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SUMMARY

Rainfall data registered between 1910 and 1979 at Manaus confirm the existence of a dry season between June and November (monthly rainfall: 42-162mm) and a rainy season from December until May (monthly rainfall: 211-300mm). Annual precipitation amounted to 2105mm with about 75% of the rainfall recorded during the rainy season. Rainfall data collected over 12 months at eight stations in the vicinity of and at Manaus are compared. Annual precipitation was lower in Inundation Regions (1150-2150mm) compared with Dryland Regions (2400-2550mm). Considerable differences are found in rainfall patterns (intensity, frequency and time of rainfall). This is also true for neighbouring stations, even if data of a 11-year record period are compared. Thus, it is highly recommended that precipitation data for bioecological studies be collected at the study site.

INTRODUCTION

In the vicinity of Manaus, heavy rains are observed to fall locally. Defined rain screens are characteristic of the onset and end of the precipitation area covered. Thus it happens e.g., that it may rain in front of a house but not in the back. Bioecological studies near Manaus often use precipitation data obtained at meteorological stations in the suburban district of the city (e.g. Dantas, 1979; Falcão & Lleras, 1980a; 1980b; Ferraroni & Hayes, 1979; Santos, 1981; Werder, 1983). We therefore considered it necessary to test the suitability of these rainfall data for field studies, by comparing them with precipitation values and rainfall patterns gathered in

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the vicinity of Manaus over a period of 12 months. Annual rainfall is also compared with data collected over 11 and 70 year periods near and at Manaus.

The main objective of this paper is to show that from year to year there may be a great spacial variability of rainfall parameters among sites relatively close to each other, especially where most of the precipitation is of convective origin as it is the case of the majority of rainfalls for the Central Amazon (Salati *et al.*, 1978, 1983).

STUDY AREAS AND METHODS

Main precipitation data were collected in three study areas near Manaus (Fig.1), frequently subject to bioecological investigations:

- 1) In a **Black Water Region** at Rio Tarumã Mirim ($03^{\circ}02'S$, $60^{\circ}17'W$), a tributary of the Rio Negro, about 20 km upstream from Manaus (cf. Adis, 1981, 1983; Beck 1971, 1976; Irmiler, 1975, 1979a, 1979b,; Katz 1981). Abbreviation: **TH**.
- 2) In a **White Water Region** on Ilha de Marchantaria ($03^{\circ}15'S$, $59^{\circ}56'W$), the first island in the Rio Solimões, about 15 km above its confluence with the Rio Negro (cf. Irion *et al.*, 1983; Junk *et al.*, 1983). Abbreviation: **MA**
- 3) In the **Dryland Region** at Reserva Florestal Ducke ($02^{\circ}55'S$, $59^{\circ}59'W$) situated at Km 26 on the Manaus-Itacoatiara highway (AM-010; cf. Marques *et al.*, 1981; Ribeiro, 1976; Adis & Schubart, 1984; Beck, 1971; Penny & Arias, 1982). Abbreviation: **RD**.

Continuous precipitation data were collected and monthly averages calculated for the period October 1981 to September 1982, with one pluviometer in each area. (Hellmann's apparatus; opening diameter 200cm^2 , height 120cm, type 54.015.00, A. Thies, Göttingen, FRG). In the White Water Region, the pluviometer was part of a meteorological station mounted on a wooden raft ($4 \times 5\text{m}$) maintained in a lake at the study area. The White and Black Water Regions are periodically flooded by annual cycles of rivers (Prance, 1979) and are referred to as Inundation Region.

Terms frequently used in this paper are:

rainfall frequency = number of single rainfall events

maximum rainfall

intensity = largest amount of precipitation for a single rain event (in mm/h)

average rainfall

intensity = average amount of precipitation for all rainfall events (in mm/h)

For a statistical evaluation of data the linear correlation-test (Cavalli-Sforza, 1972) was applied, using the original field data.

Complementary precipitation data were obtained from meteorological stations (Fig. 1) at:

- a) Manaus ($03^{\circ}08'S$, $60^{\circ}01'W$): Instituto Nacional de Pesquisas da Amazônia (Estrada do Aleixo, km 3.5, suburban district; cf. Ribeiro, 1976). Abbreviation: **IN**.
- b) Manaus: Instituto Nacional de Meteorologia, Ministério da Agricultura (alt. 71m; Estrada do Aleixo km 2.5, suburban district). Abbreviation: **MN**.

- c) Km 30 on the Manaus-Itacoatiara highway (AM-010): Embrapa-Uepae (02°53'S, 59°59'W ; alt. 50 m; cf. Teixeira, 1981); Dryland Region. Abbreviation: **EM**.
- d) Km 54 of the Manaus-Boa Vista highway (BR-174): Embrapa-Uepae (Distrito Agropecuário) Dryland Region. Abbreviation: **ED**.
- e) Ilha do Careiro: Instituto Nacional de Pesquisas da Amazônia (03°10'S, 59°44'); location on the right bank of the Rio Solimões, about 10km below its confluence with the Rio Negro; White Water Region (cf. Annibal, 1983). Data available only from December 1981 until May 1982 (= rainy season). Abbreviation: **CA**.

RESULTS

Although situated only 325 km south of the equator and considered a Tropical Rainforest region a pronounced rainy and dry season has been noted for the Manaus area (cf. Adis, 1981; Falesi *et al.*, 1971; Salati *et al.*, 1978, 1983). Table 1 gives the monthly climate of Manaus, calculated from data recorded over a 70-year period. Between June and November, rainfall was less than 200mm per month (= dry season), with July, August and September being the driest months.

About 75% of annual precipitation is recorded between December and May (= rainy season) with March and April showing the highest rainfall per month. Total annual rainfall amounted to 2105mm.

Precipitation at main stations

Total annual precipitation was highest in the Dryland Region (2542.1mm) and somewhat lower in the Black Water Region (2156.5mm; Fig. 2). There was distinctly less rainfall in the White Water Region with 1150.4mm; about 45% of the total precipitation in the Dryland Region.

The months of highest rainfall were February and April at the Dryland site, and February at the Black Water site (Fig. 2).

At the White Water site, there was no month with distinctly more rainfall, although somewhat higher precipitation was recorded in November, January and March. This is also true for the Black Water Region in November and May. Of 365 days of observation, there were 239 days (65.5%) with rain in the Dryland Region, 200 days (55%) in the Black Water Region, and 119 days (33%) in the White Water Region. Up to six single rains or rain showers per day were recorded at the Dryland site (in January), up to four rains at the White Water site (in May and September) and only up to three daily rains at the Black Water site (in various months). About 72-79% of all single rains recorded at the three stations fell during daylight hours (6 A.M. - 6 P.M.; Table 2). More rains occurred between noon and 6 P.M. at the Dryland station (about 72% of all rain events recorded during daytime) and, to a lesser extent, at the Black Water station (about 64%). No difference was observed for the White Water station (about 52%; Table 2). There was also no difference for rain events recorded at night within a six local rainfall variability ...

hour period and after midnight at any of the three stations (Table a). However, the total number of single rains falling at night was somewhat higher during the rainy season from December until May (7-13%) when compared to the dry season (June - November; cf. Discussion). The rainfall frequency does not always correspond with high precipitation values (Fig. 3). In Dryland Region, for example, it rained many times throughout January, March and May, but highest precipitation was recorded in February and April. Over the period of one year, however, rainfall frequency and total monthly precipitation are significantly correlated in all three areas (RD: $p < 0.01$, $r = + 0.784$; TM: $p < 0.01$, $r = + 0.821$; MA: $p < 0.05$, $r = + 0.664$). The maximum rainfall during a single rain event recorded per site (Fig. 4) was 110mm/h in the White Water Region (in October), 76.6 mm/h in the Dryland Region (in March) and 73.2mm/h in the Black Water Region (in June). The yearly mean of the maximum rainfall intensity was highest at the Black Water station, and lowest at the White Water station (Fig. 4). The yearly mean of the average rainfall intensity, however, was highest at the White Water site and lowest at the Dryland site (Fig. 5). There was no correlation found either between the precipitation/month and the average or maximum rainfall intensity/month, or between the maximum rainfall intensity/month and the rainfall frequency/month and the rainfall frequency/month. During the study period, high rainfall intensity was recorded for different months in the areas under study (Figs. 4,5). In the Black Water Region, average rainfall intensity was highest in June; in the White Water Region it was highest in October and January (Fig. 5). The highest maximum rainfall intensity was recorded in November, March and June at the Black Water site, in March at the Dryland site and in October at the White Water site (Fig. 4).

Precipitation at all stations

In 1981/82, annual precipitation was lower in the Inundation Region (1150-2150mm), especially at White Water sites (MA, CA), compared to the Dryland Region (2400-2550mm; Fig. 6). Annual rainfall in Manaus was somewhat intermediate (about 2200mm).

Main differences in total rainfall were observed during the rainy season from December until May (cf. Discussion), ranging between 713 and 1800mm (= 60% difference). Variation in total precipitation during the dry season was less pronounced (437-653mm; = 33% difference). During the rainy season, there was somewhat more rainfall events at night compared to the dry season at stations in the Inundation Region. No difference was found for stations in the Dryland Region.

Comparison of data from the Dryland station at Reserva Florestal Ducke (RD) and from Embrapa (EM), only 4 km distant from one another, show no significant difference in total rainfall in 12 months, neither in the rainy nor in the dry season (Fig. 8). There was also no difference in monthly rainfall frequency nor in the number of rain events recorded during the day or night. At both stations, monthly rainfall was significantly correlated with monthly rainfall frequency (RD: $p < 0.01$, $r = + 0.784$; EM: $p < 0.01$, $r = + 0.835$). However, there were 239 days of the year with rainfall at Reserva Florestal Ducke and only 209 days at Embrapa (Table 2). The average monthly

rainfall intensity and, above all, the maximum rainfall intensity differed considerably at both stations (Fig. 7). Altogether, annual rainfall intensity values were higher at Reserva Florestal Ducke. Nevertheless, monthly rainfall was significantly correlated with average monthly rainfall intensity recorded at Embrapa station ($p < 0.01$, $r = + 0.860$), but not at Reserva Florestal Ducke ($r = - 0.270$).

DISCUSSION AND CONCLUSION

Precipitation data from the vicinity of Manaus clearly show that while annual or even monthly rainfall at adjacent sampling sites may be similar, precipitation patterns, such as rainfall frequency and intensity are quite different (Figs. 7,8). If data are studied for a longer period, even monthly differences in precipitation are found between closely situated sampling stations. In the Dryland Region, for example, average rainfall from 11 years was about 40mm higher in March at Reserva Florestal Ducke, compared to the Embrapa station 4 km away (Fig. 8b). Data from still longer sampling periods continue to reveal differences in monthly precipitation: at Manaus, lower rainfall is recorded in December from 11 years of records (187mm) or from 70 years of records (219mm; Fig. 8A). However, monthly rainfall from a one year period may differ distinctly from longer periods (cf. Figs. 8A, B). Total rainfall during the dry season was somewhat higher in the Dryland Region (RD: 773mm, EM: 835mm) compared to Manaus (MN: 655mm) from 11 years of records, which indicates a "meteorological evidence" for spacial variability of rainfall. In general, rainfall patterns in the vicinity of Manaus differ significantly, as shown for Inundation and Dryland Regions. These patterns, undoubtedly, have a great impact on flora and fauna, such as the activity and population density of arthropods (cf. Adis, 1981,1984). If the amount and frequency of rainfall is found to be similar in a biotope, but the rainfall intensity differs locally (Fig. 7), more rain may reach the forest floor at some sites, resulting in temporarily wetter and drier habitats over relatively small areas.

In conclusion, we have shown that there is a high spacial rainfall variability among the sites studied near Manaus within a particular year period, viz. 1981/82. Therefore, bioecological studies cannot rely on precipitation data collected far away from the site being studied under the argument that they belong to the same general or macroclimate. Data collected "in situ" will help to clarify differences of biota types and behaviour found locally.

There was considerably less annual rainfall recorded in the White Water Region (Fig. 6). One possible reason for this is the existence of rain and wind corridors along rivers or recently constructed highways. Another reason might be, that "heating of the (dryland) forest's canopy makes its temperature higher than the river's surface temperature. The horizontal temperature gradient thus established would dynamically favor cumulus cloud formation over land and relative descending air over large bodies of water. That, in turn, would, on a statistical basis, cause higher precipitation over

the (dryland) forest" (anonymous referee's comment). Rainfall data should be collected at least for another year at Ilha de Marchantaria (AM) and Ilha de Careiro (CA) in order to give support for the low annual precipitation observed in the White Water Region.

ACKNOWLEDGMENTS

We heartily thank Engr^o. Alberto Doza de Oliveira (EMBRAPA/UEPAE, Manaus) and B.Sc. Edgard Klinger Neves (INEMET, Manaus) for providing us with meteorological data and for valuable discussions. Special thanks are due to M.Sc. Alvaro Alves Vieira, Edilson Fereda and Maria Aparecida Gomes (INPA, Manaus) for help received during data evaluation. Dr. Norman Penny and Dr. Anthony B. Rylands (INPA, Manaus), Dr. Eneas Salati (CENA, Piracicaba) and Dr. Luiz Carlos Molion (INPE, São José dos Campos) kindly reviewed and improved the manuscript, and Irmgard Adis typed it. Jorge Soares Dácio (INPA, Manaus) made the drawings. We are also indebted to three anonymous referees for their valuable comments on the submitted paper.

RESUMO

Dados de precipitação registrados entre 1910 e 1979 em Manaus confirmam a existência de uma época de seca entre junho e novembro (precipitação mensal: 42-162mm) e uma época de chuva de dezembro até maio (precipitação mensal: 211-300mm). A precipitação anual somou 2105mm, com aproximadamente 75% de precipitação registrada durante a época de chuva. São comparados dados de precipitação coletadas durante 12 meses em oito estações em Manaus e nos arredores. A precipitação anual foi menor nas regiões inundadas (1150-2150mm). Observou-se diferenças consideráveis nos padrões de intensidade, frequência e hora de chuva. Isto também é o caso em estações vizinhas, mesmo comparando-se dados de um período de 11 anos de registro. Por isso, é altamente recomendado coletar dados para estudos bioecológicos na área de investigação.

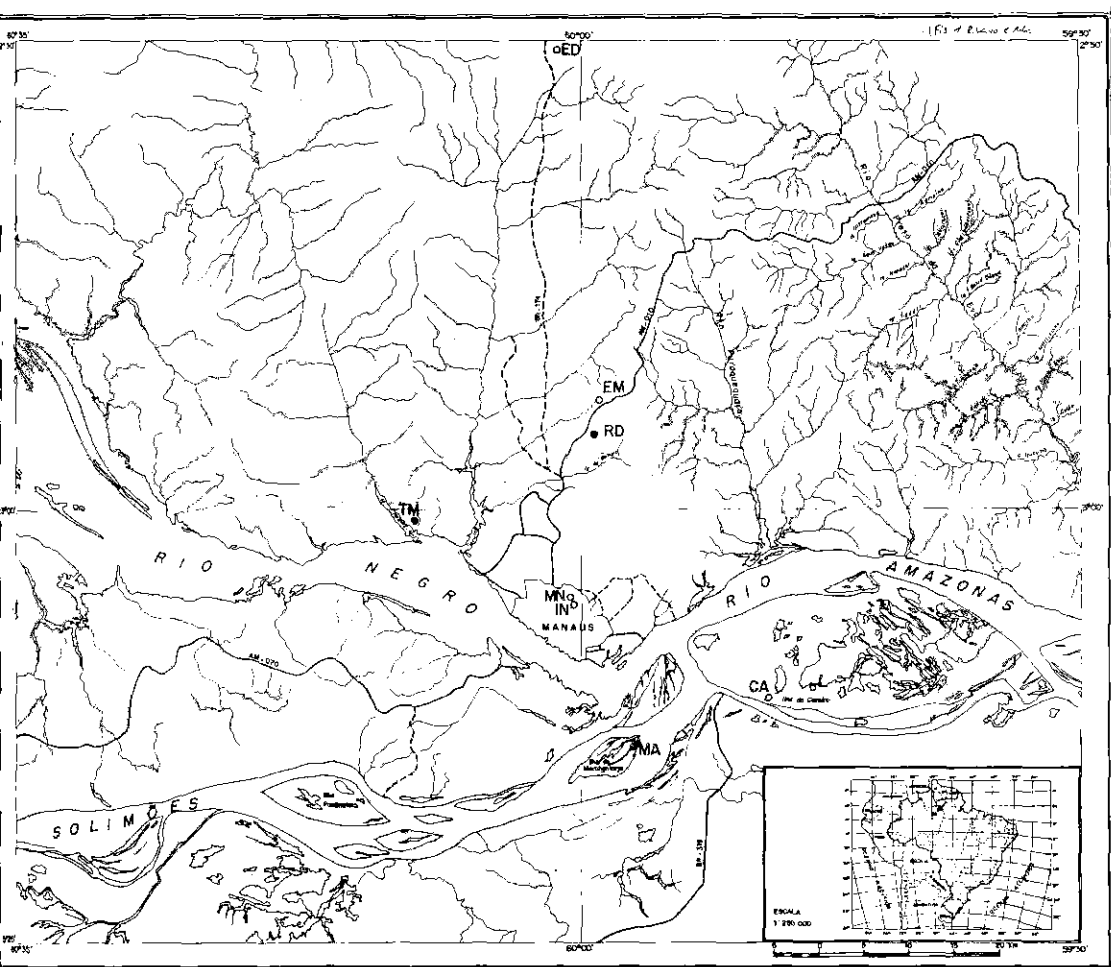


Fig. 1 - The study area in the Central Amazon with rainfall measurement sites indicated. For descriptions of sites see text.
 ● = main sampling station, o = complementary sampling station.

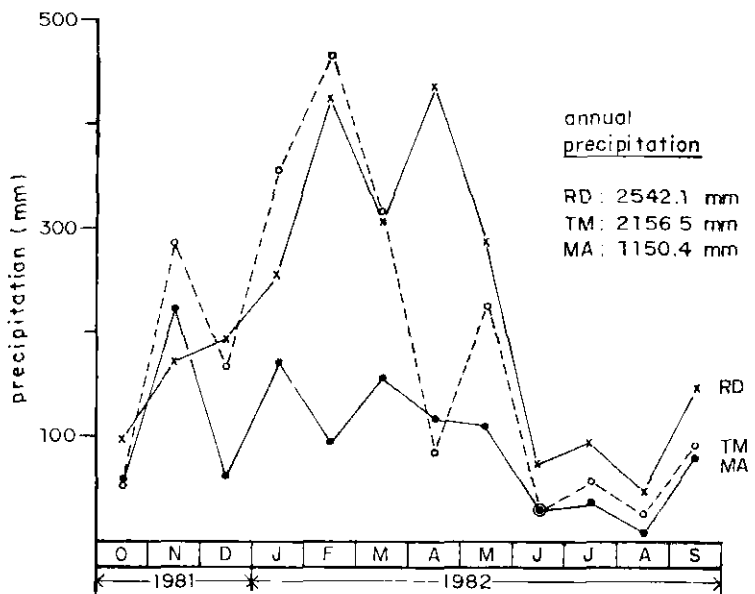


Fig. 2 - Total monthly and annual precipitation recorded at the sampling station in the Dryland Region (RD), Black Water Region (TM) and White Water Region (MA); October, 1981 - September, 1982.

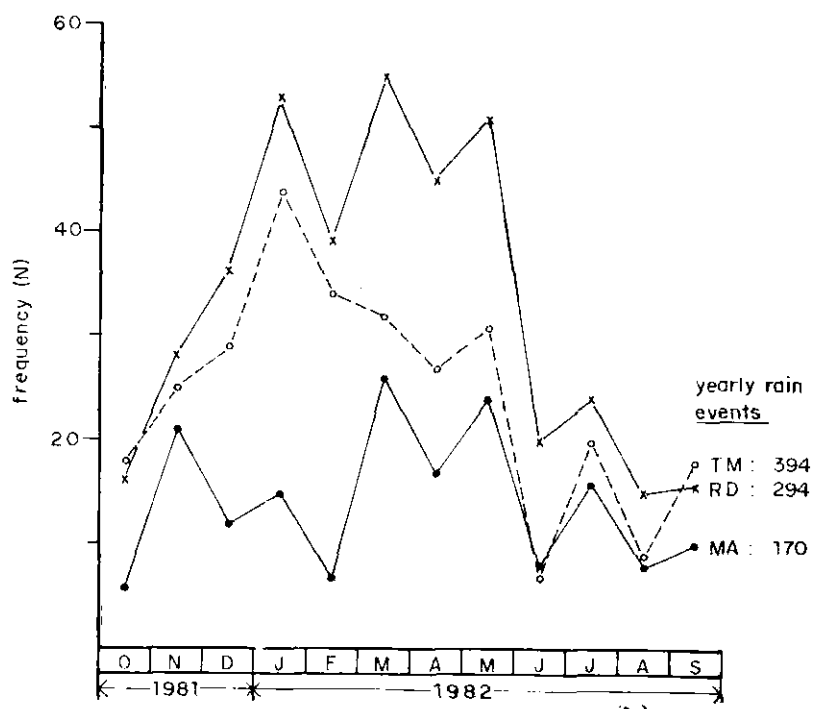


Fig. 3 - Rainfall frequency (= number of single rainfall events) per month and year at the sampling station in the Dryland Region (RD), Black Water Region (TM) and White Water Region (MA); October, 1981 - September, 1982.

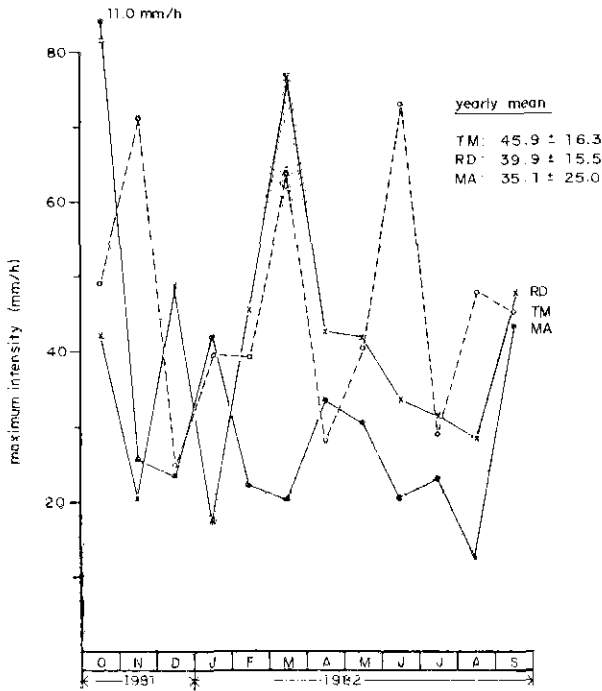


Fig. 4 - Maximum monthly rainfall intensity with yearly means at the sampling station in the Dryland Region (RD), Black Water Region (TM) and White Water Region (MA); October, 1981 - September, 1982.

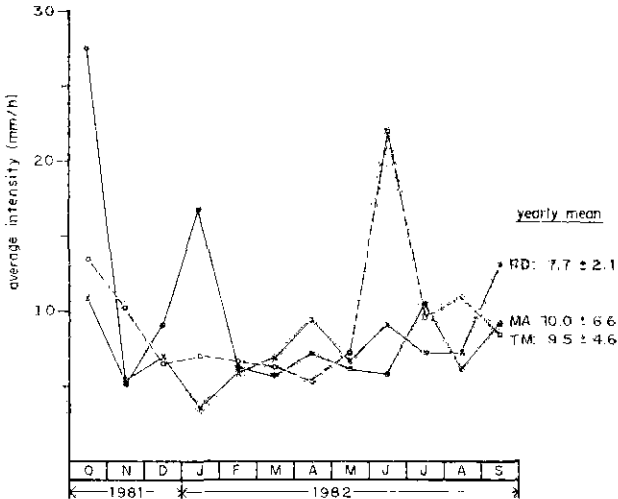
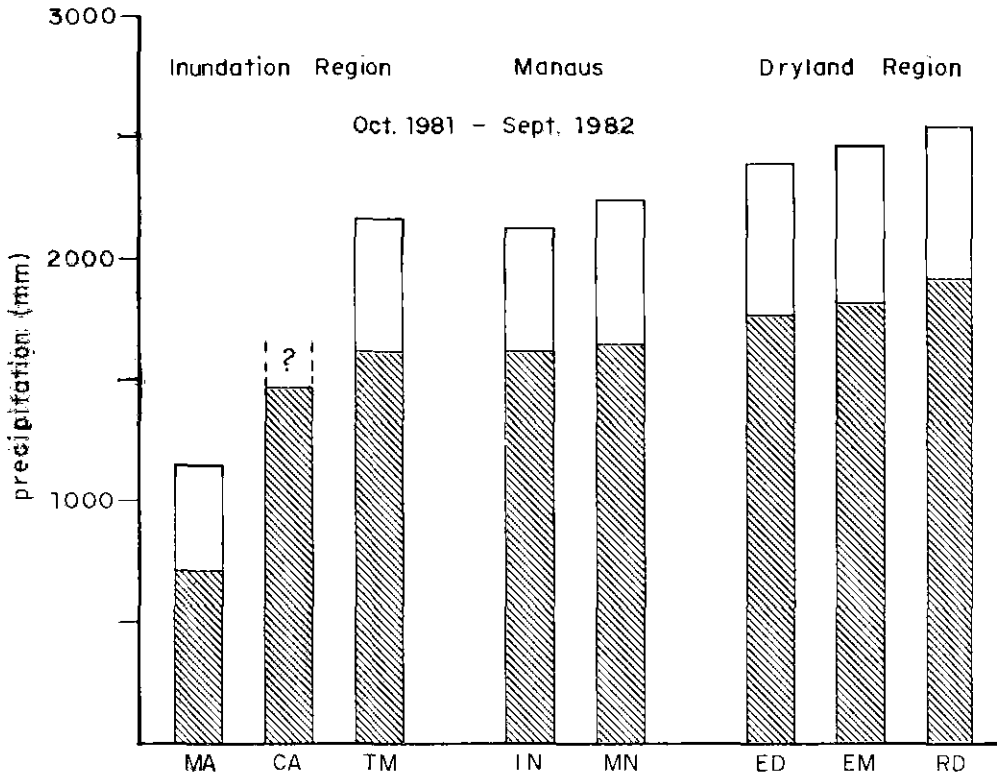


Fig. 5 - Average monthly rainfall intensity with yearly means at the sampling station in the Dryland Region (RD), Black Water Region (TM) and White Water Region (MA). October, 1981 - September, 1982.



	MA	CA	TM	IN	MN	ED	EM	RD
total (mm) :	1150.4	?	2156.5	2123.8	2246.3	2394.6	2461.5	2542.1
□ dry season :	437.5	?	542.7	505.9	611.8	629.0	653.5	634.7
▨ rainy season :	712.9	1467.9	1613.8	1617.9	1634.5	1765.6	1808.0	1907.4

Fig. 6 - Total annual rainfall recorded during one year at eight sampling stations near and in Manaus. For localities and abbreviations see METHODS; no data were obtained at station CA between June and November, 1981.
 ▨ = rainy season (December-May);
 □ = dry season (June-November).

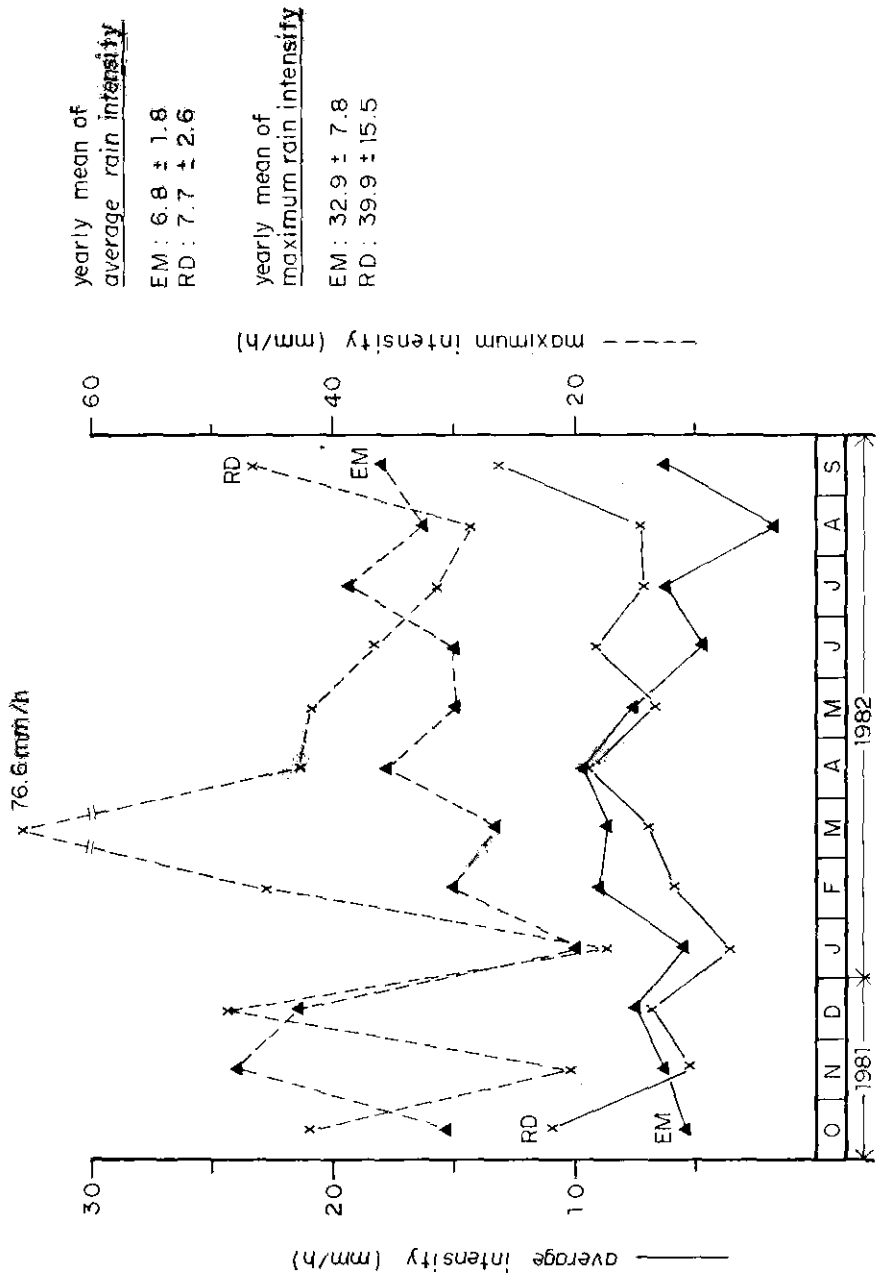
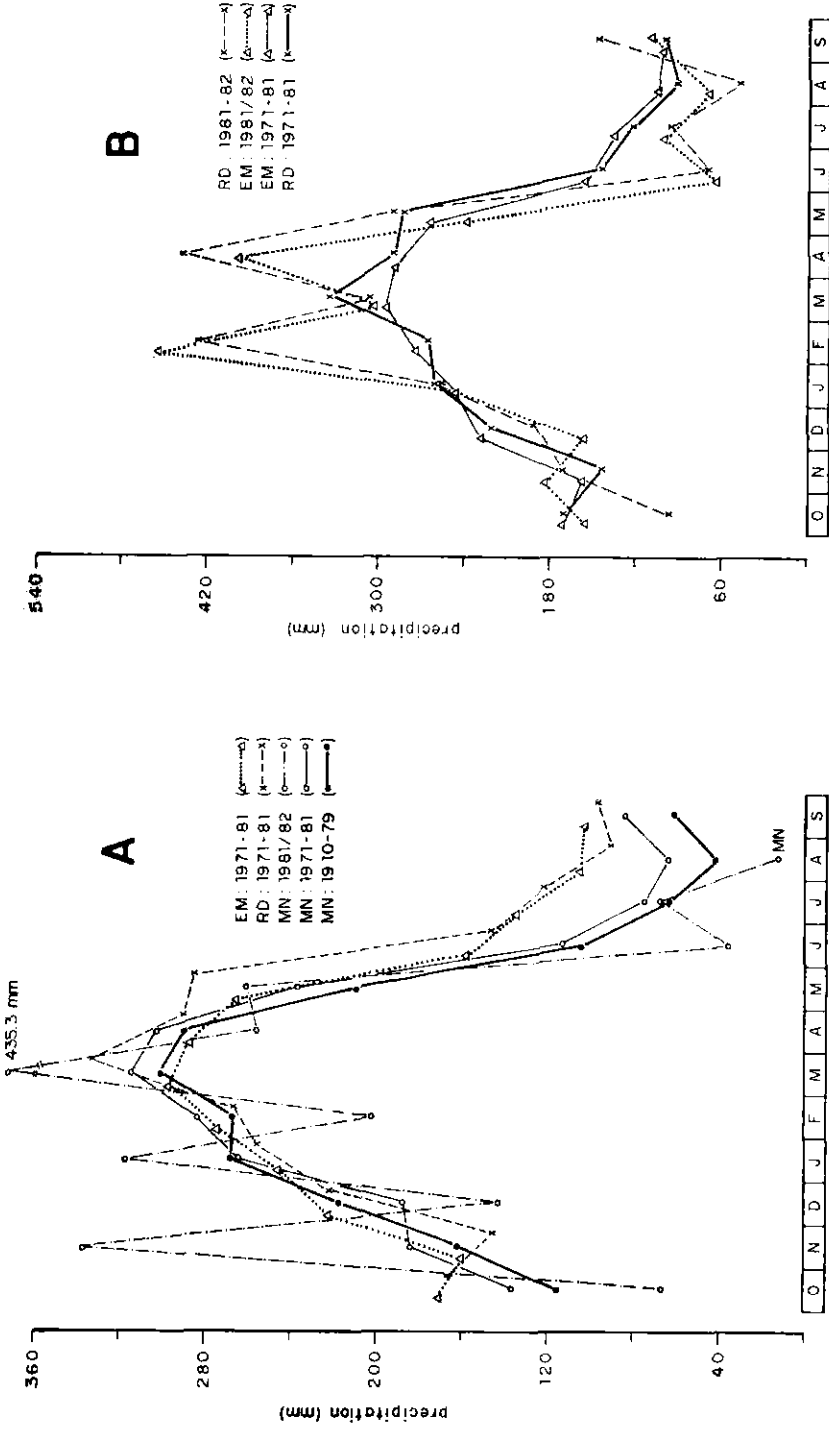


Fig. 7 - Average and maximum monthly rainfall intensity with yearly means in the Dryland Region at Reserva Florestal Duce, Km 26 (RD) and at Embrapa, Km 30 (EM) on the Manaus - Itacoatiara highway (AM - 010).



	MN			RD			EM	
	1910-79	1971-81	1981/82	1971-81	1981/82	1971-81	1981/82	
total	2 104.6	2 245.4	2 246.3	2 433.2	2 542.1	2 439.3	2 461.5	
dry season	550.8	654.6	611.8	772.8	634.7	834.7	653.5	
rainy season	1 553.8	1 590.8	1 634.5	1 660.4	1 907.4	1 604.5	1 808.0	

Fig. 8 - Average monthly, seasonal and annual precipitation for different sampling periods at the three meteorological stations near and in Manaus: A - Rainfall at Reserva Florestal Ducke (RD), Embrapa (EM) and Manaus for 1981/82 (one year) and 1910-1979 (70 years). B - Rainfall at Reserva Florestal Ducke (RD) and at Embrapa (EM) recorded for 1981/1981 (one year) and 1971-1981 (11 years). Dry Season = June - November; rainy season = December - May; for further explanation see text. Precipitation data from Adis (1977a) for MN, Ribeiro (1976) for RD and Teixeira (1981) for EM.

Table 1 - Climate of Manaus: average monthly values from 1910 to 1979, (= 70 years; complements Adis, 1977a, 1977b).
 Locality of meteorological stations:
 1910 - 1959: Igreja Dom Bosco (on the church-tower); altitude 48m.
 1960 - 1975: Igreja São José (since 1964 in the yard of the church); altitude: 1960/61: 48m, 1962/63: 40m, 1964-1976; 59,5 m.
 1976 - 1979: Estrada do Aleixo Km 2,5 (grass-plot); altitude 71m.

month	temperature (°C)		compen- sated mean	relative humidity (%)	precipitation (mm)		evaporation (mm)	insolation (hrs.)	wind speed (m/sec.)
	mean	min.			total	max. in 24 hrs.			
	max.	max.			total	max. in 24 hrs.			
January	30.5	23.2	26.1	85.6	267.2	50.0	44.1	121.0	2.3
February	30.3	23.1	25.9	85.9	266.2	57.5	39.5	105.3	2.3
March	30.2	23.2	25.9	86.4	300.2	60.5	43.3	109.0	2.4
April	30.2	23.3	26.0	86.7	290.9	59.6	38.5	114.9	2.3
May	30.5	23.3	26.2	85.5	210.7	48.1	46.6	154.5	2.3
June	30.9	23.1	26.3	82.4	103.8	29.7	56.9	202.4	2.3
July	31.5	22.9	26.5	79.2	66.2	22.0	72.9	232.6	2.3
August	32.8	23.2	27.2	75.8	42.2	19.4	85.2	248.5	2.4
September	33.2	23.7	27.6	75.6	61.6	24.8	85.9	216.4	2.6
October	32.9	23.8	27.5	77.6	115.5	35.8	79.0	197.6	2.6
November	32.2	23.7	27.2	80.4	161.5	47.6	64.6	165.2	2.5
December	31.3	23.5	26.6	83.3	218.6	50.3	53.8	149.8	2.3
mean	31.4	23.3	26.6	82.0	175.4	42.1	59.2	168.1	2.4
Total					2104.6		710.4	2017.4	

Table 2 - Total number of days with rain per year and number of single rainfall events per day and night at sampling stations in the Black Water Region (TM), White Water Region (MA) and Dryland Region (RD, EM). For localities and abbreviations see METHODS.

station	number of days with rain	Single rainfall events		
		day	night	total
TM	200 (55 %)	231 (79 %)	63 (21 %)	294
MA	119 (33 %)	122 (72 %)	48 (28 %)	170
RD	239 (65 %)	308 (77 %)	92 (23 %)	400
EM	209 (57 %)	318 (81 %)	74 (19 %)	392

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(Aceito para publicação em 16/4/84)