causes and how do they affect streamflow? This implies the identification of *i*) the specific compartment of the system where the effect has its root cause; *ii*) how important its relative contribution may be; and *iii*) the feasibility of solutions that satisfy both environmental conservation and rural development. Quantification of water dynamics in natural and modified systems allows the evaluation of main inputs, outputs and stored water leading to the detection of bottlenecks. Published information regarding water dynamics in cloud forests is scarce, and most of it refers to aerial fluxes (14–16).

CLOUD FOREST AND PASTURE LAND IN LA MUCUY: A CASE STUDY

In 1996, we began a study program on water dynamics, aimed at progressively quantifying the main water fluxes in an Andean cloud forest in Venezuela. Here we report on rainfall, fog interception, stemflow, throughfall, surface runoff, and the first estimates of transpiration and soil moisture, as measured in the cloud forest and pastureland under grazing.

STUDY AREA

The study area is located at La Mucuy (08°38'N, 71°02'W), at 2300–2400 m, near the city of Merida, Mérida State, Venezuela. The study plots with undisturbed cloud forest are in the Sierra

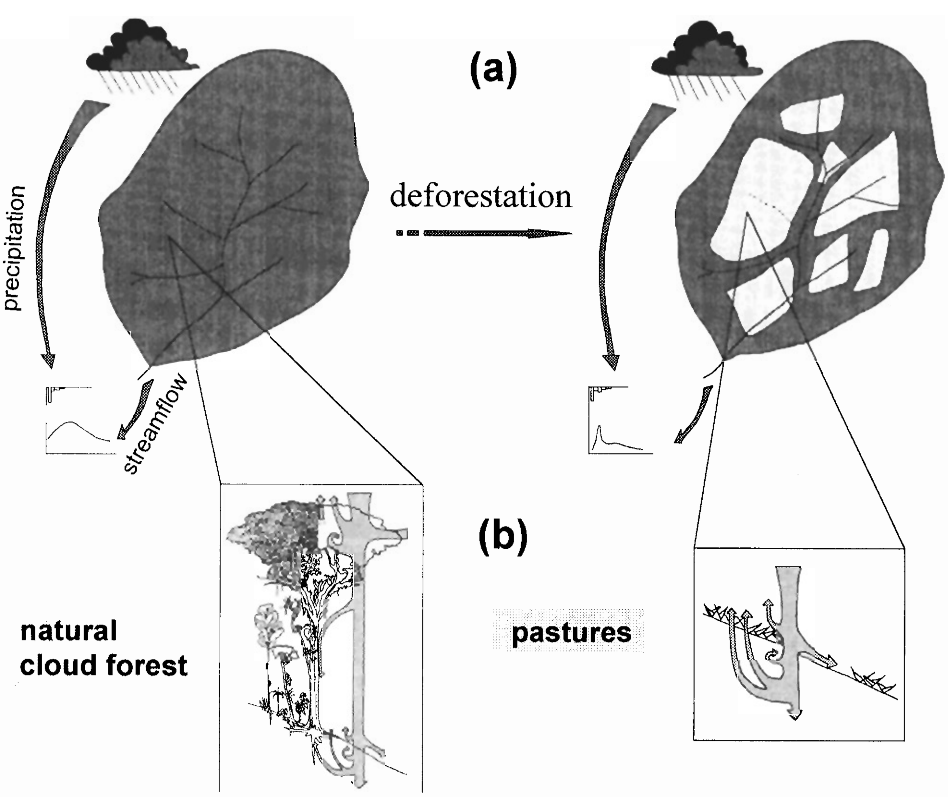


Figure 2. Two level analysis of water dynamics: a) watershed hydrology; and b) water fluxes in natural cloud forests and kikuyu pastures.

Nevada National Park, while the plots on pastureland are in the neighboring ranch, Agropecuaria La Isla.

The vegetation type corresponds to that of the lower limit of the upper montane cloud forest, which grows under a very humid and cloudy environment. Its structure is very complex with an irregular canopy at 20–30 m supporting a high diversity of epiphytes. The most frequent tree species include: *Clusia multiflora*, *Guettarda steyermarkii*, *Laplacea fruticosa*, *Oreopanax moritzii*, *Sapium stylare*, and *Billia columbiana*. The most frequent epiphytes include: *Tillandsia tetrantha*, *T. biflora*, *Epidendrum dendrobii*, *Oncidium falcipetalum*, and *Peperomia microphylla* (8, 17). In the pastureland, the dominant grass species is *Pennisetum clandestinum* Hochst. ex Chiov. (kikuyu grass).

Mean annual temperature at La Mucuy is 14°C. Rainfall is very variable with annual values between 1700 and 3500 mm and with no climatically dry months. The precipitation pattern shows two annual peaks: one between April and May, and the other between October and November. Low clouds are the main ecological factor acting on these forests most of the year, starting to form early in the afternoon and remaining until midnight.

METHODS

Rainfall was recorded with a rain gauge collector connected to a Data Logger (LI-COR 1000). In addition, complementary information was obtained from the research team of Campo Experimental Truchícola (FONAIAP) of La Mucuy. All instruments were placed in a clearing as in a standard meteorological station. Daily measures were taken from 1996 to 1998.

Cloud water interception was estimated from two Standard Fog Collectors (1 m^2 double layer Raschel mesh, approximately 60% shade coefficient (18)) one located at the bottom of the valley (2300 m), and the second on the slope side (2400 m), both at a height of 5 to 6 m, and orientated towards main wind movement. The bottom-valley-collector was placed inside the meteorological station, whereas the slope-collector was placed on a 30° slope with the front cleared of vegetation while the natural forest was left intact at the rear of the collector.

Three 10 x 3 m erosion-runoff plots, 6 fixed throughfall gutter-type collectors (3 x 0.2 m) and a 20 x 15 m plot with annular and/or spiral stemflow collectors in all plants with over 2.5 cm diameter stems, were installed in the forest. Three 10 x 3 m erosion-runoff plots were also installed on the pastureland. All data were collected weekly, between Jan. 1996 to Dec. 1998 in the forest, and between Aug. 1997 to Dec.1998 in the kikuyu pasture.

Litter interception was estimated from desaturation curves for 5 undisturbed 481 cm^2 samples ($8.35 \pm 0.7_{SE}$ Mg ha^{-1}) of litter, and calculated daily (from Jan. 1996 to Dec. 1998) relating water input (throughfall) to water status of litter depending on number of previous dry days. Gravimetric measures of water content were done weekly for the forest and the pasture, on 3 soil samples at 3 depths: 0 to 10 cm, 10 to 20 cm, and 20 to 30 cm, during 3 high-rain season months and 3 low-rain season months in 1998.

Transpiration was measured with a portable gas exchange system (Analytical Development Co.). Measurements in pasture were made on *Pennisetum clandestinum* at Monterrey, a nearby site with similar altitude and precipitation as La Mucuy, and in the forest, on 5 canopy species (*Clusia multiflora*, *Guettarda steyermarkii*, *Sapium stylare*, *Solanum* sp. and *Miconia resinoides* (19)) and 4 understory species (*Palicourea demissa*, *Psychotria aubletiana*, *Chamaedorea bartlingiana* and *Diplazium hians* (20)). Approximate amounts were estimated by averaging daily transpiration calculated for 8 hrs of activity during the low-rain season (90 days) and 7 hrs of activity during the high-rain season (275 days). The relation between transpiration and area was evaluated using leaf area index values (canopy and understory, separately) for the two seasons.

Ten vertical gradients (every 3 m from ground level up to 21 m) were used to determine leaf area index (LAI) for canopy and understory in the forest (Plant Canopy Analizer, LI-COR LAI-2000). Differences in LAI between high and low-rain seasons were estimated according to the relation given by Acevedo et al. (21). This difference corresponded to a 17% decrease in LAI, at 1 m aboveground, during the low-rain season. As a result, LAI values were 1.36 and 1.04 for canopy and understory, respectively, during the low-rain season, and 1.64 and 1.25, respectively, for the high-rain season. For the kikuyu grass the LAI considered, measured with a leaf area meter (LI-3000A, LICOR, Inc.), was 3.11 ± 0.23.

WATER FLUXES IN FOREST AND PASTURE

Rainfall values in the study area have a high interannual variability. Annual rainfall (1996–1998) ranges between 2800 and 3445 mm with an average of 3124 mm. However, to estimate total incoming water, cloud-water interception must be considered. Assuming that values obtained by cloud-water collectors are estimators of cloud-water interception by the vegetation, our current results show that rainfall provides 91% of total incoming water into the cloud forest, while the remaining $9 \pm 1.1_{SE}$% corresponds to cloud-water interception, adding up to an average of 3433 mm of total incoming water (pp + cw), whereas in the pastureland, rainfall represents 100% of incoming water (Fig.

Figure 3. Water dynamics in a natural cloud forest and kikuyu pasture at La Mucuy, Merida State, Venezuela.

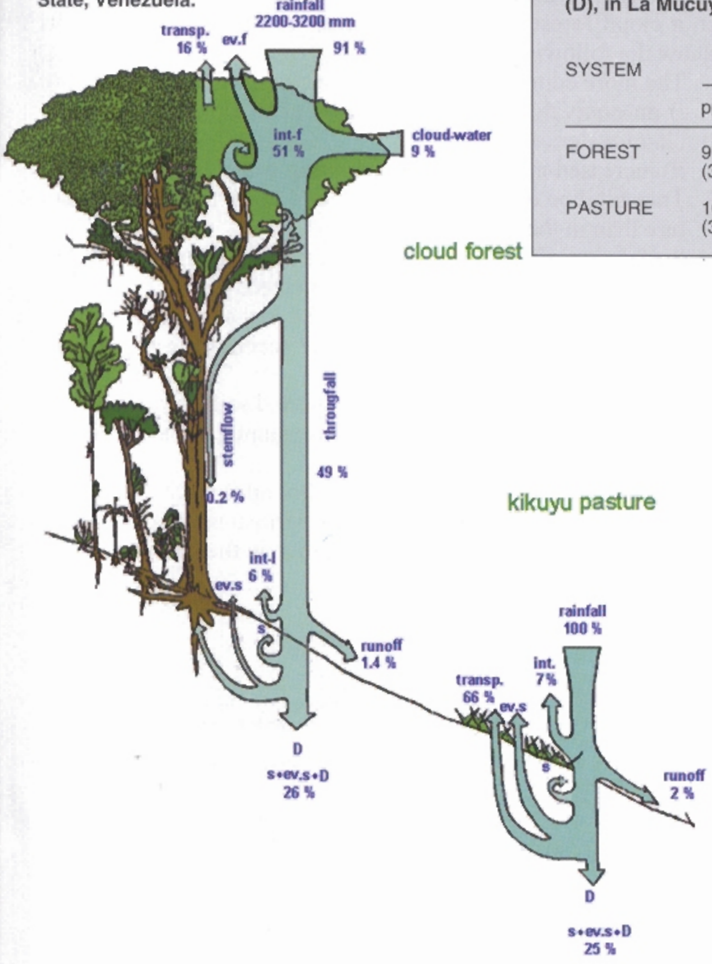


Table 1. Rainfall (pp), cloud-water interception (cw), transpiration (tr), foliage interception (fi), litter interception (li), surface runoff (r), soil evaporation (ev.s), soil storage (s), throughflow (D), in La Mucuy, Mérida, Venezuelan Andes. Values in parentheses are in mm.

SYSTEM	INPUTS		OUTPUTS					
	pp	cw	tr	fi	li	r	ev.s	s+D
FOREST	91% + (3124)	~ 9% = (~ 309) =	~ 16% + (~ 558)	51% + (1751)	~ 6% + (~ 214)	1% + (48)	~ 0% +	26%
PASTURE	100% + (3124)	0% =	~ 66% + (2067)	~ 7% + (~ 625)	0% +	2% + (63)		25%

3, Table 1). Given the high rainfall values, the estimated amount of cloud-water interception (9%) is not very high. Nevertheless, the absolute mean annual value (309 mm) is equivalent to an extra month of rain. This result falls around the mean annual value for cloud-water interception (horizontal precipitation) in cloud forests around the world, which ranges from 150 to 803 mm (16).

Canopy water interception is high: 51% including cloud-water interception (maximum of 52.5% in 1997, minimum of 46,5% in 1998) or 54% of rainfall (maximum of 57.2% in 1997, minimum of 50.7% in 1998), when compared to other montane tropical forests (16, 22). This could be due to the complex vertical structure and the high quantity of "tank type" and "cushion type" epiphytes. Even though the role played by these plants in water retention is not well known, Veneklaas et al. (23) have shown that it might be very high. Forest throughfall is equivalent to 49% of incoming water (pp + cw), with a very small portion running down stems (0.2%).

We have not measured throughfall in the pasture at La Mucuy site, but using data from previous work with kikuyu pastures (24), we have made a correlation between monthly total precipitation and throughfall ($y = 1.0036x - 18.037$; $r^2 = 0.94$). We used this curve to obtain throughfall at the corresponding total monthly precipitation for La Mucuy site. The estimated throughfall value was 93% of incoming rainfall. Without a doubt this measure is highly dependent on pasture LAI, which in turn is dependent on the degree of grazing. The estimate given above corresponds to relatively low grazing.

According to our estimates, the litter layer in the forest intercepts 6% of total incoming water (pp + cw). In kikuyu pastures, the litter layer is insignificant. The remaining water is partitioned in two fluxes, surface runoff and infiltration. Surface runoff is low in both systems in spite of the steepness of the slope (greater than 30°. The forest values indicate that 1.4% of the total incoming water (pp + cw) is lost through this means (maximum of 1.6% in 1998, minimum of 1.1% in 1996). Surface runoff in the pasture is slightly higher, showing an average value of 2% (Table 1). Similar values have been reported for other Andean kikuyu pasturelands (0.9%–2.3% (24–26)).

Thus, water reaching the upper horizon of the soil in the forest is 42% of incoming water (about 1442 mm yr^{-1}). In comparison, near 91% of incoming water (about 2843 mm yr^{-1}) reaches the soil in the pasture. This water is available for uptake by plants, storage in the soil, or drainage by throughflow.

The vapor flow back to the atmosphere has two components: transpiration and evaporation. Global forest transpiration has been estimated at 558 mm yr^{-1}, corresponding to 16% of total incoming water. Even if these values are based on relatively few species, they are the most important ones (very frequent and from diverse families) and they give us the first estimate of this important flux. On the other hand, estimated values for kikuyu grass are about 2070 mm yr^{-1}, corresponding to 66% of incoming rainfall (27). It is important to note that these initial values correspond to pasture lands with low grazing, further studies are necessary to estimate this species' physiological activity under different degrees of grazing.

Most studies of transpiration in tropical montane forests (excluding cloud forests) show values between 510 and 830 mm yr^{-1} transpiration (22), whereas values reported for tropical montane cloud forests range between 250 and 675 mm yr^{-1} transpiration (16). All these transpiration values were derived as estimated evapotranspiration minus canopy interception of incident rainfall. Our results fall within the upper part of this latter range.

Evaporation has two components: canopy evaporation and soil evaporation. It is generally accepted that all intercepted rainfall is lost by evaporation, but in our opinion the cloud forest is a special case in which the role of epiphytes may change this relation. In terms of soil evaporation, it may be estimated as litter interception, 6% of total incoming water. But, we can reasonably assume that actual soil evaporation is insignificant in cloud forests, due to the high humidity conditions occurring in the understory and the thick litter layer which remains wet most of the year. Mean minimum relative humidity measured at 1.5 m aboveground in the understory at La Mucuy during high-rain and low-rain seasons were 90.3 ± 1.6% and 75.0 ± 4.4%, respectively (20, 28–29). On the other hand, soil evaporation in pastures would have to be considered and values still remain unknown. So far, we have studied ecophysiological responses (such as transpiration) and LAI for this species under low grazing. However, as grazing increases, we would expect compacting of the upper soil horizon by cattle and a decrease in plant cover and LAI. As a consequence, increasing grazing will probably increase surface runoff and soil evaporation, but, at the same time, will decrease interception and transpiration. At present, it is not possible, from our results to predict the relationship between these above fluxes for different degrees of grazing. For this particular case, remaining pasture soil water, subtracting that involved in transpiration, is in the order of 25% of total incoming rainfall (Table 1). This value will certainly decrease if soil evaporation is added. Therefore, at equal soil storage conditions, total evapotranspiration in the kikuyu pasture would be higher than in the cloud forest.

These results suggest that a lower amount of water would be available for subsurface drainage in the pasture, and our data on soil moisture seem to support this. The upper horizon of the forest soil (0–30 cm) always shows significantly higher moisture values (23%) than those of the pasture (14%).

A lot of work is still needed to understand all the changes in water fluxes involved in replacing cloud forest by kikuyu pastures, but we can begin to form an idea of the main differences. Water outputs of the system due to drainage, evaporation and transpiration, as well as the role of epiphytes in water dynamics, are currently under study.

CONCLUSIONS

The deforestation process in cloud forests and its replacement by kikuyu pastures, impacts water fluxes. The process decreases water input and affects the partitioning of the water output, changing the vapor fluxes going back to the atmosphere and changing the surface and subsurface drainage. Comparing fluxes in a cloud forest and a pasture under low grazing, our results show the following.

- The more complex structure of the cloud forest enables:
  i) an equivalent of one month of extra rainfall due to the cloud-water capture;
  ii) increased interception of incoming water.
- Transpiration estimates show values 4 times higher in the pasture than in the forest.
- Surface runoff is higher in kikuyu pasture than in cloud forest, however, it is not as high as expected.
- Due to the lower interception and the low surface runoff values, a large proportion of the water reaches the upper horizon in kikuyu pasture.
- Losses due to transpiration, and expected soil evaporation, are so high that our estimates of water remaining in the soil would be lower than in the forest.
- Consequently, water for long-term throughflow (or subsurface flux), which is the main source of permanent streamflow, is expected to be higher in the forest than in the pasture.

References and Notes

1. Hamilton, L.S., Juvik, J.O. and Scatena, F.N. 1993. The Puerto Rico tropical cloud forest symposium: introduction and workshop synthesis. In: *Tropical Montane Cloud Forests*. Proc. International Symposium. Hamilton, J.O., Juvik, L.S. and Scatena, F.N. (eds). East-West Center/UNESCO/USDA, Río Piedras, Puerto Rico, pp 1–16.
2. Monasterio, M. 1980. Los páramos andinos como región natural: características biogeográficas generales y afinidades con otras regiones andinas. In: *Estudios Ecológicos en los Páramos Andinos*. Monasterio, M. (ed.). Ediciones Universidad de Los Andes, Mérida, Venezuela, pp. 15–27. (In Spanish).
3. Long, A.J. 1993. Restricted-range and threatened bird species in tropical montane cloud forests. In: *Tropical Montane Cloud Forests*. Proc. International Symposium. Hamilton L.S., Juvik, J.O. and Scatena, F.N. (eds). East-West Center/UNESCO/USDA, Río Piedras, Puerto Rico, pp 47–65.
4. Cavelier, J. and Etter, A. 1995. Deforestation of montane forests in Colombia as a result of illegal plantations of opium (*Papaver somniferum*). In: *Biodiversity and Conservation of Neotropical Montane Forests*. Churchill, S.P., Balslev, H., Forero, E. and Luteyn, J.L. (eds). Proc. Neotropical Montane Forest Biodiversity and Consevation Symposium. The New York Botanical Garden, New York, pp 541–550.
5. Stadtmüller, T. 1987. *Los Bosques Nublados en el Trópico Húmedo*. CATIE, Costa Rica. (In Spanish).
6. Brown, A.D. 1993. Ecology and conservation of the Argentine mountane forest. In: *Tropical Montane Cloud Forests*. Proc. International Symposium. Hamilton, L.S., Juvik, J.O. and Scatena, F.N. (eds). East-West Center/UNESCO/USDA, Río Piedras, Puerto Rico, pp 66–71.
7. Sarmiento, G., Monasterio, M., Azocar, A., Castellanos, E. and Silva, J. 1971. *Vegetación natural. Estudio integral de la cuenca de los ríos Chama y Capazón* Ediciones Fac. Ciencias Forestales, Univ. Los Andes, Mérida, Venezuela. (In Spanish).
8. Lamprecht, H. 1954. *Estudios Selviculturales en los Bosques del Valle de La Mucuy, Cerca de Mérida*. Ed. Fac. Ingeniería Forestal, Univ. Los Andes, Mérida, Venezuela. (In Spanish).
9. Vareschi, V. 1992. *Ecología de la Vegetación Tropical*. Ediciones Soc. Venezolana de Ciencias Nat. Caracas. (In Spanish).
10. Veillon, J.P. 1994. *Especies Forestales Autóctonas de los Bosques Naturales de Venezuela*. Ediciones Inst. Forestal Latinoamericano, Mérida, Venezuela. (In Spanish)
11. Kelly, D.L., Tanner, E.V., NicLughadha, E.M. and Kapos, V. 1994. Floristics and biogeography of a rain forest in the Venezuelan Andes. *J. Biogeography 21*, 421–440.
12. Ataroff, M. 1999. *Water Fluxes in a Venezuelan Andean Montane Cloud Forest*. Second International Colloquium on Hydrology and Water Managment in the Humid Tropics, Panamá.
13. Bono, G. 1996. *Flora y Vegetación del Estado Táchira, Venezuela*. Monografie XX, Museo Reg. Scienze Naturali, Torino. 951 pp.
14. Steinhardt, U. 1979. Undersuchungen über den Wasser- und Nährstoffhaushalt eines andinen Wolkenwaldes in Venezuela. *Göttinger Bodenkundliche Berichte 56*, 1–185.
15. Cavelier, J. and Goldstein, G. 1989. Mist and fog interception in elfin cloud forest in Colombia and Venezuela. *J. Tropical Ecol. 5*, 309–322.
16. Bruijnzeel, L.A. and Proctor, J. 1993. Hydrology and biogeochemistry of tropical montane cloud forests: what do we really know? In: *Tropical Montane Cloud Forests*. Proc. International Symposium. Hamilton, L.S., Juvik, J.O. and Scatena, F.N. (eds). East-West Center/UNESCO/USDA, Río Piedras, Puerto Rico, pp 25–46.
17. Ataroff, M. 2000. Selvas y bosques de montaña. In: *Biodiversidad en Venezuela*. Chapter 48. Aguilera, M., Azócar, A. and González-Jiménez, E. (eds). CONICIT/Fundación Polar, Caracas, in press. (In Spanish).
18. Schemenauer, R.S. and Cereceda P. 1994. A proposed Standard Fog Collector for use in high-elevation regions. *J. Appl. Meteorol. 33*, 1313–1322.
19. Rada, F., García-Núñez, C. and Ataroff, M. 1998. Estrés hídrico en especies del dosel de una selva nublada andina. Abstracts from the VII Congreso Latinoamericano de Botánica, México. (In Spanish).
20. Vilanova, I. 1996. *Intercambio de Gases y Relaciones Hídricas en Plantas del Sotobosque de la Selva Nublada de La Mucuy, Edo. Mérida, Venezuela*. Undergraduate thesis, CIELAT, Fac. Ciencias, Universidad de Los Andes, Mérida, Venezuela. (In Spanish).
21. Acevedo, M.F., Monteleone, S., Ataroff, M. and Estrada, C. Apertura del Dosel y Espectro de la Luz del Sotobosque en una Selva Nublada Andina de Venezuela. Unpublished. (In Spanish).
22. Bruijnzeel, L.A. 1990. *Hydrology of Moist Tropical Forests and Effects of Conversion: A State of Knowledge Review*. IHP-UNESCO Humid Tropical Programe, Paris.
23. Vencklaas, E., Zagt, R., VanLeerdam, A., Van Ek, R., Broekhoven, G. and Van Genderen, M. 1990. Hydrological properties of the epiphyte mass of a montane tropical rain forest. *Vegetatio 89*, 183–192.
24. Ataroff, M. and Sánchez, L.A. Precipitación, intercepción y escorrentía en cuatro ambientes de la cuenca media del río El Valle, estado Táchira, Venezuela. *Rev. Geogr. Venezolana 41* (1), in press. (In Spanish).
25. Malavé, J.C. and Marín, W.E. 1985. *Intercepción, Escurrimiento Superficial y Erosión en un Area Bajo Fresno con Ganadería de Altura en El Joque Estado Mérida*. Undergraduate thesis, Fac. Ciencias Forestales, Universidad de Los Andes, Mérida, Venezuela. (In Spanish).
26. Salm, H. 1997. Erosión de suelos bajo diferentes tipos de uso de la tierra en el valle del río Camacho, Departamento de Tarija-Bolivia. In: *Desarrollo Sostenible de Ecosistemas de Montañas: Manejo de Áreas Frágiles en Los Andes*. Liberman, M. and Baied, C. (eds). UNU- PL-480, La Paz, Bolivia, pp 159–167.
27. Ataroff, M., Rada, F. and Schwartzcopf, T. 1999. Report presented to CDCHT, corresponding to Project C-703-95. Unpublished.
28. Ataroff, M. 1985. Field work report of Tropical Ecology Postgraduate Course-1985: Microclimate at La Mucuy. CIELAT, University of Los Andes, Mérida, Venezuela. Unpublished.
29. Ataroff, M. 1994. Field work report of Tropical Ecology Postgraduate Course-1994: Microclimate at La Mucuy. CIELAT, University of Los Andes, Mérida, Venezuela. Unpublished.
30. This project was partially supported by CDCHT-ULA (C-703-95). We thank INPARQUES for permiting us to work at Parque Nacional Sierra Nevada, and to Edgardo and Erasmo Rodriguez, owners of Agropecuaria La Isla for permission to work at their ranch. Carlos García-Núñez, Martha Ramirez and Hely Saul Rangel assisted us with field work. Hilda Bastardo and Sara Sofia from Campo Experimental Truchicola La Mucuy (FONAIAP) provided climatic data and logistic help.

Michele Ataroff is professor in ecology at the Institute of Environmental and Ecological Sciences (ICAE) at the Universidad de Los Andes (ULA). She has a PhD in tropical ecology from the ULA. Her current area of research is focused on plant and environmental ecology. Her main research topic is water dynamics and erosion of natural and disturbed tropical mountain ecosystems. Her address: Instituto de Ciencias Ambientales y Ecológicas (ICAE), Facultad de Ciencias, Universidad de los Andes, Mérida, Venezuela.
E-mail: ataroff@ciens.ula.ve

Fermin Rada is currently Director of the Institute of Environmental and Ecological Sciences (ICAE) at the Universidad de los Andes (ULA). He has a PhD in tropical ecology from the ULA. His area of research is plant physiological ecology. Some of his studies include plant responses to different environmental stresses in tropical and subtropical high mountains. His address: Instituto de Ciencias Ambientales y Ecológicas (ICAE), Facultad de Ciencias, Universidad de los Andes, Mérida, Venezuela.
E-mail: frada@ciens.ula.ve