TRANSPIRATION RATES FOR SEVERAL WOODY SUCCESSIONAL SPECIES AND FOR A PASTURE IN THE UPPER AMAZON BASIN IN VENEZUELA.

Jeffrey C. Luvall (*)
Christopher Uhl (**)

SUMMARY

Evapotranspiration rates for a eight month old tropical pasture were estimated using the Penman-Monteith equation. Transpiration rates for several woody secondary successional species and stump sprouts in the pasture and conucos (farm sites) were measured using the tritiated water technique.

The study area was located near the village of San Carlos de Rio Negro (1^0 56' N, 67^0 03' W) in southern Venezuela, near the confluence of the Casiquiare and the Rio Guania which forms the Rio Negro. The terrain was gently rolling with the areas between the small ridges supporting Amazon caatinga forests on spodosols, and higher never flooded areas (tierra firma) supporting a mixed species forest.

Results indicated that for a one month period, ET loss 0.46 cm/day) from the pasture, including soil and root mat evaporation, was about 0.43 cm/day less than estimated from the adjacent undisturbed forest (0.89 cm/day). Pan A evaporation for the same time period was 0.64 cm/day. Transpiration rates for seed established species were significantly less (0.38 cm/day) than for stump sprouts (1.09 cm/day) of the primary forest in the pasture.

INTRODUCTION

The rate of destruction of tropical rain forests in increasing at an alarming pace. At the current rate, an area the size of the state of Delaware is being permanently converted from tropical rain forest to other uses each week and an area the size of Great Britain every year (National Research Council 1980). At this rate, within 50 years the total destruction of all major tropical rain forests worldwide will occur.

The destruction of the tropical rain forests may alter the hydrologic cycle with a resulting drastic effect on the local climate and perhaps a worldwide effect on precipitation patterns. Budyko (1974) states that for the European part of the USSR, only 12

(*) NASA, Marshall Space Flight Center, ES43, MSFC, AL. 35812.

(**) 202 Buckhout Lab. Department of Biology, Pennsylvania State University, University Park, PA 16802.

percent of the total precipitation is derived from local evaporation, the rest being brought in from outside the region. Several studies in the Amazon Basin (Jordan and Heuveldop 1981, Marques **et al**. 1977, Salati **et al**., 1978) found that 50 percent of the precipitation there was derived from local evapotranspiration. In some areas of the Amazon Basin, as much as 70 percent of the precipitation came from local sources (Villa Nova **et al**., 1976). Villa Nova **et al**. (1976) concluded that intensive deforestation would also change the energy balance, since 90 percent of the net radiation is used for evapotranspiration. The shift in energy flow from latent heat fluxes to sensible heat fluxes could, in their words, cause "desertification of the region".

Other large-scale effects may be observed in the hydrologic cycle. Gentry and Lopez-Parodi (1980) report a possible link between extensive deforestation in the Upper Amazon region of Ecuador and Peru and increased high water levels of the Amazon River at Iquitos, Peru. They found that the increased high water levels were largely independent of precipitation and possibly related to changes in drainage and runoff associated with deforestation of the area.

In southern Venezuela near the village of San Carlos de Rio Negro, deforestation is primarily caused by slash and burn agriculture of small areas (0.5-2 ha) called "conucos". After abandonment, these sites are quickly recolonized by successional vegetation (Uhl, 1981). Cattle ranching is done on a small scale in this region. As pastures and conucos are the two most extensive disturbance types in the Amazon, we have focused our transpiration studies on these sites.

The objectives of the transpiration research are two-fold: 1) to estimate the evapotranspiration (ET) rates of the vegetation in a tropical pasture and compare those ET rates to the ET rates for the undisturbed rain forest and 2) to examine the transpiration rates of several common woody secondary successional species which are present in conucos (farm sites) and in the pasture. Additional work is in progress to expand the ET estimates of the pasture from point-in-time estimates presented in this report to the entire year.

Study area

The study area was located near the village of San Carlos de Rio Negro (1^{o} 56' N, 67^{o} 03' W) in southern Venezuela near the confluence of the Casiquiare and the Rio Guainia which forms the Rio Negro.

The long-term precipitation average is 3565 mm per year, with no pronounced dry season, every month receiving at least 200 mm (Jordan and Heuveldop 1981).

The terrain is gently rolling with the areas between the small ridges supporting Amazon caatinga (Klinge **et al**., 1977) forests on spodosols, and higher, never flooded areas (tierra firma) supporting a mixed species forest.

A pasture site and a farm (conuco) site were chosen for study. The pasture site was formed by cutting and burning about 80 ha of tierra firma forest. The site was planted to **Brachiaria** sp. about eight months previous to the experiment. Primary forest species had sprouted and were about 1-1.5 m tall. **Cecropia** spp. (1 m tall) also were present, and other woody successional species were just becoming established. During the study period, **Brachiaria** covered 44 percent of the area, native grasses 2 percent, woody plants 20 percent, root mat 16 percent, bare soil 8 percent, and slash 10 percent (Buschbacher, unpublished data).

The conuco site was about 2.5 years old and planted in **Manihot esculenta**. This site was in the process of being abandoned. Woody successional species had become established and were 2-3 m tall.

METHODS

Three different methods were used to estimate ET. The tritiated water method was used to estimate woody plant transpiration (T), the Penman-Monteith evaporation formula was employed to estimate grass evapotranspiration and lysimeter weighing was used to determine soil and root mat evaporation.

Methods of using HTO as a tracer to estimate transpiration have been used in several forest studies (Kline **et al.**, 1970, 1971, 1976; Jordan & Kline, 1977; Luvall & Murphy, 1982; Martin **et al.**, 1970). Luvall & Murphy (1982) evaluated the use of the HTO method to measure transpiration and found the HTO method comparable with both the Penman-Monteith formula and soil-water balance methods.

Transpiration was calculated by the equation:

$V = S/\int C(t)\,dt$

V = volume of flow (transpiration)
$C(t)$ = sample activity (pCi/ml)
t = time
S = spike activity (pCi)

Eight woody successional species common to conucos were studied using the HTO method. They were **Clidemia sericea** D. Don, **Psychotria poeppigiana** ssp. **barcellana** (M. Arg.) Steyermark, **Solanum subinerme** Jacq, **Cecropia ficifolia** Snethlage, **Ormosia** sp., **Vismia lauriformis** (Lam.) Choisy, **Bellucia grossularioides** (L.) Triana, and **Goupia glabra** Aubl. Transpiration of the food plants, **Manihot esculenta** Crantz and **Anacardium occidentale** L. and of three forest species which occurred as sprouts in the pasture was also measured using the tritium method.

At least five individuals of each species were used for transpiration determinations. At the base of each tree a small hole was drilled and an Eppendorf pipet tip was sealed into the hole. Then 250-500 µl of tritiated water (.7 m ci/ml) was volumetrically pipeted into the tips and sealed with a cork. A lower branch end was enclosed within a plastic bag and sealed. Condensed water was collected daily with a syringe, and HTO activity was determined using standard liquid scintillation techniques (Luvall & Murphy 1982). Sampling was continued for four weeks in November 1980. At the end of the experiment all trees used were harvested to determine leaf biomass, leaf area, and wood biomass.

Evapotranspiration in the pasture was estimated using the Penman-Monteith formula. Climatological values used in the equation for net radiation and specific humidity were determined at 1 m above the pasture vegetation. Precipitation and Pan A values were obtained from the Venezuelan National Meteorological station at San Carlos.

Stomata resistance was determined using a LiCor diffusive resistance meter. Measurements were taken on 10 grass leaves both adaxially and abaxially every hour. Since there was little difference in stomata resistance between leaf surfaces, an average value for the leaf was used. Aerodynamic resistance was estimated from the value given by Monteith for natural grasslands.

The Penman-Monteith equation has been proved to be valid for a range of vegetation surfaces for both hourly and daily basis under a variety of experimental conditions (Van Bavel, 1966).

Pasture soil and root mat evaporation were determined by weighing lysimeters (12 cm day) on a daily basis over a three week period.

RESULTS

There were differences among species in their transpiration rates on a per unit leaf area basis (Table 1). Species with the highest transpiration were sprouts. The transpiration of sprouts exceeded evaporation (E) from the Pan A during the study period, whereas the transpiration for seed-established plants was less than Pan A evaporation. The species with the largest leaves, a very common successional species, **Cecropia ficifolia**, transpired the largest volume of water, but on a leaf per unit area basis it only ranked third.

An examination of one day's microenvironment and grass stomata resistance indicates considerable change in vapor pressure deficits and stomata resistances (canopy resistance) throughout the day (Table 2).

It appears that canopy resistance was not correlated with vapor pressure deficits ($r^2 = 0.021$). Maximum ET occurred with a combination of high net radiation fluxes, large vapor pressure deficits (VPD), and low stomata resistances (canopy resistance). The maximum VPD occurred around 14:00 and coincided with the maximum air temperature.

The ET rate for grass about 72 percent of the E rate of the Pan A (Table 1). However, if the ET rate for grass is adjusted by the percent cover, the ET rate is only 30 percent of the Pan A value. The ET rates of the other components of the pasture added together and adjusted for percent cover, are only ~ 52 percent of the primary forest value.

DISCUSSION

The significant difference in transpiration rates between seedlings and sprouts is interesting. Two possible explanations for the differences exist. First the sprouts are still coupled to the root system of a mature tree, thus having a much larger soil volume to exploit for moisture. The seedlings do not yet have a well developed root system, and periods of 3-4 days without rainfall may cause an increase in stomata resistance and thus possible moisture stress. Another factor which may be important is that the sprouts tended to be isolated individuals, taller than the surrounding vegetation, and were surrounded by bare soil and root mat. Thus, it is possible for advected energy to supply additional energy to the sprouts for transpiration. This phenomenon is often called the oasis affect and its occurrence has been well documented (Rosenberg,1974). However sprouts comprise only 20 percent of the cover in the pasture and that value is expected to be reduced as sprouts are weeded out to prevent shading of the grass.

It was observed during the experiment that the grass leaves would curl longitudinally as the day progressed. This was accompanied by an increase in stomata resistance. Both factors are indicative of moisture stress. Other workers have found that soil moisture deficits is important in causing increased stomata resistance in grasslands but not changes in VPD. Since the grass rooting volume is small and the sandy Ultisols have a limited water holding capacity, even one or two days without rain could limit moisture available to the grass thus reducing ET.

If we compare the ET rate for the pasture with the ET rate for the primary forest, Table 3, we observe 52 percent reduction in the amount of water being lost. If we assume the November pasture ET value (1380 mm) is approximately the mean value for a year then it represents only 36 percent precipitation, whereas the ET value for a primary forest is ~ 50 percent of precipitation (Jordan & Heuveldop, 1981, Luvall, 1984).

Little comparable work has been done in assessing the effects of deforestation on the evapotranspiration process. Luvall 1984 examined the effects of cutting (without using heavy logging equipment and all material was left on the ground) a mature lowland tropical rain forest in Costa Rica and its subsequent recovery. He found that ET was reduced about 31% in the cut area during the 160 day period following the cut (Table 4). Recovery of ET appeared to depend on increasing leaf areas as the cut area regenerated. Regrowth did not start until about 38 days after the cut. After about 65 days of regeneration, the vegetation ET exceeded the evaporation from the soil. Initially the water loss was from soil evaporation until the LAI was about 0.3, then water loss was primarily through stump and root sprouts. At the termination of the experiment plant ET was about four times greater than soil evaporation, but soil evaporation still accounted for 23% of the total water loss.

The most significant finding of his study was that five to six months after cutting, the monthly total ET from the cut area was only about 20 - 23% less than from the primary forest canopy. His results indicated that if these forests are allowed to recover following this type of cutting that ET quickly recovers.

It appears that when a forest is converted into a pasture that the impact on the ET rate may be greater and longer lasting than if the area was left to recover naturally. However, more research needs to be done for a wide range of climate, soils and pasture types in the tropics to assess the long term effect of rain forest conversion into pastures on the hydrologic budget.

CONCLUSIONS

1) The amount of water removed from the soil by transpiration of seedlings depends on the species. **Goupia glabra** transpired 8.5 times more water than did **Vismia lauriformis**.

2) The transpiration rates of sprouts are about three times greater than seed established pioneer trees. The reduction in ET appears to be greater for a pasture which, compared to a Costa Rican primary forest which was cut, then allowed to recover through succession.

3) The conversion of primary rain forest to pasture results in about 52% decrease in ET values.

RESUMO

As taxas de evapotranspiração de uma pastagem de oito meses foram estimadas usando a equação Penman-Monteith. As taxas de transpiração de várias espécies lenhosas sucessionais e rebrotos na pastagem e conucos (fazendas) foram medidas com o uso de água radiada com tritio. O local de estudo estava localizado perto do vilarejo de São Carlos do Rio Negro (1° 56' N, 67° 03' W) na parte sul da Venezuela, próximo a confluência do Casiquiare e Rio Guania, que formam o Rio Negro. O terreno era levemente ondulado com as áreas entre os pequenos cumes que sustentam as matas de caatinga da região Amazônica com spodosols, e mais alto, com áreas nunca inundadas (terra firme) que sustentam uma mata de espécies mistas. Os resultados mostraram que durante o período de um mês, a perda de ET (0.46 cm/dia) da pastagem, incluindo a evaporação do solo e da camada das raízes, foi de cerca de 0.43 cm/dia menos que a estimada para a mata adjacente não-pertubada (0.89cm dia). A evaporação Pan A para o mesmo período foi de 0.64 cm/dia. As taxas de transpiração para as espécies estabelecidas através de sementes foram significativamente menores (0.38 cm/dia) do que para os rebrotos (1.09 cm/dia) das espécies da mata primária na pastagem.

Table 1. Transpiration of several woody secondary successional species and tree sprouts common in abandoned conucos and pastures in southern Venezuela.

	Number of Individuals	Average Leaf Area (cm²)	Transpiration * Average (l/day)	Transpiration * Average (cm/day)
SEED ESTABLISHED				
Manihot esculenta Crantz	8	9,350	2.9 ± 1.7	.32 ± .11
Clidemia sericea D. Don	2	2,143	1.1 ± .47	.49 ± .11
Psychotria poeppigiana sub. sp. *Barcellana* (M. Arg.) Steyermark	2	10,156	5.1 ± .42	.54 ± .22
Solanum subinerme Jacq.	3	8,539	1.8 ± .31	.22 ± .06
Cecropia ficifolia Snethlage	10	25,972	8.2 ± 4.1	.32 ± .11
Vismia lauriformis (Lam.) Choisy	4	15,981	2.3 ± 1.5	.13 ± .02
Ormosia sp.	4	17,022	2.5 ± 0.8	.15 ± .02
Bellucia grossulariodes (L.) Triana	2	35,876	6.7 ± 7.1	.17 ± .03
Goupia glabra Aubl.	3	6,239	6.9 ± 2.6	1.10 ± .09
Average ± 1 sd				.38 ± .31**
SPROUTS				
Species 1	1	4,229	6.1	1.44
Species 2	3	2,922	3.3 ± 1.1	1.12 ± .38
Species 3	1	4,733	5.2	1.10
Average ± 1 sd				1.09 ± .30
Pan A				.69 ± .26

(*) Transpiration determined by the tritiated water method.

(**) Significant difference (t test, α 0.01) between the transpiration rates of sprouts and seedlings.

Table 2. Hourly microenvironment and plant characteristics for one day and the resulting estimated evapotranspiration for a tropical pasture in Southern Venezuela.

Hour Ending	Maximum Q* (wm^{-2})	Air Temp. (°C)	Vapor Saturation Deficit ($g\ cm^{-3}$)	Canopy* Resistance (scm^{-3})	E** ($cm\ hr^{-1}$)
8:00	353	26	2.60	3.158	3.585×10^{-2}
9:00	353	28	4.20	3.158	5.790×10^{-2}
10:00	417	31	6.30	3.789	8.799×10^{-2}
11:00	417	34	11.80	3.789	1.648×10^{-1}
12:00	385	33	11.30	6.316	9.270×10^{-2}
13:00	417	33	11.30	6.316	1.004×10^{-1}
14:00	417	35	13.90	5.684	1.359×10^{-1}
15:00	353	32	9.50	5.684	7.860×10^{-2}
16:00	192	31	7.70	14.210	1.478×10^{-2}
17:00	64	30	3.20	14.210	2.047×10^{-3}
				Total	$.77\ cm\ day^{-1}$
Pan A					$1.01 cm\ day^{-1}$

(*) Canopy resistance = $\frac{\text{Stomata resistance}}{\text{Leaf area index}}$; Leaf area index = .950

(**) Estimated using the Penman-Monteith equation

Table 3. November evapotranspiration rates for various components within a tropical pasture and for primary forest.

	Evapotranspiration (cm/day)	Percent Cover	Adjusted Evapotranspiration
Pasture Grass[1]	.42	46	.19
Pasture Sprouts[2]	1.09	20	.22
Pasture Root Mat[3]	.19	16	.03
Pasture Bare Soil[3]	.23	8	.02
Pasture Slash	0	10	0
Pasture, Total		100%	.46 cm/day[1]
Mature Forest[4]	.89	100%	.89 cm/day[1]
Pan A	.64	100%	.64 cm/day[1]

(1) Evapotranspiration estimated by the Penman-Monteith equation

(2) Transpiration determined by the HTO method

(3) Evaporation determined by weighing lysimeters

(4) Jordan, Heuveldop and Peek unpublished data. A two-year average for November for a mature tropical rain forest at San Carlos of the same type cut for pasture.

Table 4. A comparison of microclimate parameters in a mature low land tropical rain forest in Costa Rica and a adjacent clear cut area over 160 day period following cutting.[1]

MICROCLIMATE PARAMETERS	FOREST TREATMENT		
	Primary Forest	Cut Forest	% Change
Solar Radiation (average) (cal cm-2 day-1)	332 ± 101	-	-
Net Radiation (average) (cal cm-2 day-1)	285 ± 59	273 ± 70	-4
Average Ait Temperature (Celsius)	27.9 ± 1.6	29.9 ± 2.1[a]	+7
Vapor Pressure Deficit (g cm-3 x 10-6)	6.98 ± 2.9	8.43 ± 3.67[b]	+17
Evapotranspiration (cm day-1)	0.55 ± 0.20	0.38 ± 0.22[a]	-31

a P(0.0001

b P(0.005

1/Adapted from Luvall, 1984.

References

Budyko, M. I. - 1974. **Climate and life**. New York, Academic Press. p. 242-243.

Gentry, A. H. & Lopez-Parodia, J. - 1980. Deforestation and increased flooding of the upper Amazon. **Science**, 210:1354-1356.

Jordan, C. F. & Kline, J. R. - 1977. Transpiration of trees in a tropical rainforest. **J. Appl. Ecol.**, 14:853-860.

Jordan, C. F. & Heuveldop, J. - 1981. The water budget of an Amazonian rain forest. **Acta Amazonica**, 11(1):87-92.

Kline, J. R.; Jordan, C. F.; Rose, C. R. - 1971. **Transpiration measurement in pines using tritiated water as a tracer**. AEC CONF-710501-P1. 190 p.

Kline, J. R.; Martin, J. R.; Jordan, C. F.; Koranda, J. J. - 1970. Measurement of transpiration in tropical trees with tritiated water. **Ecology**, 51:1068-1073.

Kline, J. R.; Reed, K. L.; Waring, R. H.; Stewart, M. L. - 1976. Field measurement of transpiration in Douglas-Fir. **J. Appl. Ecol.**, 13:272-283.

Klinge, H.; Medina, E.; Herrera, R. - 1977. Studies in the ecology of the Amazon caatinga forest in Southern Venezuela. **Acta Cientifica Venezolana**, 28:270-276.

Luvall, J. C. - 1984. **Tropical deforestation and recovery:The effect on the evapotranspiration process**. Ph.D. dissertation. Dissertation, University Microfilms International, Ann Arbor, Michigan. 146 p.

Luvall, J. C. & Murphy, Jr., C. E. - 1982. Evaluation of the tritiated water method for measurement of transpiration in young **Pinus taeda** L. **Forest Science**.

Marques, J.; Santos, J.; Villa Nova, N.; Salati, E. - 1977. Precipitable water and water vapor flux between Belem and Manaus. **Acta Amazonica**, 7(3):355-362.

Martin, J. R.; Jordan, C. F.; Koranda, S. S.; Kline, J. R. - 1970. **Radioecological studies of tritium movement in a tropical rain forests**. Univ. of Calif. UCRL-72256.

Monteith, J. L. - 1965. Evaporation and environment. **Symp.Soc.Exp.Biol.**, 19:205-234.

National Research Council - 1980. **Research priorities in tropical biology**. National Academy of Sciences. 116 p.

Villa Nova, N. A.; Salati, E.; Matsiu, E. - 1976. Estimativa da evapotranspiração na Bacia Amazonica. **Acta Amazonica**, 6:215-228.

Prance, G. T. - 1978. The origin and evolution of the Amazon flora. **Interciencia**, 3: 207-222.

Ripley, E. A. & Saugier, B. - 1978. Biophysics of a natural grassland: evaporation. **J. of Appl. Ecol.**, 15:459-479.

Rosenberg, N. J. - 1974. Microclimate: In: **The biological environment**. John Wiley and Sons (eds.). New York. 315 p.

Salati, E.; Marques, J.; Molion, L. - 1978. Origem e distribuição des chum na Amazonia. **Interciencia**, 3(4):200-205.

Uhl, C. - 1982. Recovery following disturbances of different intensities in the Amazon rain forest of Venezuela. **Interciencia**, 7:19-24.

Uhl. C. - Successional patterns associated with slash and burn agriculture in the upper

Rio Negro region of the Amazon Basin. **Biotropica** [in press].

(Aceito para publicação em 03.01.1990)